Virtual reality applications in the house-building industry

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Abstract

This study explores the potential for British housing developers to use virtual reality (VR) for the design and evaluation of housing developments. Four research questions were formulated after a review of relevant literature on house-building, VR technology and industrial innovation. These cover the context, technical problems and implementation issues related to VR use in the house-building industry.

To address these questions the following tasks were undertaken: firstly a survey of the top 100 British housing developers’ use of computer-aided design (CAD) and visualisation software and their attitudes to VR; secondly practical trials of PC-based VR systems for the modelling of housing developments; thirdly a case study of VR implementation in a British house-building company; and fourthly a multiple case study of VR use in Japanese house-building companies.

The overall research problem is addressed by recourse to the findings of the different research methods. The use of IT and the house-building organisation, similarities and differences between CAD and VR implementation, and comparison between Japanese and British house-builders VR use are discussed. VR in house-building practice and policy is then considered.

A number of general conclusions are drawn from this study. First, that PC-based VR is of use to British housing developers for explaining design intent to non-designers, both within and outside to the organisation. Second, that housing developers’ use of virtual reality at the early design stages is hampered by the current state of the technology. Third, that organisational transformation is required for housing developers to implement and obtain maximum benefit from virtual reality.

Finally future scenarios are explored to provide the house-building industry and policy makers with information on which to base decisions about how to invest or promote investment in virtual reality.
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<td>API</td>
<td>Application Programming Interface</td>
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<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
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<td>CIC</td>
<td>Computer Integrated Construction</td>
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<tr>
<td>fps</td>
<td>frames per second</td>
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<tr>
<td>GUI</td>
<td>Graphic User Interface</td>
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<tr>
<td>HTML</td>
<td>Hyper Text Markup Language</td>
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<tr>
<td>IAI</td>
<td>International Alliance for Interoperability</td>
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<td>IGES</td>
<td>International Graphics Exchange System</td>
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<td>ISO</td>
<td>International Standards Organisation</td>
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<tr>
<td>IT</td>
<td>Information Technology</td>
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<td>IFC</td>
<td>Industry Foundation Class</td>
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<tr>
<td>LOD</td>
<td>Level of Detail</td>
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<td>MB</td>
<td>Megabytes</td>
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<td>MHz</td>
<td>Megahertz</td>
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<td>NHBC</td>
<td>National House Building Council</td>
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<td>Open GL</td>
<td>Open Graphics Library</td>
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<td>PC</td>
<td>Personal Computer</td>
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<td>RAM</td>
<td>Random Access Memory</td>
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<td>RGB</td>
<td>Red Green Blue</td>
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<td>RIBA</td>
<td>Royal Institute of British Architects</td>
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<td>SGI</td>
<td>Silicon Graphics Inc.</td>
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<tr>
<td>STEP</td>
<td>STandard for Exchange of Product model data</td>
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<td>UML</td>
<td>Universal Modelling Language</td>
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<td>VR</td>
<td>Virtual Reality</td>
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<td>WTK</td>
<td>World Tool Kit</td>
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<td>Virtual Reality Modelling Language</td>
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Chapter 1 Introduction

1.1 Background

Virtual reality (VR) enables interactive real-time viewing of three-dimensional data (Isdale, 1998). It developed from research on computer graphics (Sutherland, 1965; Brooks, 1986) and flight simulation (Furness, 1986). With the evolution of VR systems based on the personal computer (PC) widespread industrial application has become possible.

Architecture and construction companies can now use VR to visualise, communicate and evaluate the design of buildings and urban environments (Bertol, 1994). VR may evolve to allow the construction professional to view, alter and test any function or part of a proposed design at any stage of the project life cycle (Issa, 1999).

Though house-building has been considered as a traditional sector with little scope for advanced IT use, modernisation of the house-building sector of the British construction industry was recommended in the government report *Rethinking Construction* (Egan, 1998). Initiatives are underway to promote innovative house-building processes (Hooper, 1999) and visualisation tools may be required to enable better communication and evaluation of design.

In this chapter the research problem, research questions, justification for the study, methodology and major achievements are described. The structure of the thesis is then outlined.

1.2 The Research Problem and Research Questions

This research investigates the use and potential use of VR in the house-building sector of the construction industry. The research problem addressed is:
What is the potential for British housing developers to use virtual reality for the design and evaluation of housing developments?

It is argued that VR can provide benefits to house-builders, by improving the communication of design and allowing greater participation in the decision making process. VR is considered as a building design tool in the same family as other computer-aided design (CAD) tools, and it is found that there are similar organisational and technical barriers to the implementation of VR technology. These barriers are explored and the technological maturity of British house-builders’ use of VR is compared with VR use in other innovative sectors.

The research questions addressed are:

- What are the uses of, and attitudes toward, CAD and virtual reality across the house-building sector of the British construction industry?
- What practical and technical issues arise when creating virtual reality models for the design and evaluation of housing developments?
- What is the experience of a British house-building company implementing a virtual reality system?
- How does a similar innovative sector use visualisation tools such as virtual reality?

These research questions explore different aspects of the research problem. Their identification through a review of the previous literature is discussed in chapter 2.

1.3 Justification for the Study

The research problem under consideration is important on several theoretical and practical grounds:

- The design quality of new housing developments is a focus of concern (Rogers, 1999). There is a need to improve the operations of British housing developers. It is private housing developers that build the majority of new houses in Britain and their operation is important for the production of a sustainable urban environment.
Demographic and lifestyle changes are altering the population's housing requirements and the government predicts the need for 4.4 million new homes between 1996 and 2016 (DOE, 1996). At the same time, increasingly demanding environmental and planning considerations are being introduced and there is growing concern about sustainable development (Rudlin & Falk, 1999). The government's Urban Task Force (Rogers, 1999) has set out recommendations to regenerate towns and cities, based upon the principles of design excellence, social inclusion and environmental responsibility. Housing is a major factor, as it covers 70% of urban land in Britain (Ball, 1996).

- The role of IT in the adoption of innovative house-building processes has not been sufficiently investigated. Following the government report, Rethinking Construction (Egan, 1998) innovative approaches to British house-building are being discussed (eg. Barlow, 1999; Gann & Barlow, 1999; Roy & Cochrane, 199; Roy & Gaze, 1999) and initiatives are underway to improve current practice. Technical maturity of British house-builders has been compared with that of other innovative sectors, particularly the house-building and car manufacturing industries in Japan (Gann, 1996). The application of Japanese-style manufacturing and supply-chain management techniques to the British house-building sector is being explored (Barlow, 1999; Gann, 1996; Roy & Cochrane, 1999; Roy & Gaze, 1999). However the use of advanced IT tools such as VR, which could complement the approaches being explored in such initiatives and improve the operations of British house-builders, have not been investigated.

- The construction industry has been identified by the DTI as a key sector for the introduction of VR into British business. However despite substantial academic research, the implementation of VR techniques within the construction industry has previously been slow (Bouchlaghem & Liyanage, 1996). House-building is a suitable sector of the construction industry in which to introduce VR as the use of semi-standardised products in a repetitive manner (Hooper, 1998) facilitates the prototyping of a VR system. However the potential for housing developers to use VR has not previously been researched.
• The PC-based VR systems investigated in this research are within the means of the average construction company. In the past VR was only possible on high-end computers due to its computationally intensive nature, however VR systems are rapidly evolving toward smaller, cheaper and more flexible systems. Since the start of this research in 1997, the potential for using the PC for VR applications has changed from controversial to accepted fact as acceleration for graphics is written into hardware. The minimum frame rate for VR has been described as 10 frames per second (fps) (Rosenblum & Cross, 1997) but at the time of writing frame rates of 300 fps are being attained on PCs in benchmark tests (see http://www.3Dbenchmark.com).

• This research uses qualitative research methodologies to consider the relevance of technological developments to British business practice. Previous researchers within the construction IT discipline have neglected these methodologies, which are discussed in chapter 3. Research has been focused on technical issues with the result that many technologically sophisticated academic projects have been developed but many of these have been unsuccessful at impacting business practice (Leslie, 1997; Wix, 1998; Eastmann, 1997).

• The findings of the study will be useful to housing developers interested in investing in VR. The costs of unsuccessful innovation in the highly volatile British house-building market are potentially damaging (Hooper, 1998) making housing developers slow to innovate. The research findings provide a structured understanding of early VR use in house-building to facilitate uptake and use of the technology by house-building companies.

1.4 Methodology and Work Undertaken

The research problem was investigated at multiple levels of analysis, the level of the industry sector (both through internal and external analysis), the technology, and the house-building organisation. The research has been conducted in an exploratory manner, structured around research questions. Instead of developing and testing a priori hypotheses, theory has been generated and tested iteratively. Four methods of
systematic inquiry were used to answer the research questions and address the research problem:

- **Survey of Computer Use in the House-Building Industry** – to explore the uses of, and attitudes toward, CAD and VR across the house-building sector of the British construction industry. The industrial survey records British housing developers’ use of CAD and IT and attitudes towards VR.

- **VR Development Project** – to explore the practical and technical issues that arise when creating VR models for the design and evaluation of housing developments. A housing site layout was modelled, to explore the suitability of PC-based VR packages, data translation and modelling approaches.

- **Case Study of VR Implementation** – to explore the experience of a British house-building company implementing a VR system. A longitudinal study of organisational aspects of VR implementation was conducted with the first British house-builder to use VR in-house.

- **Comparative Study of Japanese House-Builders’ VR use** – to explore other innovative house-builders’ use visualisation techniques such as VR. Japan was identified as a country in which the technical maturity of house-builders’ VR use is high. A visit was made to Japan, to interview house-builders and visit industry bodies, research establishments and VR companies.

The separate parts of the research were then compared and analysed to provide a contextual understanding of the issues raised in the research problem. The methodology used is further explained and discussed in chapter 3.

**1.5 Main Achievements**

The major achievements of this research are:

- **Overview of computer use for design in the British house-building industry**

The survey of computer use is a unique record of house-builders’ use of CAD and VR in the 1990s. It shows widely variant levels of computer use and expertise in different
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house-building companies across both regional developers and the nation-wide volume-builders. Some housing developers have sophisticated information technology strategies and are well placed to successfully implement advanced techniques whilst many have very little or no computer use for design and visualisation and rely on more traditional competitive strategies.

- **Taxonomy of modelling approaches**

The different approaches to the creation of VR models were considered. Three types of modelling approaches, a library-based approach, a straight-forward translation approach and a database approach were identified in the literature and their suitability for use in the creation of VR models of housing developments was tested through practical modelling work. It was found that different modelling approaches were appropriate for different tasks; a library approach was useful when complicated activities are associated with the sets of geometric data, and when standard parts are frequently used. A straight-forward translation approach, in contrast, is more suitable when fixed geometric data predominates and there are few activities associated with the data. A database approach can be used for rapid prototyping, where a central database controls component characteristics and both CAD and VR are used as graphical interfaces to that database.

- **Identification of similarities and differences between CAD and VR adoption**

In the case study, similarities were found between the difficulties faced and the procedures used for system development and introduction of both CAD and VR systems. In both the literature on early CAD use and the case study of VR use, insufficient co-operation between the company implementing the system the software developer and the lack of involvement of top management were major barriers to success. This suggests that user-developer communication and strategic decision making by top management could be critical issues to be addressed for successful VR implementation. A major difference in the technological environment in which early CAD and VR use was identified as the maturity of network technologies for design visualisation.
Chapter 1 Introduction

• **Characterisation of the similarities and differences between VR use in Japan and Britain**

VR is being used extensively by Japanese house-building companies, both to present and explain the design to the house purchaser and to allow design customisation to suit that purchaser’s specific requirements. House-builders in Japan are less concerned with the visualisation of site layouts than British house-builders. They use VR technology in a process of customer-focused product development. VR is used as one of a wide range of techniques to explain design. With the increasing use of manufacturing and supply chain management techniques the use of VR for discussion with the customer may become increasingly important in Britain, and the care taken to invest in intuitive interfaces to VR models is of relevance to the British housing developer.

1.6 Guide to the Thesis

The thesis structure is based upon the five-part thesis structure advocated by Perry (1999) with an introduction, literature review, methodology, analysis and conclusions. The sections have the following functions:

• Introduction – introduces the research problem and sets the scene (chapter 1).

• Literature review – describes the research questions arising from the body of knowledge developed during previous research (chapter 2).

• Methodology – describes the methods used in this research to collect data about the research questions (chapter 3).

• Analysis – presents the results of applying those methods in this research (chapter 4-7).

• Conclusions – presents the conclusions about the research problem based on the results of chapter 4-7, including their place in the body of knowledge outlined previously in chapter 2 (chapter 8).
The relationship between the different parts of the thesis is shown in Figure 1.1. The analysis chapters consider the individual research questions. They can be considered as consisting of two main parts, the chapters considering VR use in British house-building (chapters 4-6), and that considering VR use in Japanese house-building (chapter 7). The comparison between the findings relating to VR use in British house-building and those relating to VR use in Japanese house-building is considered in light of the research issues in chapter 8, and conclusions are drawn regarding the potential use of VR in Britain.

Figure 1.1 The thesis layout
Chapter 1 Introduction

This chapter provides an introduction and the remaining chapters cover the following:

**Chapter 2 Research Issues** – reviews the literature in areas relevant to the research problem: British house-building, VR technology, data transfer from CAD to VR, and the adoption of innovation.

**Chapter 3 Study Methodology and Design** – explores the theoretical framework used, methods, modes of analysis and verification of outcomes.

**Chapter 4 Computer Use in the House-Building Industry** – describes the findings of the industrial survey in terms of house-builders’ general IT strategies, use of CAD, 3D modelling and visualisation software and attitudes to VR.

**Chapter 5 VR Modelling Techniques** – is a review of the different VR model building and testing techniques and the four models of housing layouts that were created in the trials.

**Chapter 6 VR in a British House-Building Company** – reports on the case study of VR implementation in a British house-building organisation, and compares the findings on CAD implementation in the previous literature.

**Chapter 7 VR in Japanese House-Building** – reports on the use of VR in the Japanese house-building industry, through a multiple case study with three large Japanese house-building organisations.

**Chapter 8 Discussion and Conclusions** – analyses the combined findings of the thesis, describes scenarios for future use of VR within the British house-building industry and presents the conclusions and identification of further research

### 1.7 Delimitation of the Scope

The research is focussed on the use of VR for visualisation in the British house-building industry. The use of VR for design and evaluation of housing developments is considered, matters such as VR use for construction, scheduling, integration, simulation of environmental performance and interior design are not considered.
Chapter 2 Research Issues

2.1 Introduction

The previous chapter introduced the research problem. It described the background and justification for the research topic and summarised the research questions, methodology and major achievements.

This chapter reviews relevant literature. It is in four sections: three sections cover literature on house-building, virtual reality and innovation; the final section identifies research issues arising from this literature, which are relevant to the research problem. Formulation of the research questions from the literature is discussed.

2.2 House-Building

2.2.1 Private House-Building

Private house-building companies build the majority of new houses in Britain. Municipal rented accommodation, which was provided by large-scale public house-building programs in the post-war period (1940s-1970s), has greatly diminished in importance in the last two decades (Balchin, 1998) and public sector house-building is virtually non-existent (Gillen, 1994a). Government policy encourages homeownership and owner occupation has increased to 70% of the population (Gillen, 1994a).

In England, 87% of all new houses were built for the private sector in the first quarter of 1998 (Housing and Construction Statistics, 1999). This house-building was largely speculative, with house-building companies building houses in anticipation of demand and then marketing them to prospective customers (Ball, 1996). The remaining new houses built in England in 1998 were social housing (Housing and Construction Statistics, 1999). This was largely also built by private house-builders, working in partnership with a local authority and/or housing associations.
The private house-building companies typically have a hierarchical organisational structure, with a central design office, regional offices in each operating region, and on-site sales offices on each site. The central design office produces designs for standard house-types and deals with finances, whilst regional offices undertake site-layout design, liaise with planning officers and oversee work on sites in their area of operation (Gillen, 1997). Sales offices are built on the site of each housing development and from these employees market and sell the finished products directly to the customer.

### 2.2.2 The House-Building Process

The RIBA plan of work shows four evolutionary steps in the design process: briefing, sketch plans, working drawings and site operations (Cox & Hamilton, 1998). This approach can be modified to show stages of the housing development process. In Table 2.1 the stages feasibility, obtaining planning approval, production information, and site production reflect those in the generic RIBA plan of work, and a fifth stage ‘show house’ is added to describe the production of a show house before the wider site operations.

#### Table 2.1 The five different stages of the house-building process

<table>
<thead>
<tr>
<th>Stage</th>
<th>feasibility</th>
<th>obtaining planning approval</th>
<th>production information</th>
<th>show house</th>
<th>site production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team</td>
<td>Land Marketing</td>
<td>Land Marketing Sales Legal Planning Design Engineering Landscaping Production</td>
<td>Land Marketing Sales Legal Planning Design Engineering Landscaping Production</td>
<td>Hard gate Planning approved</td>
<td>Sales</td>
</tr>
<tr>
<td></td>
<td>Land Marketing</td>
<td></td>
<td>Hard gate Planning approved</td>
<td></td>
<td>Design</td>
</tr>
<tr>
<td></td>
<td>Legal Planning Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Surveying</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marketing</td>
<td></td>
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</tr>
</tbody>
</table>
Between these stages, key decisions are made: these are the initial instruction to proceed, the granting of planning permission, the production information for the show house and the start of main production. As shown in Table 2.1, an interdisciplinary group of professionals is involved in decision making at each stage. For example at the feasibility stage, the land department identifies potential sites, land managers suggest a mix of houses based on standard units, planners sketch a layout, and estimators check that the site is financially worth developing. Marketing staff are also involved at this stage to assess both the suitability of the house-types to the market and the potential selling prices of the properties. Design decisions are easily reversible within each stage, but not across stages. Thus the key decisions taken in meetings between stages form hard gates across which decisions are not reversible.

### 2.2.3 Size of House-Building Companies and their Operation

The private house-building sector has been described as consisting of a limited number of companies (Ball, 1996). Though a large number of house-builders and general contractors are registered to build houses with the National House-Building Council (NHBC), the majority of these build infrequently. Speculative house-building is risky for the construction companies involved (Ball, 1996) and small builders tend to undertake house-building as a supplement to their main contract work only when they decide that the market is favourable. As shown in Table 2.2, 16,909 builders registered with the NHBC in 1998, but 11,179 of these built no houses at all during 1998 (NHBC, 1999).

Table 2.2 Number of house builders in different size categories, and their percentage share of the market

<table>
<thead>
<tr>
<th>Size Category (in number of houses started per year)</th>
<th>0</th>
<th>1-10</th>
<th>11-30</th>
<th>31-100</th>
<th>101-500</th>
<th>501-2000</th>
<th>5000+</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Housebuilders</td>
<td>11,179</td>
<td>4,712</td>
<td>618</td>
<td>271</td>
<td>92</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>% of total houses started per year</td>
<td>-</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>13</td>
<td>18</td>
<td>44</td>
</tr>
</tbody>
</table>

Source: New House Building Statistics, NHBC

Thus, new housing production is concentrated in a limited number of larger house-building companies. The 16,780 house-builders in the four smallest size categories,
which represent over 99% of all registered house-builders, collectively have only a quarter of the market. In contrast, the 109 largest house-builders, which represent less than 1% of all registered house-builders, collectively have about three-quarters of the market.

These larger house-builders gain strategic advantage by using standard house-types and a ‘land bank’. Standard house-types are used to facilitate standardisation in the technology of construction and to help achieve economies of scale (Hooper, 1998). The land bank consists of plots of land that have been purchased or reserved. It is used to cope with the uncertain flow of suitable sites (Bramley, et al. 1995). House-builders with a land bank benefit from high rates of inflation in house and land prices. They also benefit from ‘development gain’, when areas surrounding the land become developed, and the value of the land increases (Bramley, et al. 1995). The use of a land bank has given the larger companies a critical strategic advantage in the volatile British housing market of the last few decades (Gillen, 1995).

House-builders in the largest size category in Table 2.2 build over 2000 houses per year each and are referred to as ‘volume-builders’. These companies were formed with the expansion of the private house-building sector during the mid-to-late 1980s (Gillen, 1994b). Following a spate of acquisitions and mergers in the 1990s, volume-builders largely operate as specialised house-building companies (Nicol & Hooper, 1998).

As the house-building industry becomes increasingly specialised, competition is increasingly structured in terms of different market sectors (Hooper, 1998). Amongst the volume-builders, competition has been characterised as essentially oligopolistic (Hooper, 1998; Ball, 1996) whilst the medium sized companies are characterised as more openly competitive.

### 2.2.4 Change in the House-Building Process

There are many barriers to innovation within the British house-building industry:

- The speculative nature of house-building encourages risk minimisation in production (Ball, 1999) as substantial risks are taken in the production of houses
before sale. House-builders aim to achieve high profit margins by maximising the
difference between the costs incurred and revenues received (Gillen, 1995).

- The volatility of the market, which went through a major cycle in the late 1980s,
  increases house-builders conservatism (Ball, 1999). Large-scale investment in
  new projects or technologies is not encouraged by market fluctuations.

- Land-oriented competitive strategies make British housing developers reluctant to
  invest in innovation and house design as they have seen little competitive
  advantage in doing so (Ball, 1996).

- Public house-building has, in the past, acted as a hidden subsidy to the private
  house-building sector (Ball, 1996). It helped to train large numbers of skilled
  workers and professional staff and was used as a test-bed for new building
  methods and products (Scoffham, 1984).

- The dominance of the second-hand housing market in Britain leads customers to
  be conservative in their approach due to concerns about the resale value of their
  homes. Customers’ conservatism is increased by the lending policies of mortgage
  brokers, who are less likely to provide mortgages for unusual properties and
  innovative construction techniques (Ball, 1996).

The quality of house-building in Britain compares unfavourably with other countries,
where the structure of housing supply forces house-builders to pay more attention to
product or process innovation (Barlow & Gann, 1999). For example, in Sweden there
has been less scope for developers to make purely inflationary profits because of the
system of land ownership and development control (Barlow & King, 1992).

In Britain, there is now “a mood for change in the housing supply industry” (Barlow
& Gann, 1999). The house-building environment is altering, making land-oriented
competitive strategies less appropriate and increasing the need for house-builders to
use innovation to gain competitive advantage (Barlow, 1999). Improvement of the
house-building sector is a focus of the government report, Rethinking Construction
(Egan, 1998). The government has established The Housing Forum to implement the
themes of this report. Initiatives to improve house-building include:
• **Meeting customers' housing needs through standardisation (MCNS)** — a three year project to test a component-based delivery system, which is capable of more closely meeting user needs in a cost effective and sustainable manner (Barlow, 1998).

• **Market-led homebuilding as a manufacturing process (HOBMAN)** — the changes in technology and the supply chain necessary are investigated to produce a customer-focused strategy for speculative volume housebuilders (Roy & Cochrane, 1999; Roy & Gaze, 1999).

The component-based and customer-focused house-building techniques, which are being explored in the MCNS and HOBMAN initiatives, are similar to those used in Japan. Reports by the Department of Trade and Industry (DTI) Overseas Science and Technology Expert Missions (OSTEM) (Bottom, *et al.* 1996; Palmer, *et al.* 1998) have brought the use of such techniques in Japan to the attention of British housebuilders. Research has been conducted into Japanese house-builders transformation of the delivery of new housing through the adoption of component-based approaches used in the manufacturing industry (Gann, 1996; Gann, *et al.* 1999), customer-focused product development, prefabrication and supply chain management techniques (Gann, 1996; Gann & Senker, 1993). These techniques are also being explored in the Europe-wide project, FutureHome (Atkin & Wing, 1999), which investigates manufacturing techniques and the American project, House_n (Larson, 1999), which looks at digital technologies in the future home.

In all of the British and European projects (Barlow, 1998; Roy & Cochrane, 1999; Atkin & Wing, 1999) agile production is being promoted, and this requires devolving decision-making to multifunctional teams to increase customer focus (Barlow & Gann, 1999). Visualisation tools could potentially facilitate this process and recently researchers (Roy & Gaze, 1999) have begun to show an interest in the use of visualisation tools such as VR to complement such initiatives.

2.2.5 **IT use in House-Building**

Despite attempts to improve house-building processes, outlined in section 2.2.4, little is known about IT use in British house-building. Attempts to improve construction
processes may be facilitated or frustrated by computing strategies (Hinks, et al. 1998) thus successful implementation of innovative house-building processes, such as agile production may require the consideration of advanced IT techniques. The current IT environment affects the adoption of advanced IT (Scott Morton, 1991) but IT use within the house-building sector has received very little attention from researchers and there is almost no data on the development of IT strategies during the 1990s.

It has been hypothesised that two types of housing developers will emerge in the near future (Freeman, 1997). The theory is that larger British housing developers will adopt an IT base using advanced computer techniques to improve their competitive edge whilst regional housing developers continue to operate on a traditional land-oriented model. However, no empirical evidence is presented and this hypothesis is not substantiated.

The empirical findings of the late 1980s and early 1990s are mainly from research focused on the functional areas of estimating and cost control (Skilton & McCaffer, 1984; Thorpe, 1992; Ewin, Oxley & Poole, 1990) although there is research on a specific instance of CAD use at Westbury Homes (Day, 1997; Counsell, 1998). From the former work a picture of the fragmented and exploratory nature of IT use within the sector in the late 1980s can be drawn. At this time house-building companies generally lacked formal explicit strategies with respect to computers and information management (Thorpe, 1992) and the house-building sector had received little attention from software developers (Ewin, Oxley & Poole, 1990).

In the latter work, Day (1997) documents the establishment of a CAD research department in one large house-building company, Westbury Homes, in the late 1980s. This house-builder has sought to use three-dimensional models in order to maximise their competitive advantage through the use of visualisation (Day, 1997) and has also worked on the use of a component library since 1989 (Counsell, 1998). The extent to which this house-builder’s use of CAD is unusual or indicative of a more general trend is unknown, because of the lack of industry-wide data with regard to CAD use in the sector.

The information available on Japanese house-builders’ IT use suggests that IT use is widespread in the Japanese house-building industry and that sophisticated IT
strategies are employed (Palmer, et al. 1998). Use of CAD has been widely documented (Palmer, et al. 1998; Matsumura, 1994) and use of VR has been recorded. Although the first DTI mission to Japan in 1994 found that there was “a surprising lack of electronic technologies used for either sales and marketing” and “no evidence of the use of new technology such as interactive CAD or virtual reality as a tool for selling houses.” (Bottom, et al. 1996), this situation had changed by 1998 when the DTI mission found VR being used for dialogue with the customer (Palmer, et al. 1998).

VR was found to be used in major house-building companies, particularly on the customer’s second visit, to attract and retain interest: “These VR facilities appear to be used as a “hook” to pull in the consumer by allowing them to experience and experiment with the home. We could anticipate further improvements in (and use of) this type of package and it may be relevant to the UK market.” (Palmer, et al. 1998)
2.3 Virtual Reality

2.3.1 What is Virtual Reality?

The term ‘virtual reality’ is used to describe a technology that enables interactive real-time viewing. Though the term only came into use in the 1980s (Bertol, 1994), development of the technology began earlier through research on computer graphics and flight simulation.

In the early 1960s, Sutherland (1963) prototyped the first graphical computer system, Sketchpad, which allowed the drawing of vector lines on a computer screen using a light pen. Two years later in a paper, The Ultimate Display, Sutherland (1965) described the concept of the head-mounted display (HMD) and an immersive 3D computer environment. Sutherland (1968) wrote “The fundamental idea behind the three-dimensional display is to present the user with a perspective image which changes when he (sic) moves.”

Development of flight simulators, by the US Air Force (Furness, 1986) and NASA (McGreevy, et al. 1990), contributed to understanding of the technical requirements for VR (Earnshaw, et al. 1993). At the same time research into civilian uses of computer generated images was being conducted. In the late 1960s, Brooks, et al. (1990) pioneered haptic (touch/force) feedback. In the mid-70s, whilst Krueger (1991) developed video projection methods, described as ‘artificial reality’, Brooks (1986) developed the first interactive architectural walk-through systems at the University of North Carolina.

VR systems can be split into two groups, immersive VR and desktop VR (Kalawsky, 1993). Immersive VR systems attempt to present the viewer with the convincing illusion of being fully immersed in an artificial world (Issa, 1999). Enabling technologies are wide-angle stereoscopic displays, tracking, haptic feedback, binaural (3D) sound and voice input/output as well as real-time computer graphics (Gigante, 1993). Desktop VR presents real-time interactive graphics on a computer screen. Though it is sometimes argued that immersive technologies are required for true VR
(Gigante, 1993), in this thesis VR is defined as a technology that enables interactive real-time viewing of data in three dimensions (referred to as X, Y, and Z) and time.

2.3.2 The VR System

VR systems are designed to achieve real-time interaction. Realism of a VR scene is dependent on factors such as the frame rate, response time and lighting. Many features of VR programs are concerned with optimising realism for a given application on a given system. Three models of run-time architecture are possible (Bryson, 1995); these are event-driven architecture, simulation loop architecture and fully concurrent architecture. The basic parts of a VR program are however the input processor, simulation processor, rendering process and world database (Isdale, 1998).

The input processor allows users to interact with the virtual reality model using a wide variety of possible input devices (Kalawsky, 1993). The simulation processor is used to update the state of the virtual model by reading values from input devices and calculating the effects of these, on the movement of objects in the world in combination with other simulation activities such as terrain following and intersection testing. Time taken for the system to respond to the users’ actions is called the system latency or control lag. Each screen update is called an update frame and a minimum requirement for interaction is described as 10 frames per second (fps) with a latency of 0.1 seconds (Rosenblum & Cross 1997).

The rendering process is facilitated by the organisation of the world in the world database. Objects are typically part of an object hierarchy (Isdale, 1998) or scene graph (WTK, 1998) as shown in Figure 2.1. Nodes of the scene graph inherit the translations and orientations of their parent and pass on their own translation and orientation to their children. Nodes may represent objects such as light sources, cameras, and geometry; and objects may have scripts added to give them behaviours. Geometric objects are described by polygons, which are planar, closed multi-sided figures (Isdale, 1998).
The scene graph is used to facilitate spatial culling, which is the elimination of unrequired geometries and their effects. The part of the model being viewed is determined and geometry and effects are selectively loaded and rendered, with unseen geometry and effects being removed to increase performance (Isdale, 1998). In packages such as WTK and VRML, the order in which the scene is rendered is dependent on the order in which the scene graph is traversed (WTK, 1998). Thus in Figure 2.1 the light node would affect the fog and geometry node 3 only.

Whilst visual rendering is considered here, VR programs can use separate rendering processes for visual, auditory, haptic, and other sensory systems (Isdale, 1998) and these may also use the scene graph to optimise performance. A first step in visually rendering the scene would be to eliminate all objects that are not visible by the camera. This can be quickly done by clipping the object bounding box or bounding sphere against the viewing pyramid of the camera. Then the hidden surface algorithm and actual pixel rendering is done. Z-buffering (Catmull, 1978) is used to determine which parts of the model are closest and hence will be seen by the viewer, allowing the scene to be correctly rendered. Scene graphs have been used with very large architectural models, which consist of over one million polygons, to enable frame rates of over 20 fps to be maintained (Funkhouser, et al. 1996).
Chapter 2 Research Issues

If the number of polygons visible from different parts of a VR model varies, the computational load varies as the user moves through the virtual environment resulting in a varying frame rate. In some applications, such as flight simulation, the frame rate is critical and the view may be simplified to maintain a constant frame rate. In other applications, such as architectural representations, the representation of the model is more important and the frame rate varies depending upon the computational load.

The rendering of lighting effects contributes to the realism of a scene. The ‘painter’s algorithm’ is used in many PC-based VR systems (Isdale, 1998); though it has limited capabilities it is easy to implement and relatively fast. This rendering is not of a high enough quality to be termed ‘photorealistic’ however photorealism is also possible. Raytracing (Kajiya, 1983) which is capable of rendering shadows, reflective and transparent objects is the method used for maximum image quality in still images and animations. However this technique is too computationally intensive to be used in VR models. Radiosity rendering, (Goral, et al. 1984) though computationally intensive, is viewpoint independent allowing rendering calculations to be computed before viewing. It has been used for walkthrough type VR systems (Isdale, 1998), by companies such as Lightscape (http://www.lightscape.com) and Atma Systems (http://www.atma.it).

2.3.3 Spatial Cognition in VR

Interaction with a virtual world can be ‘egocentric’, where a viewpoint is moved through the world or ‘exocentric’, where the observer manipulates the world in front of a static viewpoint (Edward & Hand, 1997).

From an egocentric viewpoint, users’ ability to judge directions and relative distances in a virtual building model is similar to that in the real building, improving with increased exploration (Ruddle, et al. 1997). However judgement of absolute distances in VR is inaccurate (Henry, 1992; Turner & Turner, 1997). This has been attributed to the blinkered nature of the field of view, which is typically 60-100 degrees in desktop virtual environments (Ruddle, et al. 1997). Sizes appear smaller in both horizontal and vertical dimensions (Henry, 1992) and increased exploration yields no improvement (Turner & Turner. 1997).
Differences between virtual and real environments, such as the inaccuracy of absolute distance judgements and the lack of subtle cues (Ruddle, et al. 1997) can affect performance in simple navigation and way-finding tasks (Satalich, 1995). Virtual environments can be constructed to aid navigation and the use of memorable landmarks (Ruddle, et al. 1997). For example, user-defined bookmarks (Edwards & Hand, 1997) have been suggested.

Knowledge acquired from navigating through VR models is similar to the knowledge acquired from navigating through the real world (Turner & Turner, 1997). It is different from survey knowledge acquired from exocentric views such as maps or figures (Turner & Turner, 1997). Navigation through a virtual model compares unfavourable with the use of a map for learning the navigation of a complex architectural spaces (Goerger, et al. 1998) and the use of a single egocentric view may also be inappropriate for the actual design of that space (Leigh, 1996).

Researchers (Edward & Hand, 1997; Ruddle, et al. 1997) suggested the use of maps or exocentric views to aid spatial comprehension within virtual environments. Experiments have been conducted with north-up and forward-up maps (Darken & Cevik, 1999), the results indicate that preferences may be task dependent.

### 2.3.4 VR in Construction

In early work use of VR to simulate the construction process was investigated. Op den Bosch & Baker (1995) provide the user with a choice of virtual construction equipment with which to assemble buildings. They argue that in this approach users’ attention is focussed on engineering issues relating to building construction, rather than technical computer issues relating to model construction. Other researchers focused on allowing the user to view a model of construction at various stages of completion (Retik, 1996; Adeji-Kumi & Retik, 1997; Fischer, 1995; Fischer & Kunz. 1995). Fischer & Kunz (1995) argue that with their 4D-CAD system, design and construction planning alternatives can be assessed within the context of space and time.

The International Council for Research and Innovation in Building and Construction (CIB) has set up a task group (TG24) to study VR efforts in construction (Issa, 1999).
CIB TG24 created a report to document the existing VR efforts in construction. According to the TG24 report, the user must in future be able to interact with external applications in real time (Issa, 1999). Thus VR systems should not only to be used as presentation tools but as a universal interface to all construction applications (Aouad, et al. 1997b; Issa, 1999). Research has been conducted in this area (Aouad, et al. 1997a; Underwood & Alshawi, 1997). The Open Systems for CONstruction (OSCON) project (Aouad, et al. 1997a) and The Simultaneous Prototyping for An Integrated Construction Environment (SPACE) project (Underwood & Alshawi, 1997) at Salford investigated the use of a VR module integrated with other project applications through a common central project model. Each application is supported by a virtual reality representation of its data. The projects demonstrate the usefulness of integrating project information in a central project database.

It has been argued that VR tools can be useful not only within the construction process, but also for bridging the gap between design / engineering and construction (Souba, 1999). Such applications of VR are of relevance to the research problem. Examples of VR applications in the areas of design generation; computer supported collaborative work (CSCW) and urban modelling are shown in Table 2.3 and discussed in sections 2.3.5, 2.3.6 & 2.3.7.
### Table 2.3 Examples of VR applications in construction

<table>
<thead>
<tr>
<th>Project</th>
<th>Authors</th>
<th>Project Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Generation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VoxDesign (Utrecht University)</td>
<td>Dirk &amp; Regenbrecht (1995)</td>
<td>- Small cubes (2.5cm³) used for design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Interaction is through a pen metaphor: a pointing device is used, with a pop-up three dimensional menu</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scale 1:1</td>
</tr>
<tr>
<td>Conceptual Design Space (Georgia Tech)</td>
<td>Bowman (1996)</td>
<td>- Specification of vertices and heights used for design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Interaction is through two types of tools: direct manipulation widgets and adapted 2D surface elements such as a color palette and co-ordination information box.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scale 1:1</td>
</tr>
<tr>
<td>Sculptor (ETH Zurich)</td>
<td>Kurmann, et al. (1997)</td>
<td>- Solids and voids used for design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- The interface is almost widget-less. Interaction is through 3D input devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scale dependant on display facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Two types of agents are used: design assisting agents and design generating agents.</td>
</tr>
<tr>
<td><strong>Computer Supported Collaborative Work (CSCW)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GreenSpace II (HIT Lab, University of Washington)</td>
<td>Mandeville, et al. (1995)</td>
<td>- VR used for architectural design through the Virtual Design Studio Project (VDS) (Bertol, 1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Multiple participants at remote locations, represented as avatars</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Hardware: SGI</td>
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<td></td>
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<td>- Software: tools developed using Open Inventor</td>
</tr>
<tr>
<td>Collaborative Architectural Layout Via Immersive Navigation (CALVIN) (University of Illinois, Chicago)</td>
<td>Leigh &amp; Johnson (1996)</td>
<td>- VR used for earlier stages of design</td>
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<tr>
<td></td>
<td></td>
<td>- Heterogeneous perspectives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- ‘mortsals’ view world from egocentric perspective</td>
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<td></td>
<td></td>
<td>- ‘deities’ view world from exocentric perspective</td>
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<tr>
<td></td>
<td></td>
<td>- Hardware: CAVE, LCD Shutter glasses, magnetic tracker, wand, Immersive Workbench</td>
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<td>- Software: tools developed using Open Inventor</td>
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- Hardware: PC, (SUN for wireframe-solid conversion)  
- Software: Sense 8’s World Tool Kit (WRK) |
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<td>(Matsushita Research Laboratory, Osaka)</td>
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### Urban Modelling: City Models

| Bath, England  | Day (1994); Bourdakis & Day (1997) | - Constructed in order to assist in making the planning and development control process more democratic  
- Model covers 2.5km x 3.0km and consists of well over 3 million polygons.  
- Subdivided into 160 sub-models with 4 levels of detail  
- Hardware: SGI (although can be viewed on PC)  
- Software: VRML, modelling in AutoCAD, 3D Studio, Animator and Photoshop  
- [http://fos.bath.ac.uk/projects/bath/bath.html](http://fos.bath.ac.uk/projects/bath/bath.html) |
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<td>(University of Bath)</td>
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| Glasgow, Scotland  | Ennis, et al. (1999) | - VR model was developed to enable the wider community to use the model of Glasgow built in the 1980s  
- Model covers 2.5 miles² and 10,000 properties and consists of  
- Sub-divided into 6 parts  
- Software: VRML, Perl Script used to build interface  
- [http://www.vrglasgow.co.uk](http://www.vrglasgow.co.uk) |
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<td>(University of Strathclyde)</td>
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- In the process of creating a virtual model of the entire Los Angeles basin. This area comprises well over 4,000 miles²  
- More than 12 separate area models have been built, ranging from 1-15 miles²  
- Hardware: 4 processor Silicon Graphics Onyx with Reality Engine graphics  
- Software: simulator software developed using IRIS Performer, MultiGen used for modelling and Arc View2 was the GIS application. |
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<tr>
<th>Urban Modelling: Urban Interventions</th>
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<tbody>
<tr>
<td>Tower of London (University of West England)</td>
<td>Counsell &amp; Phillips (1997)</td>
</tr>
<tr>
<td>Porta Susa, Turin (Universita' di Torino)</td>
<td>Caneparo (1997)</td>
</tr>
<tr>
<td>A Touring Machine (Columbia University)</td>
<td>Feiner, et al. (1997)</td>
</tr>
<tr>
<td>Mobile Hybrid Virtual Reality and Telepresencing (Strathclyde University)</td>
<td>Retik, et al. (1997)</td>
</tr>
</tbody>
</table>

2.3.5 Design Generation

Use of VR in the architectural design process has been widely researched (McMillan, 1994; Smeltzer & Roelen, 1995; Campbell, 1996; Campbell & Wells, 1997; Vries & Achten, 1998) as VR supports spatial thinking and rapid exploration of alternatives (Furness, 1987). Conventional CAD systems facilitate design by allowing rapid drafting and perspective modeling of objects, but they do not support the visual thought processes required for three dimensional design (Furness, 1987). Pen and paper sketches and cardboard models continue to be used in the creative phases of designing because they support ambiguity, imprecision, incremental formalisation of ideas and the rapid exploration of alternatives (Gross & Do, 1996).

Researchers (Chapin, et al. 1994; Wiegand, 1995; Dani & Gahd, 1996) have explored the use of VR for design generation using simple surfaces and solid geometric shapes. The use of simple abstract shapes offers a high degree of ambiguity and allows the
viewer to question and interpret what is seen at the conceptual design stage (Radford, et al. 1997) thus visual abstraction offers advantages over photo-realistic rendering for some applications (Boyd, et al. 1996).

As shown in Table 2.3, the generic research on design generation has been extended in projects on specifically architectural applications (Dirk & Regenbrecht, 1995; Bowman, 1996; Kurmann, et al. 1997). One example, the conceptual design package Vox Design (Dirk & Regenbrecht, 1995) allows small cubes (voxel) to be placed in a virtual space. The small cubes are intended to provide an intuitively comprehensible system for the architectural designer and to avoid the need for an extensive training program before using the system. However, it has been argued that the architect is primarily concerned with the design of spaces, not of solids (Kurmann, 1997). The software package Sculptor (Engeli & Kurmann, 1996; Kurmann, et al. 1997) introduces the concept of the ‘space element’, which consists of no material and carves out a space when it intersects with a solid element. The use of both solids and voids results in a more intuitive approach to the use of the computer as an architectural design tool at the conceptual design phase.

The modelling tools available in VR systems are not as sophisticated as those in conventional systems and tools such as layers, swap controls and high precision detailed rulers, available in conventional CAD systems are lacking (Bourdakis, 1997). Detailed VR models created at later design stages are normally made from data transferred from conventional CAD systems. This data requires simplification due to the need for performance optimisation in VR systems (Soubra, 1999). Protocols for effective data transfer have not been established and data exchange between CAD and VR continues to be problematic (Bourdakis, 1997; Soubra, 1999).

2.3.6 Computer Supported Collaborative Work

Models have been used for design evaluation for centuries. A model of the chapel at Santa Croce, Firenze, for example, was presented to the project patrons, the Pazzi family, by the Renaissance architect Brunelleschi (Vasari, 1568). In more recent times, the use of 3D models to support collaborative design work, rather than simply presentation of the final design, has been prompted by desire to increase public participation (Lawrence, 1987).
Dialogue between the architect and the client in the design process has been researched using models, built at both small and full-scale (Lawrence, 1987). The models, which were used for housing design were simple and abstract in nature so that they did not inhibit the development of alternative designs and enabled design proposals to be simulated and evaluated as simply and quickly as possible (Lawrence, 1987).

As early as 1972, it was recognised that computers made good tools for collaborative design allowing the dynamic testing of a range of "what if" scenarios (Mitchell, 1972). VR enhances the capabilities of conventional CAD tools, by enabling the creation of environments that can be entered into and interacted with directly. This greatly facilitates the process of visualising, evaluating and communicating new design ideas. The use of VR for Computer Supported Collaborative Work (CSCW) has been investigated, and the major projects are shown in Table 2.3.

The Greenspace II software (Mandeville, 1995), which was developed at the HIT Lab, Washington, was used to support distributed architectural design on the Virtual Design Studio (VDS) project (Bertol, 1997). VDS was an international collaboration on architectural student projects: participating universities included MIT, Sydney, Cornell, National University of Singapore (NUS), University of British Columbia (UBC), and ETH in Zurich. Students can discuss design issues from within the virtual world, and collaborate with others at remote locations. Avatars, which are virtual models that represent people, were used to represent the students within the virtual world.

Whilst in the VDS project all the users had the same interface to and representation in the world, heterogeneous perspectives are investigated in the CALVIN (Collaborative Architectural Layout Via Immersive Navigation) project (Leigh, 1996). Two different perspectives are introduced: these are the mortal view and the deity view. The mortal view is egocentric with mortals totally immersed within the environment in a CAVE (CAVE Automatic Virtual Environment), which projects stereo images on the walls and floor of a room-sized cube. The deity view is exocentric with deities looking down on an aerial view of the world, presented on an Immersive Workbench, which is a horizontal viewing surface on which a stereo image is visible. Whilst mortals are
capable of performing fine manipulations, deities are more capable of performing gross manipulations. Though the intention was that mortals and deities could assume the roles of apprentices and teachers or clients and demonstrators, the rigid use of different viewpoints was found to inhibit shared understanding of the design (Leigh, 1996).

Interaction between different roles through a shared perspective on the virtual world is demonstrated in the Kitchen Planning Support System (KiPS). This application is different from the above, in that it is commercially developed. It has been developed by Matsushita Electric and has been used for collaboration between clients and demonstrators in Matsushita (Panasonic) showrooms since October 1994. It was developed to allow the customer to design a kitchen by assembling components: customers can choose from 30,000 kitchen unit products and an infinite number of possible kitchen layouts (Bertol, 1997). The VR system has been extended to an application of a networked VR-supported kitchen design system (Fukuda et al. 1997) to allow customers to design at home.

2.3.7 Urban Modelling

It is argued that use of computer-based urban models can radically improve the effectiveness of policy-making and development control (Radford, et al. 1997) and bring a greater level of involvement from all participants in the planning process (Levy, 1995). VR models can be categorised as either large-scale urban models of cities and regions, or smaller scale urban models for the planning of particular urban interventions.

Three major VR models of cities and regions are shown in Table 2.3. The size and complexity of such models raises important technical issues, as real time interaction is difficult to achieve with such large data sets. The size and complexity of the Bath model, for example, requires a top-end PC or SGI platform to run it, even though extensive optimisations have been performed (Bourdakis & Day, 1997). This is despite being created from CAD models that had been structured to aid simplifications within the VR world and thus didn’t use industry standard CAD conventions.
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Such large models are not necessary for the study of specific urban interventions, desktop VR, internet-based VR, augmented reality and telepresencing have been used for smaller-scale urban applications. Examples of such applications are also shown in Table 2.3.

A model the Tower of London was created using desk-top VR, as a tool for evaluating proposals and also for future use in promotional videos, presentation of information to site visitors and Internet presentation (Counsell & Phillips, 1997). The VR model allowed much greater flexibility in its use, and evolution of uses throughout the lifetime of the project, than three dimensional walk-throughs and CAD models.

Internet use for planning consultation is also gaining increasing interest, the Glasgow and Bath models described above are now available on the Internet in simplified form. Smith (1997), describes two categories of 3D model for the Internet as the 3D Model, predominantly developed using a VR format called VRML, and the navigable movie, otherwise known as QuickTime VR. Smith (1997) looks at the integration of these technologies using RealVR, to model the built environment to a high level of realism.

In a distributed use of VR, it may be necessary for participants to have a clear idea of their roles and responsibilities within the virtual world. Some anti-social behaviour, found in earlier work on human interaction in virtual environments (Benford, 1995; Greenhalgh & Benford, 1995), has also been found in architectural applications. When a virtual model of a new railway junction was opened to the public on the Internet, anti-social behaviour of participants led to the termination of the open discussion (Caneparo, 1997). In this case over 200 participants arrived at the model and it was difficult for the researchers to focus the discussion.

Augmented reality is a technique for merging the real environment with computer generated imagery. Goodfellow (1996) speculates that in the future it could be used to enable individuals to visit a site with the developer, planners and councillors, put on cordless VR helmets and actually see the development on site, with the surrounding environment still in view. Feiner, et al. (1997) use a transparent head-mounted display (HMD) to overlay information for exploring the urban environment, building on earlier work using augmented reality to overlay structural information on buildings (Feiner, et al. 1996).
Telepresencing can also be used to merge the real and virtual worlds, in this a video image of the world is merged with graphics on an opaque display. A mobile, real-time, 3D hybrid virtual reality and telepresencing (VR/TP) system has been researched (Retik, et al. 1997). This system will allow remote surveillance of the construction site, and integration of real world images of the site with virtual reality representations, derived from planning modules, for progress monitoring.

The advantage of this merging of real and synthetic images is that it eliminates the need to rebuild the existent world. Only the new development itself, or textual data relating to it, need be modelled in the virtual world. However the use of real images limits the views that can be taken from the model. The real images need to be taken, either directly with the eye, or with a robotic head that can be controlled. It is not possible to gain the kind of exocentric viewpoint that can be seen in a purely virtual world.

There has been some early interest in the use of VR for house-building applications. Thurston (1996) provided an introductory text in a booklet the Canadian Mortgage and Housing Corporation, which discusses the potential of VR for use in housing and community planning, though his concern is with VR use by planning officers, rather than with the construction companies. There have been few academic projects looking at the visualisation of housing developments in VR. The projects recorded in the literature show alternative housing proposals (Campbell, 1996) and VR use as a platform for experimenting with housing policy to educate staff working in housing estates (Hamilton, 1996).
2.4 Industrial Adoption of Innovation

This section reviews literature on the industrial adoption of innovation as a basis for understanding the adoption of VR in the house-building sector of the construction industry.

2.4.1 Models and Studies of Innovation

Industrial innovation has been described as a process that mediates between market and technology (Allen & Scott Morton, 1994). It can be seen as a response to changes in technology or market that results in advances in technology and new products and services (Figure 2.2).

![Figure 2.2 Innovation as a response to changes in market and technology, Source: Allen & Scott Morton (1994)](image)

Early models of innovation (eg. Schumpeter, 1934) were based on mass-production industries and assumed that firms compete in a technology race while anonymous consumers purchase through arms length market transactions (Hobday, 1995). These assumptions do not hold in modern industries, such as those which produce large-scale customised products (Hobday, 1995). Firms may collaborate and users may be involved with product development. Innovation may be based on effective regulation,
inter-corporate collaboration and communications and the skills of the various working groups in sharing knowledge and reaching agreements (Miller, et al. 1995).

The process by which industrial innovation occurs has been characterised as consisting of some or all of the following stages: idea conception, invention, development, market introduction, economic benefits and diffusion (Schagerlund, 1994). Recent theorists (Schagerlund, 1994; Rothwell, 1992; Hobday, 1995) have found that the stages are not sequential, but that innovation is a cross-linked (Schagerlund, 1994) or parallel (Rothwell, 1992) process, in which the stages are interconnected through feedback loops. Rothwell (1992) theorises that innovation is becoming faster and employing a new electronic toolkit, with tools such as expert systems and simulation modelling used to aid the development process.

Adopters of an innovation, within any social group, can be categorised as innovators; early adopters; early majority; late majority and laggards according to the time they take to adopt relative to the majority (Rogers, 1962). Earlier adopters are observed to engage in more active information seeking when considering a non-diffused innovation, have above average contact with other people and greater exposure to both mass media and interpersonal communications channels (Rogers, 1962).

The first company to use an innovation, or 'first mover', gains an initial advantage (Betz, 1997; Galliers & Betts, 1998). Being first provides important lead times over competitors, enabling the company to gain experience of the technology and maintain an advantage over its competitors. However the cost of research and development is high (Galliers & Betts, 1998), and there are risks involved as there are no clear precedents to follow and competitors may learn from the first mover's mistakes.

Organisations are by their nature, and often by design, oriented towards stabilising and routinising work (Schein, 1994a). Within the organisation, planned change can be described as a three stage process of unfreezing and creating motivation to change, creating change through cognitive redefinition and then refreezing to stabilise the change (Schein, 1994b). Some early adopters of an innovation within the organisation act as change agents (Rogers, 1962) and catalyse change within the organisation. Top management is well placed to initiate change within an organisation (Schein, 1994b),
as end-users await signals of support from top-management before deciding to spend effort on learning an innovation (Zmud, 1984).

The characteristics of the innovation, as well as the innovation process, contribute to the success or failure of innovation (Rothwell, 1994; Yetton, Sharma & Southon, 1999). However, market research cannot adequately predict the need for revolutionary new technologies as insights into new product and process and service needs are constrained by real-world experience (von Hippel, 1994). Von Hippel (1986, 1988) advocates the study of the early adopters, describing these early adopters as ‘lead users’ where their present strong needs will become general in the market place years or months in the future. It is argued that lead user analysis can improve the productivity of new product development as lead users and non lead users in the same domain area have similar evaluative structures. Present judgements by lead users are likely to foreshadow similar future judgements by non lead users.

The following sections consider studies of innovation in the construction industry and its house-building sector, the organisational use of IT and the adoption and early use of CAD.

### 2.4.2 Innovation in Construction and House-Building

Compared with other industries, there are constraints placed on innovation within construction because of the characteristics of the industry. Characteristics include:

- The unusual extent to which the construction industry is regulated. Government regulation often has a greater influence on practice than customer preferences (Pries & Janszen, 1995).
- The ‘engineer’s paradigm’, which is an emphasis on short-term (project) management resulting from management usually originate from practice (Pries & Janszen, 1995). Undertaking construction innovation outside a project appears to be an unusual process (Tatum, 1987).

These particularities led Emmitt (1997) to report that though diffusion theory (Rogers, 1962) could be applied to the construction industry, modifications to the theory were necessary because of the complex nature of construction processes. As the industry is changing, it is argued that companies in the construction industry will have to operate
in a more extrovert and market-driven way and they will have to reconsider their capabilities (Pries & Janszen, 1995).

In a study of the diffusion of IT in constructed products, Gann (1993) explores the relationships between the different players in supplier networks: manufacturers, designers, specialists, contractors, sub-contractors, developers, users, professional industry associations and regulators. Gann (1993) finds that changes occur at the boundaries between traditionally defined sectors, as technology flows through interactions such as supplier-producer relations; and also that users play a part in stimulating and directing the course of innovation.

A spectrum of innovation models can be used to describe innovation in the construction industry, from incremental change to modular, architectural, system and radical change (Slaughter, 1998). Incremental change most often appears within the organisation that has the knowledge base upon which to develop improvements (Marquis, 1998). Radical innovations often appear from outside the industry and are often introduced by new companies and organisations (Slaughter, 1998). Pries & Janszen (1995) find that for this reason smaller enterprises play a very dominant role in construction industry innovation.

Though barriers to innovation in the British house-building sector have been identified (Ball, 1999), there has been insufficient research into the mechanisms for innovation in the house-building sector in Britain. Analogous research, conducted in America (Toole, 1998; Slaughter, 1991; Goldberg & Shephard, 1989), is summarised in Table 2.4.
Table 2.4 Studies of innovation in house-building

<table>
<thead>
<tr>
<th>Authors</th>
<th>Theory &amp; Studies</th>
<th>Main findings</th>
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<tr>
<td></td>
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<td>• Home builders who are more apt to adopt non-diffused innovations are those who have superior abilities to gather and process information about innovations and higher tolerances of uncertainty</td>
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<tr>
<td>Slaughter (1991)</td>
<td>Comparative Study of User/Manufacturer product innovations (builds on Schumpeter, 1934)</td>
<td>• Users of the product innovations, innovate much more than the product manufacturers do and that their innovations are implemented much more rapidly.</td>
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<td>• A pattern of continual innovation during implementation was observed, and explained as a response to low cost of user solutions, high cost of delay and the low regulatory cost for users.</td>
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<td></td>
<td></td>
<td>• Relations between the users and manufacturers are necessary for successful implementation of product innovations</td>
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<tr>
<td>Goldberg &amp; Shephard (1989)</td>
<td>Study of diffusion of nine products (builds on Rogers, 1962)</td>
<td>• Trends in the diffusion of the nine innovative technologies suggests that they can take 15 to 20 years before being adopted by the majority of builders</td>
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<td></td>
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<td>• Economic advantage and simplicity were the two most important characteristics favouring rapid diffusion and adoption</td>
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<td>• Most innovations were to some extent incompatible with the values of established economic and regulatory institutions</td>
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<td>• Small firms have the opportunity to apply more imaginative solutions to technical problems, often through the process of reinvention. However such firms do not engage in formal research and development activities and require some aggregation of resources to reach their full potential as innovators</td>
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<td>• The competitive structure of the industry can, in some respects, promote adoption of innovation in the long run because builders who adopt innovative technologies will achieve a competitive advantage over builders who do not innovate</td>
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Toole (1998) theorises that uncertainty reduction plays a critical role in the adoption of non-diffused innovations, finding empirical evidence that, "home builders who are more apt to adopt non-diffused innovations are those who have superior abilities to gather and process information about innovations and higher tolerances of uncertainty". Thus uncertainty reduction explains Rogers' (1962) characterisation of early adopters, as information gatherers; and late adopters, as having access to fewer resources.

Slaughter (1991) found that in residential construction, builders working on site innovate much more than the product manufacturers do and their innovations are implemented much more rapidly. A pattern of continual innovation was observed, and explained as a response to low cost of user solutions, high cost of delay and the low regulatory cost for users. This research implies that relations between users and manufacturers are necessary for successful commercialisation of product innovations. It also implies that such relations could be beneficial to the users, whose ability to make product innovation would be enhanced by the manufacturers different area of expertise.

Within the house-building and construction industry, IT innovation has rarely been empirically studied and theorised in its organisational context, though there have been benchmarking projects (eg. Smith, et al. 1997) and a framework has been developed using game theory to determine benefits that can be gained from the use of advanced IT (Ramcharan, 1997). In the latter project the ideal candidate for use of IT was found to be an owner with multiple projects, long term relationships with the project team, responsibility for operations and maintenance of the facility, and the insight to recognise and value all of the benefits of using the system.

2.4.3 IT and the Organisation

Use of IT not only allows organisations to automate existing processes, it allows them to 'informate' (Zuboff, 1985) making processes visible and understandable to everyone in the organisation. The greater organisational flexibility gained through the capacity of IT to informate allows the integration of business functions at all levels and between organisations (Allen & Scott Morton, 1994). The efficiency criteria used
to assess early IT projects which reduced traditional labour costs are not appropriate for evaluating such projects and effectiveness criteria should be used for assessing the adoption and implementation of advanced IT systems (Fitzgerald, 1998).

The transformation of IT from a resource, which is available to all firms in an open market, to an organisation’s core capability, with potential for competitive advantage, is a path-dependent learning process (Andreu & Ciborra, 1996). Thus attainment of sustained IT based competitive advantage may be more a process of building organisational infrastructure in order to enable innovative action strategies rather than being first on the scene (Peppard & Ward, 1999).

A classic example of the growing strategic use of information provided by IT systems is the introduction of a ticketing system into the airline industry (Monteiro & MacDonald, 1996). The text-based information system not only allowed the ticketing to be done more efficiently, but also allowed more strategic use of information to segment markets, differentiate services and maximise yields.

IT may itself catalyse and promote wider innovation within organisations (Schein, 1992). Organisations can transform into learning institutions, in which the electronic database is central, and intellectual skill is the most precious resource for productive enterprise (Zuboff, 1985). Watts, Swann & Pandit (1998) speculate that unique characteristics of VR enhance the potential of the company by increasing its capacity to experiment, involving more people in the innovation process, and capturing ideas generated in the innovation process.

2.4.4 Early Industrial Use of Computer Aided Design Tools

Early implementation of a technology will differ from later implementation of a similar technology as the characteristics of lead users and laggards differ (Rogers, 1962; von Hippel, 1986, 1988). Comparison can however be drawn between the early use of similar technologies and CAD systems can be considered as earlier innovations within the same family of building design tools as VR (Whyte, 1998). Their early industrial use is reviewed in this section.

The findings of the principal authors are summarised in Table 2.5:
### Table 2.5 Findings of research on the early industrial uses of CAD systems

<table>
<thead>
<tr>
<th>Authors</th>
<th>Date of Research</th>
<th>Sample and Nature of Study</th>
<th>Main Findings and Conclusions</th>
<th>Research Issues</th>
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| Schaffitzel - & Kersten (1985) | 20 companies, 5 of which were studied in-depth (study of introduction of CAD in medium sized companies in machine tool industry) | - Developers and users not aware of the methods and potential of user-developer communications.  
- No specific planning and analysis methods used by companies analysed, (although the procedure was systematically documented in some).  
- Preferred approach was for those responsible to participate personally in system development. Formal documentation was not encountered except in one developer organisation.  
- Responsibility for selecting system lay with company CAD specialists no direct involvement of future users.  
- CAD/CAM did not supplement an organisationally perfect work process but offered integrative effects demanding far-reaching new organisational rules that considered not only the CAD system in the design department but also that in work preparation and manufacturing.  
- Planning of CAD introduction almost always effected through newly created positions and departments made up of CAD specialists, separate from the existing computing centre and systems department.  
- Because CAD/CAM introduction took several years, changes in preconditions also often result from modifications of organisational rules arising from external factors or fundamental management decisions. | |
| Currie (1989)    | 1986-1988        | 20 companies or units (managers’ reasons for investing in CAD)                           | - Investment in CAD was not always implemented in line with wider corporate strategy but instead as part of a sub strategy                                                                                                                                                     |                |
| Robertson - (1990) | 12 companies (transfer of design information within and between groups in the product development process) | - Usage of tools related to effectiveness of performance  
- Three levels on which organisational implementation of CAD  
  - Improving an existing process  
  - Extending human capabilities  
  - A catalyst for more effectively managing relations among the organisational units involved in design  
- CAD offers greatest benefit for improving inter-group communications | |
| Brooks (1997)    | 1989-1992        | 5 companies (after initial CAD implementation.) (application of structuration theory to IT (Orlikowski, 1992))                          | - Interaction between users, the CAD system and the institutional properties of design and drawing offices can be viewed as an ongoing dialectical cycle; an active system in which structures and relationships are produced and reproduced over time. |                |
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<tr>
<th>Forslin et al. (1989) 1984</th>
<th>1 company (strategy for implementation and effects of altered procedures)</th>
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<td>• CAD introduction will have little effect on bureaucratic organisation unless such a change is included as an explicit objective</td>
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<tr>
<td></td>
<td>• A joint forum for outlining strategy is needed</td>
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Schaffitzel & Kersten found that early users of CAD systems were active in software development as well as implementation and the resultant organisational change. CAD products were immature and CAD usage was not established so installation of CAD systems could be regarded as a pilot project being used partly to develop and perfect the software. The adaptation and completion of software packages to meet specific requirements of the company meant that user-developer communications were important (Schaffitzel & Kertsten, 1985).

In this study, distinction is made between those CAD systems that were complete in their CAD-specific part, requiring only high-level adaptation or extension; and ‘computer flexible application systems’. Schaffitzel & Kersten (1985) explain that the latter consisted of a core CAD language system with which the actual application functions could be assembled.

An organisation implementing a CAD system can view the investment at three levels: as a device for improving an existing process; as extending human capabilities and introducing new processes or as a catalyst for more effectively managing relations among the organisational units involved in design (Robertson, 1990). It is at the third level of implementation that organisations are found to draw greatest benefit, improving inter-group communications by using CAD communication features to answer certain design questions and disseminate design information (Robertson, 1990). CAD introduction thus required redesigning the organisational context (Schaffitzel & Kersten, 1985) and its success CAD systems has been linked to whether the implementation was conducted as part of overall strategy or as an ‘ad hoc’ decision making process (Currie, 1989).

CAD systems are generally introduced into companies in an ‘ad hoc’ manner, with engineering managers being made responsible for achieving the benefits from technological change. This suggests that top management regarded the investment in CAD as an operational, or functional management decision, rather than a strategic
commitment by the company as a whole (Currie, 1989). This reduces the effectiveness of the implementation and is in contrast to the situation in Japan, where top management is involved in strategic decision making regarding CAD implementation (Currie, 1989). In the majority of companies studied by Currie (1989) the managers did not wish to spend time carefully evaluating CAD systems, but implemented the new technology after one or two successful benchmark tests, i.e. sample pieces of work that had proved successful. Forslin et al. (1989) found the company studied had a history of separate individuals voluntarily making technical innovations after which the development process took place within the functional line with a minimum of cross communication either within or between functions. A joint forum between management and workers is suggested for outlining the implementation strategy of CAD software.

At the time of the Schaffitzel & Kersten’s investigation the attempt to realise integrated systems was imposing solutions involving centralised hardware in the form of mainframe computers (Schaffitzel & Kersten, 1985). They report that the trend towards the use of microcomputers, which had already taken place with administrative systems was not yet apparent in the CAD sphere.

2.5 Research Issues

The literature review has summarised previous research and identified research issues that have not been addressed. In this section these issues are discussed and the research questions, outlined in section 1.2, are derived.

2.5.1 Use of CAD and VR in British House-Building

The use of IT in the house-building sector of the British construction industry has not been surveyed in the 1990s. As discussed in section 2.2.3, there is almost no data relating to the development of IT strategies, making extrapolation of future IT usage from secondary sources difficult. Freeman's (1997) prediction that larger British housing developers will adopt an IT base using advanced computer techniques to improve their competitive edge whilst regional housing developers continue to operate on a traditional land-oriented model is not substantiated. However successful
innovation in house-building processes will require investment in appropriate IT strategies and the use of VR should be explored. Understanding of the extent of CAD and VR use in the British house-building industry is required to determine the existing context and the requirements of housing developers with regard to the use of a VR system. The attitudes towards VR use may be useful to the formulation of an understanding of the potential of VR within the sector. The research question is:

**Research Question 1:** What are the uses of, and attitudes toward, CAD and virtual reality across the house-building sector of the British construction industry?

This research question is addressed in chapter 4, which presents the findings of an industrial survey of computer use in the house-building industry in terms of house-builders' general IT strategies, use of CAD, 3D modelling and visualisation software and attitudes to VR.

### 2.5.2 VR system for Housing Developments

Though there is widespread academic interest in construction applications of VR (Issa, 1999) there has been little research on its use for the evaluation of housing layouts. Research that has been conducted has not investigated the practical and technical issues that arise when creating models for design and evaluation of housing developments. The structure of VR models is very different from the structure of CAD models, and there is a need to research the modelling issues that would be faced by house-builders implementing VR systems, alongside the data exchange and VR format issues. The research question is:

**Research Question 2:** What practical and technical issues arise when creating virtual reality models for the design and evaluation of housing developments?

This research question is addressed in chapter 5, which reviews data exchange issues and different VR model building techniques. The four models of housing layouts that were created in the trials are described.
2.5.3 Experience of VR implementation

There has been little empirical study of the industrial implementation of VR, and the introduction of a new innovation into the British house-building sector has not been researched. Literature on innovation suggests that the study of the lead users of a new technology has many benefits (von Hippel, 1988). Knowledge acquired by the lead users of an innovation could be useful to similar companies implementing such a technology, and the sharing of information about innovations can advance the sector as a whole. The research question is:

**Research Question 3: What is the experience of a British house-building company implementing a virtual reality system?**

This research question is addressed in chapter 6, which reports on a case study of VR implementation in a British house-building organisation.

2.5.4 Comparison with Japan

The use of new technologies and organisational change are interrelated. Initiatives to improve house-building processes in Britain have not considered the implications of IT use. Though housing researchers have advocated new approaches to house-building, such as the prefabrication used in Japan, the use of new technologies, like VR, has received insufficient attention. There is a need to compare the technological maturity of British house-builders’ use of VR with other innovative house-builders’ use of VR. The research question is:

**Research Question 4: How does a similar innovative sector use visualisation tools such as virtual reality?**

This research question is addressed in chapter 7, which reports on the use of VR in the Japanese house-building industry, through a multiple case study of VR use in three large Japanese house-building organisations.
Chapter 3 Study Methodology and Design

3.1 Theoretical Framework

3.1.1 Research Approaches in Construction IT

Construction IT research is not the same as the study of IT as a purely technical phenomenon: concerns are closely related to human activities as well as technical aspects. Researchers tended to unquestioningly assume a positivist viewpoint and use ‘hard’ methodological approaches despite the complex organisational context of IT applications. Research has been focused on technical issues, which such approaches are best equipped to deal with. The result has been that technologically sophisticated projects have been developed but many of these have been unsuccessful at impacting business practice (Leslie, 1997; Wix, 1998; Eastman, 1997).

In construction management research, some discussion of methodology has taken place. Edum-Fotwe, et al. (1996) have highlighted the need to make explicit the methodological assumptions underpinning research whilst Seymour, et al. (1997) advocate the consideration of interpretive research approaches and have called for scholarly debate. The failure of the outcomes of much Construction IT research to achieve widespread application in industry should lead to the reappraisal of the role of academic research in this field and a reassessment of the range of ‘soft’ and ‘hard’ methodological approaches available.

Development of a theoretical framework for this study has been influenced by the more developed theoretical and methodological debate in the social science (Glaser & Straus, 1967; Stake, 1995; Van Maanen, 1988) and business management (Huber & Van de Ven, 1995; Marcus & Robey, 1998; Pettigrew, 1995, 1985a, 1985b) disciplines, and within the relatively new discipline of information systems (Doolin, 1998; Eisenhardt, 1985; Fitzgerald & Howcroft, 1998; Walsham, 1993), as well as the discussion of research methodologies in construction research.
3.1.2 Pluralistic Research Approaches

A research approach is based on a set of basic beliefs (or metaphysics) derived from philosophical assumptions in the fields of ontology, the study of being; epistemology, the study of knowledge and the acquisition of valid knowledge; methodology, the study of research method; and axiology, the theory of value (Guba & Lincoln, 1994; Fitzgerald & Howcroft, 1998). It can be seen from Table 3.1 that there are different positions that inform approaches to research. These are shown as soft/hard dichotomies, but it is worth noting that these are the extremes of spectrums of positions.

At the ontological level, Table 3.1 shows the positions of the relativist and the realist. Between these extremes lie more moderate positions like those of the critical realists, who believe in a 'real' reality which can be only imperfectly and probabilistically apprehended; and the proponents of critical theory who believe in a historically constituted reality shaped by social, political, cultural, economic, ethic and gender values. The futility of the extremist research approaches and need for mutual interpenetration of the relativist and realist positions has been explored by Fitzgerald & Howcroft (1998).

Whilst researchers at both ends of the spectrum of epistemological beliefs agree that research is systematic inquiry, positivist and interpretivist researchers make different claims about the certainty of their conclusions. The interpretivist is sceptical of positivism's claim to have access to the absolute truth, and is more concerned with justified belief (Seale, 1999). The interpretivist also recognises the importance of theorising and attempting a structured understanding beyond that which can be isolated and studied experimentally in terms of causation (Doolin, 1998).

Although the aforementioned beliefs and philosophical assumptions at the ontological and epistemological levels are important, choices of research methodologies cannot be unproblematically explained away by recourse to these alone, but are also the product of (and constitutive of) the social context in which they are invoked (Doolin, 1998).
Table 3.1: Summary of soft v. hard research dichotomies, from Fitzgerald & Howcroft (1998)

<table>
<thead>
<tr>
<th>Soft</th>
<th>Hard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ONTOLOGICAL LEVEL</strong></td>
<td><strong>Realist</strong></td>
</tr>
<tr>
<td>Relativist</td>
<td>Belief that external world consists of pre-existing hard, tangible structures which exist independently of an individual’s cognition.</td>
</tr>
<tr>
<td><strong>EPISTEMOLOGICAL LEVEL</strong></td>
<td><strong>Objectivist</strong></td>
</tr>
<tr>
<td>Interpretivist</td>
<td>Both possible and essential that the researcher remain detached from the research situation. Neutral observation of reality must take place in the absence of any contaminating values or biases on the part of the researcher.</td>
</tr>
<tr>
<td>Subjectivist</td>
<td>Distinction between the researcher and research situation is collapsed. Research findings emerge from the interaction between the researcher and research situation, and the values and beliefs of the researcher are central mediators.</td>
</tr>
<tr>
<td>Emic/Insider/Subjective</td>
<td>Origins in anthropology. Research orientation centres on native/insider’s view, with the latter viewed as an appropriate judge of adequate research.</td>
</tr>
<tr>
<td><strong>METHODOLOGICAL LEVEL</strong></td>
<td><strong>Etic/Outsider/Objective</strong></td>
</tr>
<tr>
<td>Qualitative</td>
<td>Use of mathematical and statistical techniques to identify facts and causal relationships. Samples can be larger and more representative. Results generalised to larger populations with known limits of error.</td>
</tr>
<tr>
<td>Quantitative</td>
<td>Concerned with hypothesis testing and theory verification. Tends to follow positivist, quantitative modes of research.</td>
</tr>
<tr>
<td>Exploratory</td>
<td>Concerned with discovering patterns in data and to explain/understand them. Lays basic descriptive foundation. May lead to generation of hypotheses.</td>
</tr>
<tr>
<td>Confirmatory</td>
<td>Uses general results to ascribe properties to specific instances. An argument is valid if it is impossible for the conclusion to be false of the premises are true. Associated with theory verification/falsification and hypothesis testing.</td>
</tr>
<tr>
<td>Induction</td>
<td>Begins with specific instances that are used to arrive at overall generalisations which can be expected on the balance of probability. New evidence may cause conclusions to be revised. Criticised by philosophers of science, but plays an important role in theory/hypothesis conception.</td>
</tr>
<tr>
<td>Deduction</td>
<td>Emphasis on realism of context in natural situation, but precision in control of variables and behaviour measurement cannot be achieved.</td>
</tr>
<tr>
<td>Laboratory</td>
<td>Precise measurement and control of variables, but at expense of naturalness of situation, since real-world intensity and variation may not be achievable</td>
</tr>
<tr>
<td><strong>AXIOLOGICAL LEVEL</strong></td>
<td><strong>‘Rigour’</strong></td>
</tr>
<tr>
<td>‘Relevance’</td>
<td>Research characterised by hypothetico-deductive testing according to the positivist paradigm, with emphasis on internal validity through tight experimental control and quantitative techniques</td>
</tr>
</tbody>
</table>

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Research can be seen as a craft skill (Seale, 1999; Pettigrew, 1995). It is thus relatively autonomous from the need to resolve philosophical and epistemological debates but can nevertheless draw on these as resources in developing methodological awareness (Seale, 1999).

Methodologically ‘hard’ and ‘soft’ research approaches are not mutually exclusive as both can be used in the same study, neither are they the exclusive domain of a particular epistemological position, with both quantitative and qualitative data used by interpretive and positivist researchers.

Likewise, at the axiological level, relevance and rigour are not mutually exclusive, or the exclusive domain of a particular epistemological position. To assume an interpretive viewpoint is not to necessarily deny the importance of rigour in research, but to argue for relevance. Both rigour and relevance are highly valued by researchers in construction and there is debate concerning how to achieve these (Crook, et al. 1996; Fenn, 1997; Seymour, et al. 1996; Seymour & Rooke, 1998; Runeson, 1997; Walker, 1997). The discipline is founded on the premise that it can contribute something of relevance to the construction industry. The need for rigour in research has been strongly defended (Fenn, 1997).

3.1.3 Relationship between Theory and Practice

Theory has been described as “a statement of relations among concepts within a set of boundary assumptions and constraints.” (Bacharach, 1989). Thus it is a linguistic device used to organise a complex empirical world. The purpose of theory is to challenge and extend existing knowledge, within the limits of the critical bounding assumptions, through the concise organisation and clear communication of an idea.

A theory describes the relations between constructs, which are approximated units, not observable, directly or indirectly, but defined on the basis of the observable (Bacharach, 1989). Derived from the constructs, variables are the observable entities that are capable of assuming two or more values. Schwab (1980) gives examples of constructs and their related variables (eg. performance: sales or return on investment; cohesion: rate of interpersonal interaction or member voting patterns). Propositions state the relations among the constructs; and hypotheses, which are derived from the
propositions, state the relations among the variables in a testable form (Bacharach, 1989). Thus theory can be evaluated in terms of its falsifiability and utility (Bacharach, 1989).

Three different approaches to theory generation and testing are summarised in Table 3.2. In positivist or deductive research, hypothesis are clearly stated at the outset of the research, and then tested by deduction against the empirical data. The generation of the initial hypotheses is often left unexplained, and Seymour, et al. (1997) write that:

"The all-important analysis that goes into the identification of problems, the formulation of questions, the categorisation of informants and respondents, the attribution of significance and answers, are all glossed over and hidden. The effect of this is that the ‘data’, which are often treated with explicit mathematical analyses, have already been subjected to a sophisticated and unexamined process of preparation before the reported research commences."

<table>
<thead>
<tr>
<th>Interpretivist Research</th>
<th>Positivist Research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HYPOTHESIS FORMATION</strong></td>
<td></td>
</tr>
<tr>
<td>\textit{A Posteri}</td>
<td>\textit{A Priori}</td>
</tr>
<tr>
<td>Hypothesis formation at the end of the research. “Emergence” of hypotheses from data.</td>
<td>Theory is well established at the outset of the research, and hypotheses are rigidly set out.</td>
</tr>
<tr>
<td>\textit{Induction}</td>
<td>\textit{Induction and Deduction}</td>
</tr>
<tr>
<td>Hypotheses are generated from the empirical data by induction. (use of grounded theory)</td>
<td>Hypotheses are generated and tested using induction and deduction. (hypothetico-deductive testing)</td>
</tr>
<tr>
<td>\textit{Theory Building}</td>
<td>\textit{Theory Building and Testing}</td>
</tr>
</tbody>
</table>

Thus in the approach described by Yin (1994) theory development prior to data collection is described as essential and a previously developed theory is used as a template with which to compare the empirical results. However, Yin (1994) explains
that theory generation and refinement take place in pilot studies, which are not reported in the final case study write up, but “can be so important that more resources may be devoted to this phase than to the collection of data from any of the actual cases.” Thus it can be argued that the research is selectively reported to fit the positivist approach.

By contrast, in inductive research the role of discovery and learning in the research process is acknowledged. Research is initially focused around research questions, which may be refined or altered during the research process. Some researchers use techniques for generating theories from the data, for example, grounded theory (Glaser & Strauss, 1967), and inductive case studies (Eisenhardt, 1985) whilst others advocate an iterative process of theory formation and testing (Pettigrew, 1995). These approaches allow for more flexibility in the research design. Unexpected and interesting leads can be followed up and the context can be investigated. Initial research questions can be changed during the inquiry and intermediate hypothesis, or propositions can be tested and revised.

3.1.4 Research Strategy Taken

The ontological position of the critical realists (Bhaskar & Lawson, 1998), who believe in a ‘real’ reality, which can be only imperfectly and probabilistically apprehended, informs the research methodology and methods used for this research. Theory generation and testing have been conducted in an iterative manner throughout the life of the project and a contextual approach has been taken (Pettigrew, 1995).

Formative research was conducted with a house-building organisation. From CAD data, VR models were prototyped and feedback was obtained from the house-builder. This early work, which was used to scope the project, determined the interest in the visualisation of site layouts. At the outset it was assumed that in order to investigate the research problem this research would be concerned with the development of a prototype VR system or a protocol for VR usage. This would be tested in field trials, to assure its appropriateness to the house-building sector, and then proposed as an implementable solution.
However after the industrial survey, which was undertaken as a means of ensuring the relevance of the development work, it became clear that the industrial situation was more complex than had originally been assumed. VR models were created and feedback was obtained from house-builders regarding their requirements. Whilst commercial work was then beginning to be undertaken by housing developers and software specialists, with the aim of creating VR systems, there was little theoretical understanding of the nature and implications of the implementation of VR in the house-building industry. It was decided that the bulk of the study would not be concerned with developing a VR application. Though this in itself would be internally coherent and valid, it may have lacked external relevance and validity. Instead a more interpretive viewpoint has been taken in order to theorise about the future of VR in house-building and attempt a structured understanding of VR in house-building.

The relationship of the different parts of the research is shown in Figure 3.1. The researcher has taken an analytical role, evaluating the use of a commercial VR system that has been developed and used in a British house-building company. The research approach is not only longitudinal but also seeks to analyse processes in their intra-organisational and social, economic, political and business context as advocated by Pettigrew (1995).

![Figure 3.1: Relationship between the different parts of the research project](image)
Such a holistic understanding of the use of VR in house-building organisations requires a qualitative observationally based study. A contextualist mode of analysis is used, as described by Pettigrew (1995, 1985a, 1985b) and the potential of VR is assessed within the framework of the historical, processual and contextual situation of the British house-building industry. The more mature use of VR in the Japanese house-building industry has also been studied to sharpen understanding of the contextual factors and allow comparison. Thus the research problem is investigated at different levels of analysis: the industry sector (both through internal and external analysis), the technology, and the house-building organisation.

Although different methods were adopted for the research of VR use in Britain and the research of VR use in Japan, the same instrumentation was used to compare findings across the studies as discussed in section 3.3.3.

3.2 Choice of Methods

3.2.1 Research Methods Available

Fellows & Liu (1997) describe styles of research available to construction researchers as action research, ethnographic research, surveys, case studies, and experiments:

**Action research** – This involves the active participation by the researcher in the process under study, in order to identify, promote and evaluate problems and potential solutions. It is typically research that is aimed at directly influencing practice. Prototype development and implementation, which is here considered to be a form of action research, involves the design and development of a prototype system for field testing in a selected firm and subsequent modification in light of any findings (Wroe, 1986).

**Ethnographic research** – Van Maanen (1988) describes ethnographic research as resting on the “peculiar practice of representing the social world of others through the analysis of one’s own experience in the world of these others.” The researcher engaged in ethnographic research becomes part of the group under study, but tries to limit active ‘intrusion’ and be a passive observer. The ethnographer spends a
significant amount of time; sometimes this is months or even years, in the field. Validity and ethical issues that are raised by this research are field issues. (e.g. reflexivity, reactivity, ‘going native’, divulging private information, deception).

**Surveys** – The normative characteristics of groups can be assessed through a survey of the group, or a representative sample of it. Questionnaires and interviews are often used, as described by Oppenheim (1992). The selection of samples often operates on the basis of statistical sampling, although other sampling methods are possible, eg theoretical sampling (Glaser & Strauss, 1967).

**Case studies** – These are in-depth investigation of particular instances within the research subject. Bloomfield (1998) describes the use of case studies for advocating best-practice in construction IT, whilst Simister (1995) describes a methodology for the use of case studies in construction management, based on Yin’s approach (Yin, 1994). Case study research can be described as positivist (Yin, 1994), interpretive (Walsham, 1993) or critical, where critical research is mainly concerned with social critique (Habermas, 1984). Yin (1994) defines a case study as an empirical inquiry that: investigates contemporary phenomena within its real-life context, when the boundaries between phenomena and context are not clearly evident, and in which multiple sources of evidence are used. Case studies are generalisable to theoretical propositions, the investigator’s goal is to expand and generalise theories (analytic generalisation) and not to enumerate frequencies (statistical generalisation). Data is translated ideographically, in terms of the particular case, rather than nomothetically, in terms of law like generalisations (Simister, 1995)

**Experiments** – Best suited to ‘bounded’ problems or issues in which the variables involved are known, or at least hypothesised with some confidence. Usually relationships between identified variables are tested within the controlled environment of the laboratory where the effect on the dependent variable of changing any one independent variable can be assessed.

Within each of these categories one or more data collection methods may be used, hence interviews and questionnaires may be used in both surveys and case studies. The word ‘method’ is used to describe both the overall style of research, and their constitutive data collection methods (Fellows & Liu, 1997). Researchers have
advocated the collection of ‘rich data’ that are detailed and complete enough to provide a full and revealing picture (Maxwell, 1996; Seale, 1999) to enable the testing of developing theories (Maxwell, 1996). Multiple strategies are also used in order to overcome the criticisms of subjectivity, impressionism, idiosyncrasy and bias to which studies relying upon a single theory, single method, single set of data and single investigator are open (Burgess, 1984).

3.2.2 Research Methods Used

A survey, action research, a single case study and a multiple case study have been used in this study to investigate different aspects of the general research problem. The methods to investigate the research questions, derived in section 2.5.2, are:

1. A survey of computer use in the house-building industry is used to explore the uses of, and attitudes toward, CAD and VR across the house-building sector of the British construction industry. The industrial survey records British housing developers’ use of CAD and IT, and attitudes towards VR.

2. A VR development project is used to explore the practical and technical issues that arise when creating VR models for the design and evaluation of housing developments. A housing site layout was modelled, to explore the suitability of PC-based VR packages, data translation and modelling approaches, and feedback was obtained from house-builders.

3. A case study of VR implementation is used to explore the experience of a British house-building company implementing a VR system. A longitudinal study of organisational aspects of VR implementation was conducted with the leading British house-builder, which was the first to use VR in-house.

4. A comparative study of Japanese house-builders’ VR use is used to explore how other innovative house-builders use visualisation techniques such as VR. A visit was made to Japan, to conduct a multiple case study with house-builders and to obtain background information from industry bodies, research establishments and VR companies.

The focus of the research on British house-building is shown in Figure 3.2.
Secondary sources of information were also investigated and extensive literature reviews were carried out. The outcome of the thesis is a carefully argued interpretation of the evidence relating to the potential use of VR in the British house-building industry, through a consideration of scenarios for the future use of VR.

3.3 Valid Analysis

3.3.1 Standards for Validity of Research

One advantage of the positivist methodology is a range of well-established and widely accepted methods for validating research outcomes. These validation methods were developed for quantitative research, but have also been applied to qualitative research.
Although the interpretivist would argue that these are predicated on false assumptions (such as the possibility of objectivity), the establishment of alternative standards for the validity of interpretive research continues to be a contentious issue (Seale, 1999). A wide range of different approaches are taken by post positivist, critical theorist, constructivist, post-modernist and post-structuralist researchers, as summarised in Table 3.3.

The more extreme anti-foundational views of the post modernists and post structuralists and the historically situated and emancipatory views of the critical theorists are not considered further, but more attention is given to realist alternative standards for validating research outcomes.

Miles and Huberman (1994) provide a formal analysis within what they broadly term the post-positivist ‘critical realist’ tradition as shown in Table 3.3. They pair the traditional terms; objectivity, reliability, internal validity, external validity, and utilisation, with those proposed as alternatives for assessing trustworthiness and authenticity; confirmability, dependability/auditability, creditability/authenticity, transferability/fittingness, and application/action orientation.

Their analysis is not unique or uncontended. Seale (1999) simply asks the questions: how well grounded are the concepts in data? how have the theories emerged from the data, or are they preconceived and forced on the data? has there been active searching, through theoretical sampling perhaps, for negative instances in order to develop the theory by a method of constant comparison?
Table 3.3: Summary of approaches to research legitimacy (based on the description in Altheide & Johnson (1994), with Miles & Huberman (1994) proposed alternative terms for validity of critical realist research.)

<table>
<thead>
<tr>
<th>CRITERIA FOR EVALUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criteria well defined and universally agreed.</strong></td>
</tr>
<tr>
<td>• <strong>Positivist</strong> - applies four standard criteria to disciplined inquiry:</td>
</tr>
<tr>
<td>a) <strong>Objectivity</strong> – the researcher ensures that neutral observation of reality takes place.</td>
</tr>
<tr>
<td>b) <strong>Reliability</strong> – the extent to which a measure, procedure or instrument yields the same result on repeated trials.</td>
</tr>
<tr>
<td>c) <strong>Internal Validity</strong> – the extent to which there can be shown to be a cause-effect relationship between the independent and dependent variables.</td>
</tr>
<tr>
<td>d) <strong>External Validity</strong> – the degree to which the conclusions in the study can be generalized.</td>
</tr>
<tr>
<td><strong>Criteria not well defined or universally agreed.</strong></td>
</tr>
<tr>
<td>• <strong>Constructivist</strong> – argue for the quality criteria, trustworthiness and authenticity, to be used in the evaluation of research.</td>
</tr>
<tr>
<td>• <strong>Post Positivist</strong> (Critical Realist) – pairs traditional terms with those proposed as alternatives for assessing “trustworthiness” and “authenticity”.</td>
</tr>
<tr>
<td>a) <strong>Objectivity -&gt; Confirmability</strong> – demonstration that results depend on “the subjects and conditions of inquiry” rather than the inquirer; relative neutrality and freedom from unacknowledged researcher biases is sought – at the minimum, inevitability of biases that do exist should be explicitly stated; replicability of the study by others.</td>
</tr>
<tr>
<td>b) <strong>Reliability -&gt; Dependability/ Auditability</strong> - whether the process of the study is consistent, reasonably stable over time and across researchers and methods.</td>
</tr>
<tr>
<td>c) <strong>Internal Validity -&gt; Creditability/ Authenticity</strong> - “truth” value of the study findings. Different types of understanding may arise: descriptive, interpretive, theoretical and evaluative.</td>
</tr>
<tr>
<td>d) <strong>External Validity -&gt; Transferability/ Fittingness</strong> – extent to which the findings of the study have any larger import. The issue is whether they are transferable to other contexts and whether they &quot;fit&quot;.</td>
</tr>
<tr>
<td>e) <strong>Utilization/ Application -&gt; Action Orientation</strong> - if a study’s findings are “valid” and transferable, questions can still be asked about its pragmatic value: this leads to questions of ethics, who benefits from the conclusions of the research, and who may be harmed.</td>
</tr>
<tr>
<td>• <strong>Critical Theorists</strong> – stress action, praxis and the historical situatedness of the findings.</td>
</tr>
<tr>
<td>• <strong>Post Modernist</strong> – argues that “the character of qualitative research implies that there can be no criteria for judging its products”</td>
</tr>
<tr>
<td>• <strong>Post Structuralist</strong> – contends that an entirely new set of criteria, needs to be constructed, emphasizing subjectivity, emotionality and other antifoundational factors.</td>
</tr>
</tbody>
</table>

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3.3.2 Modes of Analysis

Modes of analysis have not received the same attention as research methods in the previous literature and the definitions of, and boundaries between, different research styles, data collection methods and modes of analysis are neither clear nor widely agreed (Miles & Huberman, 1994). Contextualism, which is used in this research, has sometimes been described as a research paradigm (Rosnow & Georgoudi, 1986). It has also been described as a mode of analysis (Pettigrew, 1985a) as it involves a process of searching for empirical patterns of similarities and differences to develop bounded empirical generalisations whilst also seeking contextual factors that help to understand and explain the observations.

The units of analysis in a study are the entities about which theories pose concepts and relationships, such as technologies, organisations and industries. Mixing levels of analysis may be useful in research and theory on IT to explore the dynamic interplay among individuals, technology and larger social structures (Markus & Robey, 1988). Technology implementation is a mixed-level phenomenon and the use of multiple levels of analysis allows conclusions to be drawn at different levels.

Miles and Huberman (1994) define analysis as consisting of three concurrent flows of activity: data reduction, data display and conclusion drawing/verification. Though the collection of ‘rich data’ has been advocated by researchers (Maxwell, 1996), volume should not been substituted for quality. The inability for researchers to manage very large data sets seems to point to the importance of identifying relevant data, at both the collection and sorting stages, and using discernment with regard to the creation of simple but useful coding and sorting methods (Miles & Huberman, 1994).

The frequent display of findings in extended text is described as cumbersome by Miles & Huberman (1994), and the display of information in an organised, compressed manner, through matrices, graphs, charts and networks is advocated, to allow relationship to be clearly seen. Data reduction, or data condensation (Tesch, 1990), is not seen as something separate from analysis but as a form of analysis that sharpens, sorts, focuses, discards and organises data in such a way that ‘final’ conclusions can be drawn and verified.
The activities have also been described as summarising and packaging data, repackaging and aggregating the data, and then developing and testing propositions to construct an explanatory framework as shown in Figure 3.3 (Carney, 1990).

**Figure 3.3: The Ladder of Analytic Abstraction (adapted from Carney, 1990)**

At all stages, comparison is described as the main mode of analysis available in qualitative research and "the method of comparing and contrasting is used for practically all intellectual tasks during analysis." (Tesch, 1990). Analysis is seen as an interpretive process of relating different theoretical ideas and constructs, modes of understanding, abstractions, and language systems to the empirically collected data by comparing and contrasting them.

The processes of data collection and analysis are often concurrent or cyclical (Tesch, 1990), and the stages of analysis may be performed iteratively. Review of background literature continues throughout data collection and analysis and emergent theory should be compared with conflicting and similar literature (Eisenhardt, 1989). Theoretical saturation is described as the point at which incremental learning is minimal because the researchers are observing phenomena seen before (Glaser &
Strauss, 1967), ideally this is the point at which closure is reached and data collection stops (Eisenhardt, 1989).

Triangulation, member checking, and searching for discrepant cases have been proposed as methods for ensuring the validity and reliability of research findings. Denzin (1970) discusses triangulation, which is the use of different sources to confirm the findings. Though the approach has been criticised for assuming a single fixed reality that can be known objectively (Bloor, 1997), it can be of use to interpretative researchers for generating multiple perspectives (Seale, 1999). Denzin (1970) describes data triangulation, which involves using diverse sources of data, and methodological triangulation, which involves the use of different methods to study the same object.

Member checking is the soliciting of feedback about data and conclusions from the people studied to rule out the misrepresentation of their meaning (Maxwell, 1996). A reading of an actor’s viewpoint should not be presented as an explanation in itself (Silverman, 1997) but member checking offers a method for testing researcher’s claims by gathering new evidence (Seale, 1999).

Searching for discrepant and negative cases is a key part of the attempt to falsify proposed conclusions (Maxwell, 1996). The basic principle is to rigorously examine both the supporting and discrepant data to assess whether it is more plausible to retain or modify the conclusion. Seale (1999) writes that seeking out and accounting for negative instances (deviant cases) that contradict an emerging account lies at the heart of a fallibilistic research strategy.

3.3.3 Prior Instrumentation

To allow effective analysis of data, it is sometimes necessary to undertake some preplanning and structuring of information before collecting it (Miles & Huberman, 1994). Prior instrumentation focuses the study by setting out the constructs to be researched and the variables being used to measure those constructs (Eisenhardt, 1989). It reduces the amount of superfluous data collected, and enables the researcher to validate the instruments, to ensure that there is no inherent bias before data is collected, helping to guarantee the dependability of the findings. Using the same
instruments on different studies also allows comparison across studies (Eisenhardt, 1989).

However, the rigid use of prior instrumentation is not appropriate in all cases: if the most important or underlying constructs are not in the instruments then they will be overlooked or misrepresented. Adjustment allows the researcher to probe emergent themes or to take advantage of special opportunities which may be present in a given situation (Eisenhardt, 1989)

3.3.4 Approach to Analysis Used

The different parts of the research used to address the research questions use different levels of analysis. Data has been collected with regard to the use and attitudes to use of CAD and VR across the industry, the technical characteristics of VR, the implementation of VR in regional offices of a house-building organisation, and the use of VR in another comparable other sector. Problems of inference can occur when concepts are defined and data are collected at levels of analysis inappropriate for the theoretical propositions being examined (Markus & Robey, 1988). Therefore, care has been taken at each stage of this research to use appropriate levels of analysis for the research question and the theoretical propositions examined.

Different levels of prior instrumentation were used in the different parts of the research and at each stage care was taken to ensure the validity of the outcomes. The level of analysis, level of prior instrumentation, major constructs and variables of the different parts of the research are shown in Table 3.4.
<table>
<thead>
<tr>
<th>Research Part</th>
<th>Unit of Analysis</th>
<th>Level of Prior Instrumentation and Structure</th>
<th>Major Constructs</th>
<th>Related Variables (and method used to measure the variables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey of British House-builders</td>
<td>House-building organisations</td>
<td>High for questionnaire</td>
<td>Level of CAD use&lt;br&gt;Number of CAD users in the company (questionnaire)&lt;br&gt;CAD strategy&lt;br&gt;Level of VR use&lt;br&gt;Size of house-building operation&lt;br&gt;IT infrastructure&lt;br&gt;Attitudes to VR and emerging technologies</td>
<td>Percentage of design work done using CAD (questionnaire)&lt;br&gt;Distribution of CAD users (in-depth interviews)&lt;br&gt;Considerations when choosing software (questionnaire)&lt;br&gt;Turnover (market reports)&lt;br&gt;Number of units per year (market reports)&lt;br&gt;Number of regional offices (in-depth interviews)</td>
</tr>
<tr>
<td>Trials of VR Systems</td>
<td>VR System or protocol</td>
<td>Low</td>
<td>Suitability of modelling approaches</td>
<td>Data translation (modelling work)&lt;br&gt;Model complexity (modelling work)&lt;br&gt;House-builders views (interviews)</td>
</tr>
<tr>
<td>Case Study of VR Implementation</td>
<td>A house-building organisation&lt;br&gt;Sub-unit: regional office of a the house-building organisation</td>
<td>Medium</td>
<td>Motivation for VR use&lt;br&gt;IT infrastructure&lt;br&gt;Strategy for VR introduction&lt;br&gt;Regions’ operations</td>
<td>Task on which VR was to be used&lt;br&gt;Expectations of VR&lt;br&gt;Company members responsible for IT purchase&lt;br&gt;Provisions of training&lt;br&gt;Distribution of staff using CAD&lt;br&gt;Regional departments&lt;br&gt;Number of staff&lt;br&gt;Number of houses built</td>
</tr>
<tr>
<td>Survey of Japanese House-builders</td>
<td>House-building organisations</td>
<td>High</td>
<td>Level of CAD use</td>
<td>Number of CAD users in the company (in-depth interview)</td>
</tr>
<tr>
<td>----------------------------------</td>
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<td>------</td>
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<td>---------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CAD strategy</td>
<td>Percentage of design work done using CAD (in-depth interview)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Size of house-building operation</td>
<td>Distribution of CAD users (in-depth interview)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IT infrastructure</td>
<td>Considerations when choosing software (questionnaire)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Propensity to invest in emerging technologies</td>
<td>Turnover (market reports)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>House-building processes</td>
<td>Number of units per year (market reports)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Number of regional offices (market reports)</td>
</tr>
<tr>
<td>Integrated Research Findings</td>
<td>Multiple levels of analysis</td>
<td></td>
<td>Suitability of modelling approaches</td>
<td>Time-scale, iterations of development and testing, managed and structured (historical data provided by implementers)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Success of VR implementation</td>
<td>Is this an accurate description of the house-building processes (from the company perspective)?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>House-building processes</td>
<td>How do you see VR impacting the processes?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Strategy for VR introduction</td>
<td></td>
</tr>
</tbody>
</table>
1. In the survey of British house-builders, a high level of structure and prior instrumentation was used for the postal questionnaire, with lower instrumentation used for the interviews that followed. A formative interview was used to establish the type of data sought before the questionnaire was sent out. The questionnaire was used to gain an overview of the current situation. Prior instrumentation allowed generalisations to be made about the sample as a whole and correlations to be sought, with the results displayed in tables and graphs. Discrepant and negative cases were identified and explored further in the interviews that followed, which used a lower level of prior instrumentation and were semi-structured. This allowed the exploration of discrepant and negative cases but also allowed previously unthought of factors to arise and be explored. The companies selected for interview were chosen on the basis of their questionnaire answers. Rather than seeking statistical generalisation, analytic generalisation was sought. Thus theoretical sampling was used to allow the selection of theoretically relevant cases which challenged existing propositions, in order to extend and broaden the scope of emerging theory (Glaser & Strauss, 1967).

2. A low level of prior instrumentation was used for the trials of VR systems to allow the exploration of all factors relating to data transfer. Literature was studied extensively and compared with the findings of the work to ensure the validity of inferences made from the research. Pattern matching was used to identify a typology of modelling approaches.

3. A medium level of prior instrumentation was used for the case study of VR implementation, and interviews were semi-structured. This allowed data regarding the constructs to be collected, but allowed previously unthought of issues to be explored. The regional office was taken as a sub-unit of analysis and pattern matching was used across the sub-units of analysis. Interviews were transcribed and member checks (Maxwell, 1996) were used to systematically solicit feedback about data and conclusions from the people studied, to rule out the misrepresentation of their meaning.

4. A high level of prior instrumentation was used for the study of Japanese house-builders VR use. As multiple case studies were used, there was a need to collect
comparable data in each company visited to allow cross-case analysis. The data collected also had to be comparable with findings from other parts of the research, and had to be collected in a limited time frame. The data was analysed within each case to gain familiarity, cross-case pattern search was also used to see the evidence through multiple lenses (Eisenhardt, 1989). The use of the same instruments used in prior studies also enabled comparison between the situation in Japan and that in Britain, and pattern searching was used to find differences and similarities between VR use in the two countries’ house-building industries.

Comparison and contrast of these different parts of the research project was used to formulate and test empirically well-founded theories about the potential of VR in British house-building. From the four parts of the research, analytic generalisation was used to generate and test theories with regard to future scenarios of VR use in the house-building industry.

3.4 Synthesis and Summary

The overall research problem is addressed by recourse to the findings of the different research methods, and the relationship between the different parts is summarised in Table 3.5. A contextual approach is taken, instead of an oversimplified normative statement being produced in the absence of context. The complexity of the situation is analysed in terms of the suitability of VR technology, internal macro-level characteristics affecting VR use in the sector, micro-level characteristics and experience of a particular house-building company implementing VR, and the external macro-level comparison with similar industries and sectors. This is achieved through a consideration of the answers to the different research questions addressed in the different parts of the research project.
<table>
<thead>
<tr>
<th>Research question addressed</th>
<th>Method</th>
<th>Sample</th>
<th>Focus</th>
<th>Advantages</th>
<th>Disadvantages (or Limitations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) What are the uses of, and attitudes toward, CAD and virtual reality across the house-building sector of the British construction industry?</td>
<td>Survey of British House-builders</td>
<td>Top 100 house-builders (questionnaire) 15 of these (interviews)</td>
<td>Industry sector (internal analysis)</td>
<td>Can contact many companies and assess some normative characteristics</td>
<td>Difficulty of sample selection and assessing the representative nature of those that do respond</td>
</tr>
<tr>
<td>2) What practical and technical issues arise when creating virtual reality models for the design and evaluation of housing developments?</td>
<td>Trials of VR Systems</td>
<td>5 house-builders</td>
<td>Technical issues</td>
<td>Allows for comparison between different VR systems and protocols, and identification of technical issues and house-builder's preferred VR model.</td>
<td>Not possible to know generalisability of house-builder's preference to other companies.</td>
</tr>
<tr>
<td>3) What is the experience of a British house-building company implementing a virtual reality system?</td>
<td>Case Study of VR Use</td>
<td>1 house-builders</td>
<td>Case study</td>
<td>Allows an in-depth study of a real situation, against which hypothesis may be tested. A longitudinal element allows some compensation to made for initial novelty effects</td>
<td>The case study cannot be simplistically generalised. It is describes what has happened (and might happen under similar circumstances) not what will happen, or what ought to happen. It is not necessarily representative of what will happen in other housebuilding organisations when they implement VR.</td>
</tr>
<tr>
<td>4) How does a similar innovative sector use visualisation tools such as virtual reality?</td>
<td>Survey of Japanese house-builders</td>
<td>3 house-building organisations</td>
<td>Industry sector (external analysis)</td>
<td>Allows particularly British factors to be isolated and identified.</td>
<td>Cross-cultural misunderstanding possible as mother language not English in all cases.</td>
</tr>
</tbody>
</table>

**Research Problem “What is the potential for British housing developers to use virtual reality for the design and evaluation of housing developments?”**

*Synthesis of different research methods compensates for some of the limitations of the individual methods and can allow for sound theories to be made drawing on different levels of analysis. The result should be a good picture of the potential for VR to be implemented in private housebuilding companies.*

*Research is limited to the private house-builder, and their world-view. Analysis of the requirements of other stakeholders in the housebuilding process not deducible. Thus the attitudes of house-buyers, planners, architects and suppliers to VR are dealt with more superficially.*
The trustworthiness and authenticity of the outcomes of the research have been carefully controlled using many of the tactics suggested by Maxwell (1996). Comparison is used at all stages and triangulation of the data from the different sources has been used to verify the theoretical outcome and conclusions of this thesis. Searching for discrepant evidence and negative cases (Maxwell, 1996) has been an ongoing process at all levels of the investigation and the data has been continuously compared with background theory and similar cases.
Chapter 4 Computer Use in the House-Building Industry

4.1 Introduction

This chapter presents a review of the IT systems used for design generation and visualisation in the house-building sector of the British construction industry. It is based on the results of an industrial survey, which were published in an abridged form in Whyte, et al. (1999). It was undertaken to answer the research question:

- What are the uses of, and attitudes toward, CAD and virtual reality across the house-building sector of the British construction industry?

The results are presented in their entirety. They are interpreted and discussed to provide an overview of house-builders' computer use in early 1998.

4.2 Survey Methodology

4.2.1 Sample

The survey focused on the top 100 house-builders, encompassing both mid-sized regional house-builders building a few hundred houses per year and larger nationwide volume-builders. The top 100 house-builders were identified using the market report, *House Builders Major* (Business Ratio Plus, 1997) and a postal questionnaire was sent to their CAD/IT managers. This was followed up by in-depth interviews with ten of these house-builders. In addition interviews were conducted with a software developer and local authority planner.

4.2.2 Postal Questionnaires

The literature, discussed in section 2.2.5, and attendance at the Construction Industry Computer Users Group (CICUG) meeting, *Computing for Housebuilders* in October
1997 helped to shape the issues investigated. The postal questionnaire was prepared after a formative interview with the CAD manager of a house-building organisation.

The questionnaire, which is reproduced in Appendix A, covered the use of CAD, 3D modelling and visualisation software, virtual reality, general computing and network strategies. After piloting and refinement, it was sent out to the CAD/IT Managers in December 1997. A second mail shot was sent in February 1998, and after subsequent telephone follow-up, 54% of the questionnaires were returned. Twelve of the respondents did not fill in the form for the following reasons: addressees had gone away (2 respondents); companies no longer operated as house-builders (2); house-builders sub-contracted all design work and were not directly involved in the design process (2); and companies did not yet have CAD (6). The forty-two completed questionnaires obtained form the basis of the data analysed and presented in this chapter.

4.2.3 In-Depth Interviews

Following the postal questionnaire, in-depth interviews were conducted with ten of the housing developers. These semi-structured interviews provided information about the business context for IT strategies within individual organisations, and were also used as a means of clarifying ambiguities in some of the questionnaire responses.

An interview protocol was set out, as recommended by Oppenheim (1992), to ask house-builders about their working practices and software use. Questions were asked about use of external consultants; design of street layouts; standard house-types; CAD and VR use.

The potential advantages of VR techniques and their integration into current practice were discussed in more depth. The current use of CAD software was investigated in terms of the number of people using CAD packages, the use of 3D CAD, provision of training, and use of conventions and standards.

There was an opportunity to explore the different use of software packages in regional and central offices of housing developers. Three interviews were undertaken in regional offices of national house-builders, five in the central offices of national house-builders, and three in the main offices of regional house-builders.
Two further interviews were conducted in order to obtain a contextual understanding of housing developers computer use. The first interview was conducted with a software developer, MBA Computing, which specialised in providing CAD software to the sector. The managing director and sales director were both present and the purpose of this interview was to review the software that house-builders were using.

The other was conducted with the policy co-ordinator in the Environment & Development Policy Unit of Leicester City Council. The council is the local planning authority and it grants planning permission for housing developments within the city. The purpose of this interview was to discuss the uses to which visualisation could be put in the planning process.

4.2.4 Presentation of Results

For clarity the results of the survey are broken down into the general areas: CAD use, CAD training and standards, 3D modelling and visualisation software; virtual reality; general computing and network strategies in house-building companies. The related questions from the questionnaire are shown in bold italic, and the findings of the in-depth interviews are discussed with the questionnaire responses to interpret and explain the data obtained from the questionnaire.

4.3 Results

4.3.1 Current Use of CAD Software

The survey found that the level of CAD use within the industry was higher than anticipated after studying previous literature (Thorpe, 1990). This section describes the proportion of design work done using CAD; distribution of CAD use in central and regional offices; CAD products and activities for which CAD is used in house-building organisations.
Q 1) How much design work is done using CAD (as opposed to manual drafting)?

The amount of design work done using CAD in house-building organisations varied from none at all to over 90% as shown in Figure 4.1. However no direct correlation was found between the extent of CAD used within companies and macro-indicators such as turnover or the number of units built. Some national volume-builders used little or no CAD for design work whilst some regional developers did the majority of design work using CAD.

In Figure 4.1, the unequal class intervals are corrected to accurately portray the distribution across different ranges. The results showed that the general tendency was to either use manual drafting with a small proportion of CAD (or no CAD), or to computerise the majority of design work. In numerical terms this meant that most of the respondents had either below 10% or over 90% CAD use in their companies. It is...
likely that a greater number of the non-respondents were housing developers with no CAD use, as shown by the replies from respondents who did not complete the questionnaire in Figure 4.1.

49% of all the companies considered in Figure 4.1 have over 50% CAD use, with 38% having over 90% CAD use. The low numbers of respondents having between 10 and 90% CAD use may indicate that a mixture of CAD and manual drafting is a transitional phase in the move from manual drafting to the full computerisation of all design tasks. One such respondent indicated that the company's CAD system was a trial system.

Some of those with low CAD use were considering increasing it: one respondent wrote, "At present we do not use CAD in-house. We are on the brink however." Other companies with low use of CAD did not see it as relevant to their operation. Some of the house-builders in the 0 to 10% category were regional developers that did little design work in-house, relying on external architects to design new house-types and provide drawings. One of these wrote, "all our design work is done by external architects and is likely to continue that way."

One of the largest volume-builders returned a questionnaire claiming to have no in-house CAD. A follow up to the questionnaire revealed that some CAD was used in one of the regional offices as a drafting tool and the CAD manager in this regional office was interviewed. The manager did not consider that further acquisition of CAD skills would add to the company's competitive advantage and had no plans to invest in visualisation systems, as the time required to adequately acquire the new skills was seen as too great. The office saw its role as the rapid production of housing layouts for a large number of sites, in order to obtain outline planning permission on as many sites as possible.

Thus it seems that factors related to company culture can impact a company's decision to use CAD or manual drafting. Two important factors may be the extent to which design work is undertaken in-house and the importance of design work to the company. It can be seen that there is a polarisation between housing developers with low CAD use for design, who see no benefit in further CAD use and those housing developers for whom CAD use is already an integral part of their operation.
Q 2) How many staff use CAD in a) central office? b) regional offices? (combined total)

The number of staff using CAD within housebuilding organisations is quite low as shown in Figures 4.2 & 4.3. More than half of the companies surveyed had less than five people using CAD in their central offices. Interviews revealed that many companies used external consultants to do design tasks, both in central and regional offices.

Figure 4.2 Number of staff using CAD in the central office
The larger house-builders had more staff employed to use CAD than the mid-sized regional builders however, among the volume-builders themselves, there was no significant correlation between number of staff using CAD and the size of the company.

Some respondents with no CAD did not complete this question. Whilst there were 42 responses to the question about CAD use in central office, there were only 29 responses to the question regarding CAD use in regional offices. After scrutinising the missing respondents, they were found to be regional developers without regional offices.

**Q 3) Which basic CAD product is used for house design? Street layout design?**

The survey found that AutoCAD and Microstation are the two main CAD packages used in the house-building industry. These are used, often in combination with third party applications, for house design and street layout design.
Of the questionnaire respondents using CAD, 65% used AutoCAD, whilst 25% used Microstation, with only a small percentage using another system such as StarCAD (Figure 4.4). Though other packages were mentioned, most of these were add-on packages, which are used in conjunction with CAD packages. These include packages such as MBA Total Housing and Speedikon, which offer libraries of routines specific to the house design process. Ground modelling systems such as Panterra and the Professional Design Systems (PDS) products, Professional Site Developer and AutoSite from Elstree Computing, which offer libraries of routines specific to drainage and road layout design also operate as add-on packages. One product, which was mentioned, Sokia, was a geographical data collection tool rather than a CAD package.

The existence of these add-on packages indicates a clear contrast with the situation in the late 1980s when Ewin et al. (1990) reported that housing developers had received little attention from software developers. Some products used were developed specifically to assist house-builders with house design and street layout design. This suggests that software usage in the house-building sector has risen to a level sufficient to sustain companies that are specialist software developers for the sector.
Chapter 4

Computer Use in the House-Building Industry

Figure 4.4 CAD products used for house design in British housing developers

Software used for House Design

Figure 4.5 CAD products used for site layout design in British housing developers

Software used for Street Layout Design
CAD packages were not used uniformly across central and regional offices, the different offices had a degree of autonomy in purchasing decisions. In many cases different add-on packages were used for house design in central office and for site layout design in regional offices. In some cases different CAD systems were used. Many of the companies interviewed had add-on CAD packages that were used infrequently or had fallen into disuse in some of their offices.

Q 4) How many staff use CAD a) for -standard house design? - variations on standard house-types? - non-standard houses? b) for street layout design?

The survey shows that most housing developers have less than five staff working on standard house-types (Figure 4.6). There is a wider spread of staff working on site layout design, with one company having over 30 staff using CAD for site layout design as shown in Figure 4.7. In all of the housing developers interviewed, standard house design was the responsibility of the central office while street layout design was the responsibility of the regional offices. The spread of results for CAD usage in standard house-type and site layout design shown in Figures 4.6 & 4.7 is comparable with those shown in Figure 4.2 & 4.3 for central and regional offices respectively. This is because most CAD work in the central offices is for standard house-types whilst regional offices specialise in street layouts.
standard housetypes (42 respondents)

Figure 4.6 Number of staff using CAD packages for standard housetypes

street layout design (39 respondents)

Figure 4.7 Number of staff using CAD packages for street layout design
Variations on standard house-types and non-standard house-types are used within many house-building companies (Figures 4.8 & 4.9), however the frequency of their use and location of their design is variable and depends on the different working practices adopted by individual companies. Variations on standard house-types and non-standard house-types, often commissioned from external architects, were introduced to fit with local planning regulations and constraints. Central office was often keen to maintain standard methods of working across the company and when regional offices initiated alteration of house-types it sometimes became a source of tension between the central office and regional offices of large house-building organisations.

Figure 4.8 Number of staff using CAD for variations on standard housetypes
4.3.2 CAD Standards and Training

The survey found that standards for CAD drawings were not widely used in the housebuilding industry, but that both housing developers and product vendors took CAD support and training seriously.

The rigorous use of global standards for organising CAD data is not widespread. Housing developers find the use of the British Standard layering system for CAD (BS 1192 part 5) too clumsy to implement for house-building, which was described as "a small and specialist design application." Only those housing developers that have software that automatically defaults to standard layers were found to be using the BS 1195 part 5 convention. Two of the housing developers interviewed implemented their own in-house layering system for organising CAD data, each with less than 10 layers. The CAD manager from another housing developer stated that they tried introducing protocols for the use of CAD, but found this to be restrictive. Ultimately they plan to have a standardised system but rather than imposing one from above they hope that it will come about through a bottom-up approach.
The large house-building companies that used CAD were found to have between 9 and 15 years of CAD experience in their central offices. Many of these housing developers were found to have had significant difficulties with the implementation of earlier CAD systems and have had to alter and refine their CAD strategy in the light of this experience. For example, one of the housing developers with various experiences of CAD over the last 15 years had only successfully implemented CAD across the company and seen the benefits of CAD in the last three and a half years.

In these companies with longer experience of in-house CAD, there were also more established methods for training staff. For example, a large housing developer with 13 years CAD experience, building more than 4000 houses a year, had a dedicated training section in their IT department with an in-house AutoCAD trainer.

It can be postulated that the companies with greater experience of CAD use in-house are able to attract the more experienced CAD operators who have a familiarity with the CAD product. They are therefore better able to train staff and push forward innovative computer use to increase their competitive edge.

The specialist CAD vendor interviewed aimed to undertake a solution sell, rather than a product sell, as they recognised that the product they were introducing was a complex one. In the first few weeks they would undertake a review of current practice and business processes within a client organisation, then they would identify and recommend solutions and demonstrate the different aspects of their product. After this stage they would lend the software to the company, but insist that they buy training for the software. The training could be for about 8-10 days over a 2-3 month period if the company had no previous experience of CAD, and the whole sales process could take between six months and two years.

4.3.3 Use of Design Presentation and Modelling Tools

The survey found that many housing developers using CAD also used a range of additional software packages to allow creation of 3D models and visualisations. This section describes the software packages used and the uses of 3D modelling and visualisation within the industry.
Q 5) Does your company use other design and presentation software?

Before compilation of the questionnaire, design and presentation software was identified from a review of the literature. The packages identified were AutoCAD AEC, Speedikon and MBA Total Housing, which are libraries of routines for creating 3D building models in CAD; and 3D Studio, which is a generic modelling package which can also be used for visualisation. AutoCAD AEC, Speedikon and MBA Total Housing allowed the user to work in 2D and have a 3D model built in the background. The percentage of respondents already using them, considering them for future use and not considering them are shown in Figure 4.10.

![Figure 4.10 Percentage of respondents using AutoCAD AEC, Speedikon, MBA Total Housing and 3D Studio](image)

AutoCAD AEC, MBA Total Housing and 3D Studio were used by AutoCAD users, whilst Speedikon was used by Microstation users. Over two thirds of AutoCAD users used either AutoCAD AEC or MBA Total Housing as shown in Figure 4.11. Microstation users were less likely to use add-on packages because the Microstation CAD product has 3D modelling and visualisation capabilities within it.

Other software packages used by house-building companies were mentioned in the questionnaire responses, and some of these packages were CAD based. These were the CAD product ArchiCAD (1 respondent); the add-on libraries of routines for AutoCAD – Autosite (2), Autovision Housing Designer (1); and the add-on libraries...
of routines for Microstation – Microstation Masterpiece (1); and RCS OpenHouse CAD (1). Many of these software packages, which are used for design and presentation, function as add-on CAD packages thus there is some overlap between the answers to this question and the answers to question 3.

Other packages mentioned were image manipulation packages. Squiggle and PhotoShop were both used by one respondent. Squiggle has the function of making CAD drawings appear hand-drawn and PhotoShop is a generic image manipulation tool. Companies that had no in-house CAD, but completed this question, also used the generic manipulation tools Corel Suite (1 respondent) and Kipcon/Copybase (1) for presentations.

![Figure 4.11 The use of add-on packages with a) AutoCAD and b) Microstation.](image)

Q 6) In what areas do you feel that better 3D modelling and visualisation tools can help?

Before compilation of the questionnaire, key areas in which 3D modelling and visualisation tools could be used were identified, through an interview with a house-
runner. These areas were house design, street layout design, marketing, consultation with clients and consultation with planners.

The proportion of respondents that thought 3D modelling and visualisation could be of benefit in each of these areas is shown in Figure 4.12. The highest proportion of respondents, nearly 90%, thought that 3D modelling and visualisation software would be extremely or very useful for marketing. Over 50% of respondents felt that it would be extremely or very useful for consultation with planners and street layout design, with house design being rated as the next most useful area. Consultation with clients was not so highly rated as many house-builders build speculatively and did not feel that this was relevant to their operation.

![Figure 4.12 Perceived benefit of using 3D modelling and visualisation software](image)

Housing developers were already using some 3D modelling and visualisation techniques, which were either produced in-house or commissioned from external companies. The extent to which house-builders found 3D modelling and visualisation
useful in the different areas of activity may be related to the commercial importance of the area and the extent to which it involved communication with non-specialists.

**Marketing** – Housing developers wanted to be able to lead people through presentations of their schemes pointing out the salient features. They believed that an animation, which could be rendered to a very high degree of photo-realism, provided a good overall impression and allowed the audience to understand the scheme being presented. Computer visualisation was seen as a more credible representation than drawings. One housing developer said: "There is a perception that 3D visualisations on the computer are more technically based than artists' impressions."

When presenting schemes housing developers wanted to create an overall impression that they could use as the basis for a narrative about the site, without allowing the audience to become distracted or focused on minor details. Conversely, one of the advantages attributed to hand drawings was that they are far more open to interpretation than computer drawings. Some of the housing developers did not feel that they needed 3D modelling, one housing developer offered two reasons for this, "Problems of manpower and time, and the desire to leave something to the imagination." They didn’t want to show too much of their design especially if that would compromise accuracy.

Though concern was raised that computer presentations might be seen as too slick and technical, alienating some sectors of the community, there was a desire to use multimedia to appear to be up-to-date with the new technologies.

**Consultation with Planners** – The planning authority interviewed for this survey was interested in encouraging the use of 3D visualisation to make proposed developments more easily understood by a wide cross-section of the public. Many housing developers were beginning to use 3D visualisations in consultations with planners. For example one housing developer was using computer animation for a land planning consent enquiry into a proposed development in an area with scenic views. The aim of the housing developer was to promote their site and the proposed development by changing public perception and the perceptions of the planners and the inquiry inspector. As part of the development, the housing developer wanted to move the ridgeline of a hill, to stop the scenic views being altered by the new
development, the animation they produced emphasised the three dimensional changes that had been made to the site.

However, planning authorities vary in different regions of the country and some housing developers were concerned that planners looked unfavourably on computer drawn images and models. One CAD manager felt that the planning authorities liked the technology but did not want to be challenged to use it: "I truly believe that some of the Local Authorities are a little bit scared of the technology when it comes to operating it ...but they like to see it." Another national house-building company, which used a visualisation package called Squiggle to create the hand-drawn look, explained that "planners criticised the CAD drawings as too regimented when [they] started using the computer for design."

Site Layout Design – The creation of a 3D model for site layout design was seen as an advantage by many house-building companies as the model was seen as tangible, however there were still many problems associated with using 3D CAD for design. As one housing developer put it, "part of the problem is ensuring the integrity if the model ... another is the resources required for rendering the model." One of the main barriers to the use of 3D modelling techniques, identified in the interviews was that it was very time consuming. CAD departments could not make available the time required for building 3D models.

House design – Respondents felt that constraints of manpower and time limited the extent to which 3D modelling and visualisation tools could be used for house design at present. Some house-builders felt that visualisation could only be useful if they could model everything to a very high level of detail.

Consultation with clients – In contrast to the situation found in Japan, which is discussed in chapter 7, British housing developers build speculatively and are not usually involved in consultation with clients. Fewer respondents thought that consultation with clients was an area in which VR could be useful.

Other – Questionnaire respondents suggested other areas in which 3D modelling and visualisation could be useful. These were assisting with the general understanding of buildings mass and form, consultation with in-house departments and people not
familiar with IT, prototyping new designs, presentation, sales brochures/competitions, and the corporate web-site.

To summarise, 3D modelling and visualisation was found to be useful to house-builders for applications that involved the communication of design to non-specialists. A clear differentiation was found between the 3D modelling and visualisation techniques perceived as useful for external presentation and those perceived as useful for internal design discussion.

In design applications CAD managers expressed the desire to attain high levels of geometric detail and felt that the 3D nature of the modelling could be particularly useful for specific areas such as staircase design or for working out awkward details. However precise detail was seen as less important for external presentation as housing developers tend to only want to give an overall impression of the development, leaving something to the imagination of planners and potential clients.

4.3.4 Virtual Reality

The survey found respondents believed VR could be of benefit to their companies.

Q 7) Have you or your colleagues seen a demonstration of the use of virtual reality techniques in the construction industry?

Just over half of the questionnaire respondents came from companies where they or their colleagues had previously seen a demonstration of VR as shown in Figure 4.13a. It became apparent through the interviews that the term 'virtual reality' was ambiguous and was interpreted differently by different respondents. Some respondents regarded VR as an immersive experience, for example in a CAVE, whilst others regarded QuickTime VR and VRML as forms of VR. Many technical managers had seen VR demonstrated on television, for example to identify health and safety issues on an oil rig and none of them had seen a demonstration of VR specifically targeted at housing developers. A few technical directors had researched developments in the area closely.
Chapter 4

Computer Use in the House-Building Industry

Q 8) Do you see virtual reality techniques as potentially beneficial to your company?

Most respondents thought that VR was potentially useful to their company, as shown in Figure 4.13b, although a small proportion felt that they did not have sufficient knowledge to comment. Comments on the questionnaire included “immense potential” with a developer stating in interview that they were interested in “the wow factor”.

Figure 4.13 The proportion of:

a) companies where staff had seen a demonstration of virtual reality.

b) respondents who saw virtual reality as potentially beneficial to their company.

The more negative comments on the questionnaire centred on the quality of presentations and the expenditure of housing developers’ time resources and money. The comparison between animations and VR brought some negative comments with VR being described as “a little gimmicky at the moment.” One housing developer said that it “…cannot give a satisfactory level of detail compared with animation.” VR was felt to be too jumpy and not life like “Impressive VR demos are great in Hollywood films but are inadequate in other ways” The potential of VR was still acknowledged, as it impressed people.
The expenditure of time and resources attracted criticisms. One respondent wrote, “I personally feel that VR in residential house-building could never really cover its own costs.” whilst another wrote “Excellent concept – unfortunately time and resources deem it a luxury in the housing market unless financial gains can be seen.” An even less optimistic view was shown by one of the respondents who wrote that, “The majority of house-building companies are still trying to tie their shoe laces. VR is a long way off.”

However the survey revealed that some housing developers felt that they had VR capabilities in-house, or were already experimenting with the use of VR. Some of the CAD packages in use in the house-building industry include some VRML export and QuickTime VR capabilities and one respondent using Microstation wrote that their “present architectural package includes VR techniques. However these are underused due to time constraints and insufficient training.” One CAD manager wrote that they had thought about using an external consultant to introduce VR into the company but they were “not too sure what we want but we haven’t found it whatever it is”. Others commented: “we are doing some VR but to a fairly limited extent.” “have investigated but ‘on hold’ – difficult to implement at point of sales at present.” Different housing developers could see different uses of VR technologies, dependant on their own interests and the particular working contexts within which they operated.

Q 9) In what area of business do you see virtual reality techniques having the most benefit?

Marketing, followed by communication with planners and refining the design idea were seen as the areas in which VR techniques had the most to offer as shown in Figure 4.14. The communication of ideas to non-designers, both outside the company, and within, was seen as a major use of VR. Most interviewees said that designers could interpret the abstract 2D plans and sections, which formed a kind of shorthand, and VR was of no direct benefit to them. However they felt that it could be useful for presentation of design ideas externally and to allow input from non-technical staff at the earlier design stages.
The housing developers in the interviews raised issues of ambiguity, which have previously been explored by Radford, et al. (1997). There was a concern that it would be necessary to show more details than had actually been designed and that this might lead to legal difficulties. One housing developer interviewed had recently been sued by a client after showing a hallway with furniture that the fire officer later did not allow them to put in, as the hallway was an escape route.

The opinion that VR, as well as visualisation techniques, must be used with care with the Local Authorities was expressed. The housing developers were worried that there was the possibility of further questioning: "They will ask questions about materials, particular stonework etc that they would not ask if you didn’t give them the information."

Advantages of VR, raised in the interviews, included the ability to sell from plan. Often there is not a suitable example of a house-type in the near vicinity to show a
prospective client, and VR would allow a house-builder to show a prospective client a full range of house-types from within any show-house.

Q 10) In how many years time do you see virtual reality techniques in use in your company?

76% of respondents said that they thought it would take less than five years to see VR techniques used in their company as shown in Figure 4.15. A few house-builders had used external consultants to create VR models of flag-ship developments. Only two respondents said that they could never see VR being used in their company.

Figure 4.15 Percentage of respondents who expect to see VR in their company in the next 10 years
4.3.5 General Computing and Network Strategies

The survey showed that house-builders now have more coherent computing and network strategies than when considered by Thorpe (1990) in the late 1980s.

The IT department of house-building organisations, which is responsible for all computing systems; including word-processing, accounts and estimating software, is larger than the central design department in most UK-based companies. Evidence of the increasing size of this department was found in interviews and also in the press. One company interviewed had just increased its IT department five fold, to forty staff, looking at the network and the automation of bills of quantities.

The management of CAD does not fit comfortably into the mandate of the central IT department. In many companies there were parallel structures of management for CAD and IT, with separate CAD and IT managers in regional offices, and sometimes a group CAD manager, who reported directly to either the design director, or the IT director. The reason that CAD is managed separately in many companies is because specialist computer skills and an understanding of the design process are required to make strategic decisions about CAD use.

There is often conflict between the CAD and IT departments in house-building organisations due to their differing priorities. Though it is company policy to have a single IT strategy, it was found that in the larger housing developers the CAD strategy was often not aligned with the general IT strategy and that different regions had different and sometimes incompatible strategies for IT use in design. Regional CAD operators sometimes feel that the IT department in the central office lacks the hands-on experience of some CAD packages.

Since the survey, the Construction Industry Computer Users Group (CICUG), which runs a volume-builders’ IT managers group to deal with computing issues across the sector has set up a separate volume house-builders’ CAD group.
Q 11) What are important considerations when choosing software for your company?

Over half of the CAD Managers (26/42) saw external software support as an important issue. Other considerations seen as important were industrial standards (22 respondents); an integrated solution for all functions (18), separate packages which exchange data (18) and well-known trade names (15). Custom made in-house solutions (7) and stand-alone packages for different functions (2) were less popular considerations as shown in Figure 4.16. Other considerations mentioned included networking systems and units.

![Figure 4.16 Considerations that respondents thought were important when choosing software]

Although the functionality of the software was most important, another consideration for many of the housing developers was the safety associated with well-known trade
names and industry standards. One company that used AutoCAD AEC, described it as having "holes all over the place", but used it because it was a long-standing product that uses standard layers.

One company that had recently purchased some software had employed consultants. The consultants had used a systematic approach to product assessment and benchmarking to help them to compare different systems, although the final purchasing decision remained with them.

**Q 12) What network facilities does your company's employees currently use?**

The distributed nature of the house-building organisation seems to have made the use of an internal network an attractive option for the larger house-builders, and the survey revealed a high degree of network facilities.

Overall, central office design staff, followed by the sales and marketing staff, were most likely to have network facilities (Table 4.1), though on site sales staff were not networked in most cases.

**Table 4.1 Number of staff with network facilities**

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<thead>
<tr>
<th></th>
<th>LAN</th>
<th>WAN</th>
<th>Internet</th>
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<tbody>
<tr>
<td>Central Office Design Staff</td>
<td>19</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Regional Office Design Staff</td>
<td>8</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Sales and Marketing Staff</td>
<td>11</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>On Site Sales Staff</td>
<td>1</td>
<td>1</td>
<td>0</td>
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One of the developers interviewed put great emphasis on being able to share data within the company. The central design department within this house-building company is setting up an information centre that will allow all their information to be seen by the regional offices. In this way anyone in the company would be able to use Adobe Acrobat, for example, to gain access information such as specifications for materials and components. The company uses internal mail, and the central design department has access to external mail, which is used to send drawings to
organisations such as the NHBC and Thermalite who are external organisations involved in thermal and structural calculations and house-type approvals.

Q 13) When does your company plan to have a web site with information about its house-building activity?

In this survey 31% of the companies had their own web-sites, whilst 28% were planning to obtain one within the next two years. Many of those who do not have their own web-sites currently advertise in third-party web-sites such as UK Property Gold (http://www.ukpg.co.uk/) which can be used to identify the housing developers operating within a region. Whilst one housing developer mentioned that the web-site had brought them sales, it seems that its main function was for public relations at this stage, to advertise the name, rather than to directly generate sales. With 95% of American houses now advertised online (Langton, 1999), British housing developers use of the Internet to advertise their housing may be expected to increase further.

4.4 Discussion

The results of this survey do show a polarisation between those housing developers with a strong IT base and those without, however they do not show the simple picture of all volume builders embracing IT use, whilst all smaller regional developers retain land-oriented strategies, predicted by Freeman (1998).

The extent of CAD and general IT use does not correlate significantly with the size of the operation. Propensity to invest in IT seemed related to the overall business strategy and the company culture rather than macro-indicators such as turnover or units built. Some housing developers continue to have very low levels of IT use for design, whilst others undertake more than 90% of their design work on the computer.

Housing developers who have not invested in CAD tend to see their role as land developers, and may have the majority of design work done by external consultants. This category includes many of the smaller developers, but also a few of the large volume house-builders.
For large successful house-building organisations with low IT and CAD use, the initial investment in staff training and equipment may not be worth the competitive advantage obtainable, whilst competing with other companies who have many years of CAD experience. The housing developers with high CAD use tend to see design and the presentation of design as more central to their role. This may lead to the polarisation within the volume house builders as well as across size groups.

Many British house-building companies now have coherent strategies with regard to computer use for design and visualisation. Specialised software companies develop and sell customised add-on packages to the house-building sector and are involved in training users. Computer-aided design and multimedia techniques are being investigated and there is considerable interest in emerging technologies such as VR.

Companies that are likely to move towards an early adoption of emerging technologies, such as VR are those who:

- have a coherent IT strategy, and a strong IT base – invested in training staff to use CAD, visualisation and modelling software and have an experience of what characteristics of computer software are important for house-building design tasks.

- have clear business objectives to be fulfilled through the use of VR – such as the involvement of a range of construction professionals and sales and marketing staff in the design process or the facilitation of change in operational procedures.

Further investigation, in the form of longitudinal studies, should be undertaken to determine whether there is an increasing polarisation between housing developers with significant IT use and those without and to investigate related areas such as the use of external consultants for design in the private house-building industry.
Chapter 5 VR Modelling Techniques

5.1 Introduction

Virtual Reality (VR) has been used within the construction industry for design applications, for collaborative visualisation and as a tool to improve construction processes (Bouchlaghem, et al. 1996) but is currently implemented in an `ad hoc' fashion (Aouad, et al. 1998). This chapter presents practical research conducted to explore implementation of PC-based VR systems in the industry (Whyte & Bouchlaghem, 1998; Whyte, et al. 1998). A number of VR systems, including Superscape, VRML and World Tool Kit (WTK), have been tested to assess their suitability for integrated use in the house-building sector of the construction industry.

The research question explored is:

- What practical and technical issues arise when creating virtual reality models for the design and evaluation of housing developments?

VR forms a natural medium for building design as it provides three-dimensional visualisation, can be manipulated in real-time and can be used collaboratively to explore different stages of the construction process. In the future, it may be possible to generate and print two-dimensional CAD drawings directly from the VR model used for architectural design. However, in order for the use of VR to mature to such a level, the integration with existing technologies such as CAD needs to become the focus of research (Vries & Achten, 1998) and appropriate standards and protocols need to be developed.

Although it is already possible to create VR models from within VR packages, for the use of VR in construction industry, the transfer of geometrical data between CAD and VR is desirable to avoid repetitive work (Bourdakis, 1996; Alshawi, 1995). The trials undertaken by the author have posed the question of how to transfer data from traditional CAD systems into VR, and have also assessed the suitability of different approaches to the creation of VR models for different situations.
Chapter 5 VR Modelling Techniques

After a description of the three different modelling approaches identified in the literature, the related technical issues of data exchange, VR systems and 3D graphical standards are explored. The trials of VR systems are then described.

Four different models of the housing scheme have been produced, using different modelling techniques.

- The first model was built in the commercial VR package Superscape (section 5.6.1), and consists of one house-type in different positions in the street layout.

- The second was built from CAD data of the house-type translated into the Virtual Reality Modelling Language (VRML) and assembled in an authoring tool (section 5.6.2).

- The third model was built in 3D in the AutoCAD environment and then exported to 3D Studio VIZ, where it was structured hierarchically and further edited before being translated into VRML (section 5.6.3). The VRML site model is not as refined as the initial house-type models and shows the general layout of the site and linked to data from digital photographs.

- The fourth model was created in WTK (section 5.6.4). The 3D CAD model used for the third model was used together with two 3D Studio models of house-types. Functionality was coded in C, to allow the user to navigate around the world and add houses.

Feedback on these trials was initially solicited from the house-builder that provided the CAD data, with regard to the usefulness of the resultant VR models. To reduce the possibility of anomalous data being collected on the appropriateness of the models and to ensure the relevance of the findings, feedback was solicited from four other house-builders.

5.2 Data Translation and Practical Modelling Approaches

5.2.1 Data Translation from CAD to VR

The current process of translation from CAD into VR is normally a one way or 'downstream' process (Figure 5.1). The CAD model is translated into VR, either
directly, or through the intermediate stage of a rendering package. To facilitate the translation process, data on the CAD drawing is often re-ordered, usually in non-industry standard ways, to control features of the resultant VR model. The user relies on previous experience and prior knowledge of the translator and VR system to create a satisfactory model. Bourdakis (1996) notes that there is a trade-off between the amount of time spent re-ordering the CAD model to suite the translator and the time spent optimising the resultant VR model. It is thus possible to reduce the amount of time required to optimise the VR model however “It is normal to spend a few hours or even days, hand-optimising the translated file” (Bourdakis, 1997).

Complex and highly detailed CAD data, common in the construction industry, translates into excessively large VR models, but the computational time required to run these must not slow user movement during navigation to an unacceptable level. Optimisation to allow real time viewing is achieved by reducing the information to be processed and hence reducing the computational effort required during simulation.

Three different approaches to the creation of VR models have been identified in commercial applications and VR research projects (Whyte, et al. 1998). These are to build a library of standard parts, to rely on imperfect model conversion through translators, and to use VR as an interface to a central database.
5.2.2 A Library-Based Approach

A library-based approach, where a library of components is archived for reuse within the VR environment (Figure 5.2a), eliminates the need for repetitive data transfer and optimisation of common parts. Significant time and effort is initially required to build up the library, and the library components can be created from CAD data that has been optimised and had behaviours added.

Researchers have taken this approach for research into the simulation of the construction sequence (Adeji-Kumi & Retik, 1997; Retik, 1996) and the representation of construction activities (Op den Bosch & Baker, 1995). Direct translation of a whole model from CAD is inefficient as an item is simply a geometric description in CAD and doesn’t have associated information relating it to its construction processes. Instead a library of virtual elements is employed (Retik, 1996) to save and reuse information about both the geometrical nature of building components and the related processes. The time taken to create the library is compensated by the reuse of information about the complicated sequences of events.

A library of standard VR components has also been used in a networked system (Scott Howe, 1997), to investigate the potential archival of manufacturers VR models of standard parts. It was proposed that each manufacturer would upload the latest
versions of their products and these models could be used directly by building designers in their projects.

5.2.3 A Straightforward Translation Approach.

Complete CAD models can be used to generate VR models by straight-forward translation, sometimes in conjunction with algorithms for optimisation. A translation approach (Figure 5.2b) has been used in research projects where there are few repeated elements, geometric data predominates and there are few activities associated with it, or the design process is completed and the design is fixed and unchanging (Whyte, et al. 1998). Translation and optimisation can be used for the generation of highly rendered or optimised models for presentation to clients.

The CAD model of Bath, which was created as student group project has been translated into a VR urban model (Bourdakis & Day, 1997; Day, 1994), although extensive reorganisation and optimisation has been necessary to obtain suitable frame rates in such a large VR model.

5.2.4 A Database Approach.

A database approach to VR model creation utilises a central database to control component characteristics and both CAD and VR are used as graphical interfaces to that database (Alshawi, 1995; Aouad, et al. 1997a; Aouad, et al. 1997b). The building model is created in the central database and viewed through the different applications (Eastman, et al. 1997), one of which is the VR package (Figure 5.2c). A full implementation of such a system would allow updating of the model in both conventional CAD systems and VR. Thus a two-way data exchange would be effected as opposed to uni-directional or downstream data transfer.

A database approach has not been implemented commercially, but the Open Systems for CONstruction (OSCON) research project at Salford University uses case studies from real-life construction projects to demonstrate its usefulness (Aouad, et al. 1997a). This project, which builds on the earlier ICON project (Cooper, et al. 1992), has core modules that include process management, planning, CAD, estimating and VR. Thus VR operates as the user interface for interrogation of an integrated project database. Whilst the OSCON project could not currently be used for real time viewing
and presentation of large complex building or urban models, it demonstrates the potential of such an approach to VR utilisation.

5.3 Data Exchange Issues

5.3.1 Formats for Data Exchange

The de facto standards for file transfer between different CAD packages, and between CAD and other design software are the DXF file format, developed by Autodesk, and the native AutoCAD DWG format. Though such standards have often been more successful than the attempts to develop formal standards (Tarandi, 1998), their proprietary nature has been problematic, leading to incompatibility with different vendors’ software, and with different versions.

The development of neutral formats for the exchange of CAD data first started in the 1960’s with the Initial Graphics Exchange System (IGES) and out of this research the STandard for Exchange of Product model data (STEP) was developed (Bjork & Wix, 1991). STEP is the formal international standard adopted by the International Standards Organisation (ISO) and is concerned with defining product data, some of which is geometry. The pan-industry approach taken in STEP contrasts with the construction-industry based approach taken by a separate initiative, the International Alliance for Interoperability (IAI) to which STEP has made available technologies which support Computer Integrated Construction (CIC) (Liebich & Wix, 1998).

There is an increasing awareness of the necessity of convincing industry of the business benefits of standardisation initiatives (Wix, 1998). Founded in 1994 by a group of twelve companies in the US, the IAI is an industry driven standardisation initiative that is developing the Industry Foundation Classes (IFCs). These are a common set of intelligent building design objects that will enable the sharing of information at all stages of the construction process.

There is a need for standards that are straightforward in use and terminology (Wix, 1998). Standardisation initiatives can become too large and unwieldy to be implemented, or too restrictive. Standard data exchange formats and methods would
greatly help the development of protocols for the transfer of construction industry data
to VR.

5.3.2 Commonalities and Differences between CAD and VR

Whilst 3D CAD has evolved from primitive 2D drafting packages that treated lines as
simple graphical entities, VR has developed out of advanced work on flight
simulators and computer graphics (Bertol, 1997). The construction industry user has
not been active in the development of VR and the computer graphics conventions
used in VR packages are unfamiliar and often different from established CAD
conventions. An example of such a difference is the right-hand co-ordinate system
used in VR, which is different from the established CAD world-base co-ordinate
system, meaning that translation must involve a reorientation of the model. Concepts
such as Levels of Detail (LODs) are also used differently in CAD and VR. Architects
have a concept of LOD based on the paper scaled representation of real space
(1:5000, 1:1250, 1:500 etc) rather than the visualisation of varying levels of detail at
the same time (Bourdakis, 1997). The specification of many values numerically
rather than graphically is not familiar to the user of the Windows graphic user
interface (GUI) of the modern CAD environment. For example the specification of
colors and translations as red green blue (RGB) values, or 4D matrices (quaternions)
respectively, is unintuitive to the designer.

Other differences between the packages, such as the hierarchical structure of VR
packages, and the lack of a modelling kernel such as ACIS (http://www.spatial.com)
 arise from the need to optimise VR models for real-time viewing. Differences such as
the use of graphic primitives for modelling and the lack of sophisticated modelling
aids such as layers, snap controls, and high precision detailed rulers to ensure the
accurate placement of geometry allow for real-time viewing but make VR a less
suitable environment for modelling.

Whilst not necessarily truly object-oriented, PC-based VR systems use a scene graph
to organise worlds hierarchically (WTK, 1998). As discussed in section 2.3.2, this is
done as a tree of different geometries, each of which inherit the translations and
orientations of their parents and pass on their own translation and orientation to their
children. Such an explicit hierarchical structure is not currently used by the
traditional CAD packages widespread in industry, hence the translation of data from CAD to VR formats requires a fundamental restructuring of the data.

There are no standard methods for the translation of building data from CAD into VR. VR packages are generic in nature, and do not offer in-built support for complex domain-specific industrial information. Researchers have developed their own project-specific techniques for the translation of construction data to CAD and the structuring of construction data within VR (eg. Bourdakis, 1997). As the development of VR for packages for use in architectural design has not yet been widely researched, assessment of any particular system is difficult (Vries & Achten, 1998) and standard methods for the management of architectural data in VR-based design systems have not yet been established.

5.3.3 Optimisation of Translated VR Models

Optimisation can be used with any of the modelling approaches described above. Techniques used to optimise models, though commonly used by both game developers and the VR community, are alien to the CAD environment with which the building professional is familiar (Whyte, et al. 1998). Optimisation involves the reduction of the number of polygons to be processed in the VR model and it is done to increase performance, by increasing the frame rate and speed of reaction to user input. This can be achieved by simplifying the model, but such simplifications can be inappropriate and difficult to automate for the representation of building and construction data (Funkhouser, et al. 1996). Optimisation requires a trade-off between speed on the one hand, and graphics quality and accuracy on the other, and can be achieved using the following techniques:

The use of primitive solids – simple objects, such as spheres, cubes and cylinders, together with texture maps can simplify the amount of geometric data in a model. Texture mapping (Blinn & Newell, 1976) is a technique to reproduce an image onto a surface. It can be used to provide simple representations of complex objects such as trees, with bill-boards, which are planar objects that always face the viewpoint.

Distant dependent levels of detail (LODs) – simpler geometry can be used to replace complex geometry at a sufficient distance from the viewpoint for the eye not to perceive the loss of detail. Techniques for the substitution of images, or imposters,
for distant geometry are also being investigated (Sillion, et al. 1997; Decoret, et al. 1999). In many PC-based VR packages this needs to be done manually, however research is being conducted into dynamic LOD management (Arikawa, 1996).

**Selective loading** – visibility sensors determine which part of the model is being viewed and therefore which geometry needs to be loaded and rendered and which behaviour scripts need to be active (Roehl, et al. 1997).

The rapid production of VR models of construction projects is hampered by the lack of standard protocols for the translation of data from CAD and the optimisation of the VR model. The uni-directional nature of the data flow from CAD to VR and the time taken for data translation and optimisation limit the effective utilisation of VR in the iterative design and construction process.

### 5.3.4 Interactive 3D Building Design Tools of the Future

Future CAD systems may use standard methods for describing building data, be semantically richer and based on the object-oriented paradigm. They could be based around intelligent building design objects that encapsulate both data structures and methods (Eastman, 1997) and inherit properties from more generic objects.

Advanced 3D visualisation techniques, such as wireframe, solid modelling and quicktime VR are available in many contemporary CAD packages, as is the ability to export to 3D formats such as the VRML format.

Some VR capabilities are likely to be incorporated in the next generation of CAD tools. The 3D model may be used in the design process, with 2D views and sections being generated dynamically from it using sectioning tools. Thus VR techniques may be incorporated into future building design tools for rapid prototyping of design, and the simulation of construction processes. Generic VR packages will continue to be used within the construction industry, when optimisation techniques are required to attain high frame rates, or when support is required for hardware devices.

### 5.4 VR Systems and 3D Graphics Standards

This section reviews the different VR technologies currently available. VR systems range from a simple set up on a desktop PC, to high-end VR labs using Silicon
Graphics Inc. (SGI) computers with additional hardware for stereoscopic vision and auditory and haptic feedback. Whilst the computational power available has an impact on the potential for achieving real-time viewing of complex data sets, the principles of modelling are the same in both low level and high level systems.

5.4.1 3D APIs – Open GL, and Direct 3D
VR packages are built on graphic Application Programming Interfaces (APIs) that provide low-level procedural models for 3D graphics. At present many VR systems are built on the Open Graphics Library (Open GL) or Microsoft's Direct 3D. Open GL is a non-proprietary standard API, the creation of which was initiated by SGI in 1992. Unlike Direct 3D, which is limited to the PC platform, it is cross platform, and has been important in the development of many high-end and commercial VR systems. Such a low level API offers a way to render a simple set of graphics primitives such as points, lines and polygons, but further APIs are needed to build on this and offer greater levels of abstraction, and scene management functionality. SGI's Iris Performer and Open Inventor APIs build on Open GL, and are often used to provide the further functionality that allows the programmer to concentrate on world creation. They have been utilised directly, as well as indirectly, in building research. Iris Performer was designed for high-end visual simulation on SGI computers and can support fixed frame rates. It has been used for interactive visualisation of large architectural models (Funkhouser, et al. 1996; Ligget, et al. 1995). Open Inventor was designed to be more general purpose than Iris Performer and is portable to non-SGI systems. It has been used in building research projects, for direct manipulation of designs within virtual environments (Wiegand, 1996), and for design review (Mandeville, et al. 1995).

5.4.2 VRML and 3D Web Technologies
Virtual Reality Modelling Language (VRML), which in its first version was based on a subset of Open Inventor, is now the international standard for 3D modelling (VRML'97 - ISO/IEC 14772) (VRML, 1997). CAD packages, modelling applications, and proprietary VR applications export directly to it, and VRML models can be viewed, either locally or distributed across the Internet, through a plug-in in a web browser such as Netscape or Internet Explorer.
Building research projects using VRML include libraries of product data information (Newnham, et al. 1998) the VR interface to an integrated project database (Aouad, et al. 1997b), and large-scale urban models (Bourdakis, 1996; Counsell & Phillips, 1997) as well as a multi-user design environment (Mandeville, et al. 1995). However VRML is no longer being developed and a streamed technology may replace VRML as a standard.

5.4.3 Proprietary PC-based VR Systems

As well as the standard for 3D modelling, VRML, there are many commercial PC based VR packages which contain in-built modelling environments for world creation, and libraries of routines for the addition of behaviours. They are based on APIs such as Open GL, and Direct 3D but offer some higher level abstraction. Among the leading commercial VR packages now available on the PC are Superscape, WTK and Division.

Superscape (http://www.superscape.com) is one of the early PC based VR packages (originally running in DOS on a 386 processor). In the version used (VRT 4.0) in this research, importing large-scale 3D models from CAD into Superscape was found to distort the geometry. Building research which uses the Superscape software includes construction scheduling in which a library of standard parts are built up within the VR environment (Retik, 1996).

World Tool Kit (WTK) (http://www.sense8.com) is a set of C functions with which customised VR applications can be written. Applications written with WTK can read AutoCAD’s DXF files, 3DStudio’s 3DS and VRML files directly, as well as reading and writing to WTK’s own native ASCII text based format, called neutral file format NFF. It has been used for building research by the Japanese company, Matsushita Electric Works, in their Kitchen Planning Support System (KiPs) (Sawada, et al. 1996) and by the VR-DIS design application developed at Eindhoven University (Coomans & Timmermans, 1998). It has also been used in the SPACE integrated building database project (Alshawi & Che Wan Putra, 1993). The system offers the advantage that software development and VR model creation can be separated into distinct activities, undertaken by separate specialists and that the software can be highly customised to the specific task required by the construction industry user.
The Division package (http://www.division.com) is a family of product simulation tools. It is one of the early VR packages and, though it was not originally developed on the PC platform, it has also been used in building research projects and for engineering applications.

Another commercial PC-based package, QuickTime VR, allows real time viewing of data in 360 degrees around predefined viewpoints or walkthroughs. However it does not contain an in-built modelling environment and the user cannot navigate through the environment in real-time. It is not further considered in this thesis, as it is not truly interactive.

5.5 Trials of Current VR Systems

Trials were conducted to investigate the practical modelling approaches discussed above and further explore some of the technical issues.

5.5.1 Hardware and Software used

This research was undertaken using computers similar to those found in industry today rather than a highly specialised academic VR research laboratory. The computers used are a Pentium PC 32Mb RAM 133Mhz with a 4Mb Matrox Millennium graphics card and a Pentium II PC 128Mb RAM 300Mhz with a 8Mb VRAM /32Mb DRAM Diamond Fire GL 3000 graphics card, and a 6 degrees of freedom Magellan Space Mouse.

Industry standard design tools such as AutoCAD and 3D Studio VIZ were used for model creation, and the PC based VR Systems used in the trials were VRML, Superscape and World Tool Kit. CosmoPlayer was the browser plug-in used to view the VRML models, in both the Netscape and Internet Explorer browsers, and VRealm Builder and Notepad were used to assemble and edit VRML models.

5.5.2 Library of Standard House-types for Site Layout Appraisal

In the first VR trial (Whyte, et al. 1998; Whyte & Bouchlaghem 1998), using the Superscape VR system, a library-based approach was adopted for the modelling. After consultation with a leading UK housing developer, it was agreed that a library
of house-types, with their associated levels of detail and optimisations could be built up in VR.

The rationale behind the use of this approach was that, in a practical setting, a library of house-type models could be built in the central office and sent out to the regions. In the regions this library could then be used for the rapid generation of detailed site layouts.

In the trial, 2D AutoCAD data was obtained from the housing developer. Attempts to build a 3D model in AutoCAD and then transfer this to Superscape had only limited success. As the 3D data transfer was unsatisfactory, the 2D plan data was transferred to Superscape, and the 3D virtual model created within the package from the 2D AutoCAD data and the parts of 3D model successfully transferred. It was found that the translator was inaccurate and dimensions of the resultant model had to be checked.

The final model created was highly detailed and then it was instanced, or duplicated, and simplified to create two other levels of detail. These could be substituted for the detailed model when the house-type was at a distant location where the change would be noticeable to the eye. Thus a sophisticated virtual model of a standard house-type was created in VR from AutoCAD data.

This model of a standard house-type was placed in different locations in a housing layout (Figure 5.3) to demonstrate the potential use of a library of house-types.

In this trial it was found that the data transfer between CAD and the VR package used was extremely cumbersome. The creation of the VR models of the standard house-types was time consuming. Although the library approach eliminates repetitive data transfer by reducing the amount of translation required, this early work led to the consideration of the potential of standard 3D formats such as VRML and the possible development of standards and protocols for data transfer to them.

5.5.3 Library of Standard House-type in VRML

Building on experience gained in the first trial, the second model also used the library based approach to model creation, but was built from CAD data of the house-type that was translated into VRML and assembled in an authoring tool (Figure 5.4). First three-dimensional models of the house-types were created in CAD. These were taken
Library of House-types

House-types from a library can be placed directly onto the site layout in VR.

Figure 5.3 A site layout showing the use of a standard house-type to rapidly generate site layout models from a library of VR models, in Superscape.

Figure 5.4 House-types were placed into VRML and hyperlinks to other information was added.
into 3D Studio VIZ and then translated into VRML, using the in-built translator in the 3D Studio VIZ package. The site layout data, which in this trial was 2D, was also translated from CAD to VRML, via the in-built translator in the 3D Studio VIZ package.

The facilities for data transfer were much better but VRML was not very efficient at supporting complex geometry at near real-time speeds.

Using a VRML authoring tool, VRBuilder, the house-type models could be duplicated and placed onto the site model. Various different house-type models were produced, but difficulty was experienced with the accurate placement and movement of different models in the VRML world.

The VRML standard format was used for this model so that it can be accessed from any computer with a VRML browser plug-in installed. After viewing the model in the CosmoPlayer browser plug-in, some changes were made to the VRML code in the text editing package Notepad. A Java applet was used to give the current co-ordinates of the viewpoint, and this was found to be of great use for the setting up of cameras etc, but the VR environment was view only, and had insufficient support for sophisticated interactive manipulation of the data.

This model does however demonstrate the potential for VR models to be accessed through a browser, either remotely, or on the local computer. Technical data or photographic marketing images can be displayed when the user enquires about relevant parts of the housing scheme from within the virtual environment using ‘hotspots’, which operate in a manner similar to HTML links. In this trial, the VRML model was displayed in a HTML frame; and hotspots which were added to the VRML house-type models enabled further information to display in another frame of the browser.

### 5.5.4 Straight-Forward Translation from CAD into VRML

In a further trial, a 3D model of a housing development was created in VRML (Whyte, et al. 1998; Whyte & Bouchlaghem 1998), and then displayed in a web browser (Figure 5.5).
This was undertaken to further demonstrate the potential of 3D web technologies, such as VRML, to housing developers and other construction professionals. Because of the difficulty experienced in assembling models in VRML, and the need to create the model rapidly, a straightforward translation approach was taken with a simplified model. The model was built in 3D in the AutoCAD environment and then exported to 3D Studio VIZ, where it was structured hierarchically and further edited before being translated into VRML. The VRML site model is not as refined as the initial house-type models. It is a massing model, which just shows the general layout of the site.

House-types were not modelled in detail, and a library of house-types was not used, as excess detail would increase difficulties of bandwidth and hinder the attainment of real-time viewing.

5.5.5 Standard House-types in a Site Layout

In the creation of later models the World Tool Kit (WTK) software was used (Figure 5.6), and modelling approaches were chosen to suit the different modelling tasks within the model.

Housing layouts were created by the substitution of detailed house-type models, from a library of house-types, into a simple model of the site that was translated and filtered. As WTK can import models in VRML, DXF and 3DS file formats, as well as well as the native NFF modelling work undertaken for previous models was reused. The simplified VRML model, described in section 5.6.3, was taken into WTK and then the 3D Studio models of house-types, described in section 5.6.2, were added to the model. The advantages of the library approach and the straightforward translation approach are combined.
Figure 5.5 Hyperlinks to technical and marketing information were added to the VRML model after its translation from CAD.

Figure 5.6 3D Studio models, created from 3D CAD data, were viewed in WTK, where they were positioned on the VRML site layout.
5.6 Feedback from Housing Developers

Feedback was obtained from housing developers and it was found that in-house developers wanted to allow staff total freedom to navigate a site. If accurate models could be produced at reasonable cost then VR could be useful for pre-prototyping house-types. However some of the housing developers interviewed felt that accuracy, down to whether a light switch crossed border tiles, was absolutely crucial. For them the issue was the amount of time and computing power required to achieve this level of accuracy in a VR model. One respondent thought that 3D modelling should be introduced early in the design stage where it could be used as an integral part of the conceptual design process, and the construction drawings could then be generated from the model.

For external presentation, housing developers were opposed to giving total freedom of movement to users when operating their computer generated walkthrough models. They preferred to limit what people see when navigating through the model to valid human viewpoints to prevent negative reactions to views that would not be seen from a human eye-level in the built scheme. However they also wanted to be able to provide birds-eye views. Two housing developers said they would like to produce a video that could be taken home and viewed by perspective buyers. Selling from plan would be a big advantage that VR could offer.

5.7 Discussion of the Different Approaches

The library-based approach was found to be particularly suitable for this application of VR. Rapid generation of VR models is needed for the evaluation of site layout by housing developers during the design stage. The translation of all the house-types with every site model would involve significant repetitive work and would increase the time required to produce the VR models. Archiving VR models of the standard house-types allows users to rapidly generate detailed site layout models for use in discussions within the company and for presentation in planning proposals, without the need for repeated data translation. Additional information about standard house-
types, such as technical data or photographic marketing images, can be added to the VR models of standard house-types in the library. This information can then be displayed when the user enquires about particular houses from within the virtual model of a specific housing development. A library of house-types could be maintained by the central office of a housing developer and sent out to the regional offices for use in site layout design.

Straightforward translation was appropriate for the creation of a single model, at the marketing stage, when the site layout design is fixed. For the use of VR during design and evaluation of housing developments, site data could be transferred from CAD to VR on a one-off basis and then the library-based approach could be used to add more detailed 3D models of standard house types.

A database approach would allow changes made in VR to be seen in CAD. The VR software would still need to be sophisticated enough to allow the required optimisations and levels of detail to be associated with individual house-types. The implementation of the database approach would require the creation of a central database for the building model using a neutral format accessible by both CAD and VR systems. This concept has been demonstrated through projects such as EU-ATLAS (ATLAS, 1992), CIMsteel (Watson, 1997) and OSCON (Aouad, et al. 1997a) however development of such scale is outside the scope of the work presented in this chapter.

5.8 Summary of Findings

Construction industry professionals, though potential users of advanced 3D technologies, have had little impact on the development of VR technology. As discussed in section 2.3.2, this evolved from concepts laid out by computer graphics programmers developing flight simulators and military applications where the attainment of realistic real-time interaction is critical. The manner in which computer graphic programmers developed optimisation techniques for VR models, through the use of primitive solids, distant dependant levels of detail (LODs), and selective loading, does not adequately support the accurate but interactive portrayal of
geometric and architectural information. The sacrifice of accuracy for speed of interaction is also not always appropriate for construction industry professionals.

Toolkits for the creation of VR environments, such as SGI’s Iris Performer and Open Inventor, have been important in the development of VR, and have been used in building research projects. A subset of Open Inventor formed the basis for the first version of the Virtual Reality Modelling Language, (VRML 1.0). This was designed as a file format for the interactive exploration of 3D models on the Internet and has now become the formal ISO standard for 3D modelling (VRML '97). VRML has made VR techniques more widely available thus impacting low end PC-based VR, modelling and CAD packages, which now export to this format. However VRML is no longer being developed so there will be problems related to its increasing obsolescence.

Whilst many VR techniques can be incorporated into future CAD tools for rapid prototyping of design, generic VR packages will continue to be used within the construction industry when optimisation techniques are required to attain high frame rates.

In the future the use of VR techniques will mature, as some techniques are incorporated into interactive 3D building design tools. The translation of building data to specialist VR packages will be facilitated by increased similarity in the structure of the packages and the adoption of formal standards for data organisation such as Industry Foundation Classes (IFCs) and 3D formats such as VRML.

Three different practical modelling approaches for VR applications have been reviewed; the library-based, straight-forward translation and database approaches. These were explored within the context of house building highlighting the potential use of the new technologies in different practical situations within this sector of the industry. It was found that different modelling approaches were more appropriate for different tasks.

- A library-based approach is useful when straight-forward data transfer is cumbersome, when complicated activities or extensive attributes are associated with the sets of geometric data, and when standard parts are frequently used.
• A straight-forward translation approach is more suitable when geometric data predominates and there are few activities associated with the data. It can also be used when the design process is completed and the design is fixed and unchanging.

• A database approach can be used for rapid prototyping, where a central database controls component characteristics and both CAD and VR are used as graphical interfaces to that database.

These trials show the potential of PC-based VR systems to facilitate visualisation of building models.

The use of a library-based approach was time consuming at the outset but offered the possibility of rapidly producing models with a high level of detail. This also demonstrated that such a system could be used by housing developers to produce alternative housing layouts for discussions within the company and for presentation in planning proposals.

A straight translation offered a faster option for producing the initial VR site layout model and could be used for the creation of a single VR model.

A database approach to VR model creation, though not commercially available today, may arise out of developments within the CAD and VR communities.
6.1 Introduction

6.1.1 The Case Study

This case study considers the implementation of VR within a British house-building company and documents the experience of the first users of the technology. The company studied is one of the top twenty house-builders in the UK, selling over 2,000 houses in 1998. The case study is focused on the development, and then the implementation, of a VR package, Visual Designer, in the period between November 1997 and November 1999.

The research question addressed is:

- What is the experience of a British house-building company implementing a virtual reality system?

The study initially set out to assess the implementation with regard to the company’s objectives. Semi-structured interviews were conducted with the group’s CAD manager, who is based in a regional office, and with the CAD managers of the two other regional offices that planned to implement VR at the start of the case study, in late 1998. The protocol is in Appendix B. Whilst some of the technical issues discussed in the previous chapter arose, the major findings of the case study relate to the interplay of organisation and technology, rather than the purely technical issues initially anticipated. VR has not become an integral part of the company’s operation in the manner originally planned. The study revealed a variety of issues surrounding the introduction of the VR package, which affected the implementation process. More fundamental change in the underlying organisational context is also shifting the company’s software requirements.
6.1.2 The House-Building Operation

The company's house-building operation comprises: the head office, six regional offices, a subsidiary estates company and a construction company. In the house-building operation, the head office, which is a shared central overhead, funded out of the profits of the regional offices, deals with all group management procedures and accounts. Each regional office operates as a separate business, comprising sales and marketing, land buying, planning, design, technical and surveying departments. Standard house-type design is undertaken at a national level in the design department of the head office and layout design is undertaken at a regional level in the planning and design departments in each of the six regional offices (Figure 6.1). This is typical of the larger developers as discussed in section 2.2.3.

Each regional office co-ordinates work on many different housing schemes within its region. These schemes cover a wide range of different types, from refurbishment, to new-build standard and non-standard housing and flat units. The extent to which the national standard house-types are used varies across the regions, but typically between 20% and 50% of houses are built using standard designs. Variations are often produced with regard to regional constraints, such as planning requirements, although in some cases external architects are used to design some houses to completely non-standard designs, this is typically on larger projects or on sensitive sites.
At any given time, a regional office may be working on a range of schemes at different stages of development. For example, in January 1999, one of the regions had CAD drawings for seven housing schemes at feasibility stage and thirty-two housing schemes under development. These schemes varied in size from five to fifty houses each.

Different sets of skills are required for these different types of schemes, and external consultants are used in the regions to provide the specialist expertise required for different tasks such as the design of non-standard house-types; and outline planning of the larger specialist schemes. External consultants also produce working drawings for many of the regions, although there is a proposal to do more of the working drawing process in-house. To assess this proposal one of the regional offices has hired two contract CAD technicians to produce working drawings in-house on a short-term basis, in order to assess the cost.

The larger projects undertaken by the regions require additional resources, and these are often seen to be outside of the in-house ability, with about 60% of the large schemes being master planned by external consultants.

6.1.3 Previous Computer Use

The company was one of the first housing developers to use CAD in-house, although this usage was not dispersed throughout the company. CAD has been in use for house-type design in head office for 8 years, but was only introduced in the regions for site layout design in 1997. There are now 5 users in the head office, and a total of 30 users in the different regions. The regions studied have different characteristics in comparison with each other and head office, with regard to their experience of CAD and visualisation software, as shown in Table 6.1. Although the head office used Microstation, a commercial decision was taken that AutoCAD would be used in the regional offices, as AutoCAD use is more widespread in the industry.
Table 6.1 Use of CAD and visualisation packages in the regions

<table>
<thead>
<tr>
<th>Head Office (standard house-type design)</th>
<th>Regional Offices (site layout design and non-standard house-type design)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>date of first CAD use (approx)</td>
<td></td>
</tr>
<tr>
<td>CAD users</td>
<td>5</td>
</tr>
<tr>
<td>Other design software in the office:</td>
<td>N/A</td>
</tr>
</tbody>
</table>

By the start of the case study presented in this research, there was a CAD manager in every region, who met with the group CAD manager bimonthly to discuss CAD related issues. All the regional offices used the same software provider for maintenance and training, and the same add-on CAD software, MBA Total Housing, which is a library of 3D CAD functions for house-builders. They also had some visualisation software such as PhotoShop, Corel Draw and 3D Studio. This is used mainly in regions A and B, which have the larger CAD groups.

All software in the company is purchased through the IT department in the head office, which came into being five years ago and provides a purchasing and maintenance role. However the IT department doesn’t decide corporate strategy with regard to design software. The IT department consists of a network manager and technical support staff, and deals with the running of the accounts software and the contractors databases but is not felt to be well equipped to make strategic decisions about CAD. Thus decisions with regard to CAD software are made by the CAD managers, and subject to the IT department’s approval.
6.2 Development of the Visual Designer Software

6.2.1 Initial Idea

A great deal of interactive control is now familiar to computer users, having been introduced to popular 3D computer games such as DOOM, which was released by iD Software (http://www.idsoftware.com) in 1993. This popular multiple-player game used texture mapping to offer near real-time interaction in a realistic 3D environment on a personal computer. Impressive results were possible even on the PCs in common use at the time of its release in 1993. On a computer with a 386DX processor, the game runs at reasonable speed, and with a 486 processor and 33 MHz clock speed, the normal mode frame rate is almost as fast as television (Leukart, 1994). Pentium processors and graphics cards that have become available in the late 1990s have increased the realism attainable in interactive games.

The origins of the house-building company’s VR project grew out of the desire to obtain similar near real-time interactive control when viewing computer models of housing developments for layout purposes. The group chief executive (CEO) saw presentations of 3D Studio work on video that had been prepared by the group’s subsidiary construction company for sales and marketing purposes. He was impressed, but wanted more navigational control and a greater degree of interactivity. Because the animation was pre-defined, it was not possible to stop, turn, focus-in on details or interact with the information in real-time, although this was already possible in some computer games such as DOOM. The CEO thought that these options would be useful to the company to enable designers to identify design problems before construction began on site. Thus he acted as the initial disconfirming agent (Schein, 1991) praising the work that had been done, but highlighting problems to be overcome and suggesting a way to overcome them, through the use of VR.

The feasibility of using VR for design was then explored by at least two groups within the company. These groups were unaware of each other, so there was no pooling of the information generated. As well as the group discussed in this chapter, a second group at head office was actively scanning the environment and investigated the
possible use of VR as the main design medium, with the construction drawings being generated as a by-product of the model.

6.2.2 *Reason for Using Virtual Reality*

The primary reason for developing and using a VR system in the company was design, in the form of co-ordination of the process and in-house collaboration. The company objectives for using the VR system were:

A) To assess design – It was intended that VR could be used to allow designers to identify mistakes before they got to site. Using VR, parts of a scheme that fell below the company’s standards could be identified early on in the design process and the quality of the overall scheme could be improved.

B) For collaborative design decisions – By presenting the information in a manner that is tangible and easy to understand it is intended that VR can include non-technical staff in discussions about design ideas. Sales, marketing or build professionals may not necessarily be able to visualise designs, as architects and planning managers do, when looking at a plan or technical drawing, but may have valuable things to contribute to the design process. VR is a means through which information about specific design issues could be made available to everyone in the company to comment on, allowing all parties to begin discussion of a site around a common data set.

Secondary benefits were also anticipated in consultation with planners, sales and marketing. The company envisioned VR being used for inter-disciplinary collaboration throughout the design process, but particularly in the early stages of design, before land has been purchased and before the site layout has been finalised.

6.2.3 *Feasibility Study and Software Development*

The IT manager working for the house-building company’s subsidiary construction company assessed many different VR packages to determine their suitability to fulfil the design tasks required. A particular package, World Tool Kit (WTK), was chosen by the company because it was used in America to develop VR applications for design as well as for sales and marketing (WTK, 1998). The VR package chosen,
which was trialed in section 5.5.5 was a development environment for high-
performance real-time graphic applications, providing a function library and
productivity tools that allow a programmer to put together a VR application. After the
VR appraisal and package choice, the group CAD manager, who was then the CAD
manager in one of the regional offices, became involved in the project. This section
explores the commissioning of a site layout design application based on this VR
package.

In late 1997 negotiations begun with the software company to jointly develop a
suitable application for site layout design. In a manner often recorded in the previous
literature (Von Hippel, 1989) the house-building company tried to create a mutually
beneficial arrangement with the software company. It did not buy the exclusive right
to the software but anticipated gaining competitive advantage by having the system
fully working within the organisation before its competitors.

Through the appraisal of VR packages and previous experience of using multimedia
design tools such as 3D Studio, the group CAD manager had some knowledge of both
the capabilities of VR and the requirements of the regional office. Some decisions
about data import and the trade-off between speed of navigation and the complexity
of the model were made at this point as shown in the company requirements set out
below. To maintain the necessary level of visual realism for the package to be used
for design appraisal, the speed of navigation was not fixed but was to be dependent on
the complexity of the scene. In discussion with the software company it was agreed
that terrain data would be imported into the VR software, with libraries of image-
based texture data, geometric street-furniture data, and geometric house-type data
being stored in the package for reuse in different models.

At the beginning of the software development phase, the company requirements were
set out: (source: company documentation)

1. No house data created in the VR world i.e. all data created in CAD and exported
via the new software to VR. This applies even to sketch design at a very early
stage of the land buying process.
2. Initially six standard house-types 3D models will be created as part of the order. These must be created in CAD. When the software is proven, the house-building company can then add additional house-types to the 3D library. Non standard units will need to be created first in CAD.

3. Texture mapping will be actioned in the VR system to match the 3D models imported from CAD with rendered images for the elevations and roofs. These images may be photos or artistic items scanned and enhanced via PhotoShop.

4. Other items such as trees, cars, retaining walls, street lights etc. will need to be created as objects in the VR world or possibly imported from the CAD/3D Studio Clipart.

5. 3D terrain data will be transferred into the VR world. Initially it will be only the land survey details and not the 3D result of detailed design. The changing levels etc. will be handled inside the VR world.

6. For a site, a VR model will be created by moving the 2D site layout from CAD into VR with a string of data, which relates house-types, plot no. etc. to be matched.

7. Digital photos (or scanned images) could be compiled to represent a realistic backcloth for the VR model.

8. Once the VR model is ready, full real time navigation is then possible. Objects can be moved and reoriented in any direction, this including moving vertically, up or down on the 3D terrain. The speed of navigation will depend on the complexity of the data for this site.

9. At any time it is possible to export the 3D data back into CAD or MOSS or whatever.

Software development took longer than initially anticipated; it was nearly a year before a working version of the software was delivered. Table 6.2 shows the time taken from the initial contact with the software company to a working version of the software being delivered and implementation beginning. It was felt that more precision in the brief would have reduced misunderstandings at later stages. In
retrospect, it was also felt that the software company agreed to all demands, as they were anxious to get the contract, but couldn’t meet all of them due to technical limitations of VR and changes in their own operational circumstances.

November 1997  Contact with software company. The application implementer, a CAD manager in a regional office of the house-building company, becomes involved in the process and started development of the application with a software company.

January 1998  Order placed with software company. The specification written by the house-building company, was agreed with the software company. The application development commences.

(July 1998  Implementer is promoted from CAD manager of a regional office to CAD manager for the whole group. The scope of the project is broadened.)

October 1998  Working version of the software delivered.

January 1999  The software was implemented in the regions

<table>
<thead>
<tr>
<th>Table 6.2 Time taken for software development</th>
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<tr>
<td>During the development process, some technical problems arose regarding the format and translation of geometric data. Due to errors and omissions in the translation software, some geometrical shapes such as closed poly-lines did not translate well into Visual Designer, leading to unacceptable results. The issue of closed poly-lines did not get resolved in the development process, meaning that some additional manual correction is required when building models using the software.</td>
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The house-builder wanted the VR package to be capable of exporting data to, as well as importing data from: the CAD package; the mapping software, Mat Overlay Statistical System (MOSS); and other packages such as 3D Studio. The final software did not provide this former option, for reasons relating to its technical difficulty, (which has been explored in section 5.3). Instead the package allows data in the 3D Studio format and the CAD exchange format DXF, to be viewed without the need for it to be translated to the native VR format. Using the VR package, it is not possible to translate CAD models into VR for visualisation, make alterations and then have those
changes propagated back into the CAD model as originally requested by the house-builder.

Despite problems with the development process, the resultant software provided most of the options requested by the company. Although commissioning the software development was difficult, the diffusion of the software and its integration into the business were seen as even more difficult processes.

6.2.4 Functionality of the Visual Designer Software

The functionality of the software package that was developed is explained in this section through consideration of how individual VR models of housing sites were developed and visualised. The diagram used to explain the operation of a generic VR package, presented in Figure 5.1, is extended to explain the specific characteristics of the operation of Visual Designer in Figure 6.2. In a manner similar to the VR systems tested as part of this research, this software is used to create VR models of standard house-types through a process of downstream translation of geometric data from CAD or 3D Studio. The standard house-types were then built up into a library of standard house-type models for use on different site layout models.

Visual Designer can accept three different types of inputs; image data, house-type data and site layout data. The intention was that image, street furniture, and standard house-type data would be commonly available in the different regions of the house-building operation and reusable across different models. This would mean a great reduction in data translation as the only new input required for every new site layout would be the terrain data and data on non-standard house-types and variations.

The input of image data into the image library, street furniture into the clip art library, standard house-type data into the house-type library, and site layout data into the site model is shown schematically in Figure 6.2. Little modelling work is done directly in the VR package, although the creation of simple shapes is possible. Images are created in a package such as PhotoShop and then used as textures on the VR models. The 3D house-type modelling is done in 3D Studio, in the AutoCAD package, or in a combination of both, and then viewed in the Visual Designer software, which is capable of importing data in a CAD format (DXF) or in 3D Studio format (3DS).
Terrain is generated, by taking 2D electronic distance measurement (EDM) data and creating a DXF mesh of points and combining this with 2D polylines contour data from CAD.

A series of filters are used to give models created in Visual Designer default values for materials and lighting, and to position the house-types on the site layout model. When the terrain data is imported, it is textured and, the house-type models are placed onto footprints on the terrain, with a two metre under-build added to allow for height differences in the terrain and to stop the underside of the houses from being visible. It
is expected that standard layers will be used for modelling in the CAD package and the standard CAD layers are allocated appropriate images from the image library, for example the CAD brickwork layer should automatically have an image of brickwork mapped onto it when displayed in the VR package. Thus a house-type viewed for the first time in the package should automatically have default brickwork and roofing materials rendered onto it. It is then possible to change these settings from within the VR application.

A Microsoft Access database is populated with imported information and used to structure data in the VR world. This act as the database described in the database approach (section 5.2.4). The data viewed in the Visual Designer software is not one view onto a central product model. It is the product of a downstream process of translation and thus the transfer of data from the package back into CAD is impractical.

The software is Windows based and model visualisation is facilitated by a menu based graphic user interface (GUI) as shown in Figure 6.3a. Navigation through the site layout can be conducted in real time using the mouse, and houses within the model can also be reoriented, repositioned and substituted in real-time.

A range of professionals within the house-building organisation can explore virtual models, either individually or in groups. To facilitate model use, the viewpoint can be set at a human height from the terrain to allow realistic views of the development. Predetermined viewpoints can be set within the model and fly-throughs can be recorded and replayed. Different lighting conditions can be explored to simulate the different sky conditions experienced during different types of British weather and at different times of day.

6.3 Implementation

6.3.1 Implementation Procedure

The Visual Designer software was first implemented in one of the regional offices, which had initiated the project. This region’s CAD manager was involved in the
software development. After this CAD manager was promoted to the newly created position of group CAD manager, the scope of the project was widened. The implementation strategy was not formulated and then rigidly followed, but was adapted in an ‘ad hoc’ manner, as the CAD manager’s position changed.

At the beginning of this case study, in November 1998, it was the intention for VR to be implemented in all of the regional offices of the house-building operation. The three regions studied were those in which the use of VR was sought at the time. The newly promoted group CAD manager hoped that when VR was successfully being used, other regions would also invest in the software.

Visual Designer software has been used in the first region (region A) since October 1998, and then was introduced in the second region (region B) in January 1999. The software packages bought for the implementation of VR were Visual Designer and 3D Studio, for model building. The hardware used in region A is a Pentium II PC with 256 MB RAM, 400 MHz clock speed and a Diamond Fire Open GL 4000 graphics card. In region B, an existing computer was used because of cost constraints. This was a Pentium II PC with 196 RAM and 333 MHz, however a Diamond Fire Open GL 4000 graphics card was bought to increase the performance.

The relevance of VR skills to future business operation was recognised by the CAD managers as an important reason for current investment in VR technologies. CAD managers hoped that the company could gain in-house expertise in 3D visualisation techniques, to give them a strategic advantage over their competitors when 3D visualisation and VR techniques become more widespread in the industry. The group CAD manager used an early CAD system, at a time when data had to be entered numerically, in the form of numerical shape codes, and the method of design was far less intuitive than manual drafting. He felt that it was necessary to be far-sighted and invest in the future potential of VR, even though it was in its early stages, and there were still technical problems to be overcome. By developing an in-house skill base in the technology the company hoped to attain huge improvements over CAD use in the future.

Time for staff to spend learning to use the software was subject to the pressures of the other work undertaken in the regions. Some formal training in 3D Studio was
Chapter 6 VR in a British House-Building Company

provided for all three of the CAD managers interviewed in this study, in a two-day course run by their software provider. By the end of the case study, the Visual Designer software had been in use in the company for over a year but there were still no manuals for it. It was expected that the group CAD manager would write rough guidelines (for each of the regions’ users) and provide a draft manual to the CAD managers.

6.3.2 Implementation on Housing Schemes in the Regions

Finance for the introduction of the VR package was closely linked to the house-building schemes it was initially used on. Thus innovation was constrained within construction projects (Pries & Janszen, 1995). Individual regional CAD managers had to find funds and justify the implementation of the software in their regions, as the purchase of the software, which was not centrally funded, is only justified in terms of its benefits on these schemes. These schemes are described in more detail in sections 6.3.3, 6.3.4, and 6.3.5.

In all of the regions, there was a degree of uncertainty regarding which schemes were to be used as pilot projects for the VR implementation. This was due to the nature of house-building, where there is a high drop out rate for sites. It was reported that, as a company if they “look at a hundred sites in a year, [they] might get only ten...” Some schemes that were due to be put into VR, were radically altered after discussion with planners, or were left due to commercial reasons. CAD managers pointed out that they did not make the decision about potential schemes, and also that there were pressures of time.

These pressures of time led to a tendency to delay the use of VR on a scheme until the layout is nearly finalised. This was to reduce abortive work, and to produce a VR model that is of sufficient quality to impress other professionals within the regional office with the potential of using VR.

Regional CAD managers have had to put forward a case to their regional directors and then to the IT department in central office to mitigate fears that the software would not be used. This process has resulted in a concentration on short-term benefits of the VR package. CAD managers have expressed concerns that the package will increase
their workload in the short term as they bear the burden of responsibility for the successful use of VR on the initial house-building scheme, on top of their other responsibilities and without additional resources.

### 6.3.3 Region A: VR Software Used

The VR package was first piloted in region A, where the group CAD manager is based. Several schemes were modelled and visualised within the *Visual Designer* package during the first year of its use.

The first housing scheme to be put into VR was produced by the software company that developed the application, to demonstrate the software capabilities. Six standard house-types were modelled in 3D Studio and used in the model. The model covered thirty-six units on a scheme consisted of a total of 200 units. A screenshot of the model is shown in [Figure 6.3a](#). This model was later shown to the CAD managers in other regional offices to encourage them to invest in the software.

Another housing scheme, which consisted of the six standard units that had been modelled as part of the development process and were in the house-type library, was then chosen to be put into VR. The reason for this choice was to allow the first model to be built in-house to be created with relatively little less modelling work.

Models were created for a further scheme, though this "dropped out of the picture for a while but has come back in again for a number of different commercial reasons." A 3D Studio model was produced for the mews house, and at the time of interview with the CAD manager, a block of flats ([Figure 6.3b](#)) was in the process of being modelled. The manager expected it to take approximately a week to finish the modelling work. The reasons given for the time consuming nature of the modelling process were the initial time required for learning the software, when the user was at the bottom of the learning curve, and staff involvement in other projects.

### 6.3.4 Region B: VR Software Bought but not Used

Although this VR software was not specifically designed for presentations, a director wanted to use the VR system for on-site presentation to clients in the show house.
The software was purchased for region B in January 1999, however difficulties were encountered in finding a suitable scheme as a showcase to demonstrate the use of VR to the region. The CAD manager had limited time to dedicate to learning the package due to the pressures of other work and staff shortages within the region. He did not produce a model of a housing scheme, as a decision regarding the choice of scheme had not been reached. One site, which was being considered as a scheme on which to trial VR in January 1999, was not purchased, and did not progress beyond the feasibility stage. Another larger site, on the grounds of an old hospital, was under consideration in June 1999 but had still not been put into VR in November 1999.

This large project was zoned into different sites, and the first site was expected to be put into VR in the early part of 1999. Work on the VR model was delayed, to avoid abortive modelling work, as the site layout underwent major changes after a meeting with the planners.
a) The first model to be put into the package, produced as part of the development process

b) 3D Studio model of a block of flats

Figure 6.3 A view of Visual Designer and a 3D Studio model created for use in Visual Designer

Figure 6.4 Screen shots of the visualisation modelled for region C
6.3.5 Region C: VR Model Demonstrated

At the time of the first interview with the CAD manager of this region, two projects were under consideration for piloting VR. One of these, was a large brown-field development that was quite different from typical developments, and the other was a small laundry site.

At the time of the second interview, the VR package had been used on a small development of six houses, as shown in Figure 6.4. Though the site was small, each unit was of very high value and the development was contentious in terms of planning permission. It was the land director that initiated the project with the regional CAD manager.

The VR package was not used within the region for the creation of the model, this was delegated to region A and the house-building company’s subsidiary construction company. More detailed models of house-types were created to counter earlier criticism that models produced in region A were too simple.

The VR model was shown to a group of about 12 non-technical employees within the region. The software gave a good impression of the site and highlighted some previously unnoticed design inconsistencies at a stage where these were easy to rectify. For example, from the entrance of one of the houses, three triple garages were visible on the opposite side. These weren’t all in a row, and were staggered but the view of nine garage doors that belong to other plots was felt to be unacceptable. This issue was only identified after looking at the VR model. At this stage it was discovered it was easy to overcome by changing the orientation of the garages. Visualisation of detailed house-types was however not so successful as the complexity of the geometry required a long time to render, leading to lag and unacceptably slow frame rates as discussed in section 2.3.2. Other multimedia techniques were also used during this demonstration where a flythrough created in the 3D Studio package in order to build the VR model, was deemed to be impressive.

6.3.6 Use of VR in the House-Building Process

In the interviews, CAD managers generally agreed with the five-stage representation of the house-building process described in section 2.2.2. although there was some
discussion on the identification and relative importance of the stages. It was pointed out that on the larger schemes, the planning stage can be considered as split into outline planning approval and detailed planning approval.

It was a company objective to use VR early in the design stage and all three CAD managers thought that VR would be useful during the feasibility study, that is conducted at the first stage of the house-building process. At this stage there is usually very little site information available, just a map that is scanned and blown up to a reasonable scale. If the site is approved within the company then the process moves to planning and it is at this stage that the scheme is usually put onto the computer. This often happens before the land is bought, as a clause may be put into the contract that specifies purchase subject to planning. The three regional managers suggested slightly different stages of the house-building process at which VR could be used. These are prior to site layout design, during the early land acquisition process and at the later stages of the feasibility study.

Many benefits of the VR software were envisioned but the relative importance given to these benefits by the different CAD managers in the regional offices varied. VR was initially described as useful to create a system for people designing sites, to enable them to spot mistakes, but some doubts were raised as to whether this would be the main function of VR in the business process. It was felt that different departments within the house-building organisation would have different expectations of the software. The more information produced, the more changes would be required leading to unacceptable delays. So, although VR was seen as useful for visualisation at meetings with representatives of different departments, concerns were raised about directing the focus of attention, rather than allowing many changes to be made.

As the VR model is not generated instantaneously, CAD managers are concerned that non-technical staff would require greater visualisation of designs but would be reluctant to accept the required time for model creation. They were also concerned that non-technical staff would want changes to the site layout design without the resultant delays in the house-building process.

Within each stage of the house-building process, an iterative process is undergone through the generation of initial ideas, communication of those ideas, evaluation of
the options, testing and refining, to final decision-making. **Figure 6.5** shows this iterative process using a simple graphical notation based on IDEF0 (Colquhoun, *et al.* 1993). The diagram shows the inputs and outputs during the different stages, but the controls and mechanisms are not shown.

![Diagram showing iterative process of decision making within each stage of the house-building process](image)

In **Figure 6.6** the same graphical notation is used to show the decision making process in the first three stages of the house-building process. This representation was developed during the interviewing process to show where CAD is used, and where it is intended that VR will be used in the early stages of the house-building process, the feasibility, planning and production information stages.
Figure 6.6 Graphical representation of the iterative processes in feasibility, planning and production information stages
Though the intention was to use Visual Designer for design, early in the process, it is currently being used when the layout is almost agreed and the design is being refined, as shown in Figure 6.6. To minimise modelling work, CAD managers tend to wait for the layout to be more or less finalised, before putting schemes into VR. The amount of extra work required to generate the model needs to be reduced to facilitate the use of VR earlier in the process.

6.3.7 Issues arising in the Implementation Process

The VR software was perceived to be in a testing phase and it was expected that there would be some unforeseen technical problems, however the availability of funds for continual development was not apparent. It was unclear as to how the database of house-types was to be generated and maintained: whether, the regions all allocate funds for its creation, CAD managers are given time to produce the models, or the 3D house-type models are created as part of the house-type design process in the central office.

After evaluation of the data collected during the case study, and building on the practical work described in section 5.5, the author made the following suggestions to the company regarding the technical issues raised during the implementation process:

A) Level Of Detail (LOD) management will improve performance through the reduction of geometric detail. This would allow the visualisation of detailed house-types without leading to lag and unacceptably slow frame rates. A LOD node can be used in the model to switch from detailed to more simplified versions of house-types at a user-specified distance, as less detail can be perceived at a distance.

B) The Graphic User Interface (GUI) was expected to be set out more like CAD, and, though it is not difficult to learn, the functioning of the software is not immediately apparent. Standard GUI elements, familiar in the Windows environment, CAD and modelling packages should be used to assist the user.

C) Toolbars should be rationalised to allow the user to intuit their functions more quickly.
D) Co-ordinate positions and orientation should be shown for navigation and positioning purposes, in terms of X, Y and Z and compass points / degrees from horizontal.

E) Predefined camera positions should be set up and saved with the model. This would facilitate demonstration of the model and allow the user to move between exocentric and egocentric views.

Most of the company requirements, as set out at the beginning of the software development stage (section 6.2.3) were satisfied at least partially. However, the inability to export 3D data back into CAD was the main problem with the software.

The first requirement, that no house data was to be created in the VR environment was fulfilled. Data was created in CAD, and 3D studio, and then transferred to the VR package. However the package is not used for sketch design at a very early stage of the land buying process, as initially specified, due to the extra work entailed.

The second requirement, that six standard house-types were to be created in the development process, was fulfilled. However these house-types were not modelled in CAD and then translated, as originally specified. They were created in 3D Studio. There is no agreed source of funding for the creation of additional house-types, so it is still unclear how the company will add to this library.

Uses of texture mapping, 3D terrain data and digital images for backcloths (requirements 3, 5 & 7) were very successfully implemented. The creation of trees, cars, retaining walls, streetlights etc was also possible in the VR world or imported from CAD/3D Studio (requirement 4) however this capability was not used widely.

Matching of the 3D site layout with data such as house-types and plot numbers (requirement 6) and realtime interaction and navigation (requirement 8) were implemented satisfactorily. It was only requirement 9 that it would be possible to export the 3D data back into CAD or MOSS at anytime that was not implemented.

CAD managers have found VR especially valuable as one of a range of multimedia techniques, used together with pre-recorded animations, QuickTime VR or smooth move cameras from 3D Studio. The company is now investigating various other
multimedia and Internet based projects as described in section 8.5, and the idea of having centres of excellence within the company is being discussed. It is possible that VR will not be used in every region, but that one centre will be commissioned to create the VR models required by the regions.

6.4 Future Directions

6.4.1 Organisational Restructuring

The organisational structure of the company being studied is undergoing a process of change, which is shifting the company’s software requirements. Standard house-types, designed in the head office, are being customised to a greater extent in the regional offices, and the use of non-standard house-types is becoming more acceptable. Although it is difficult to draw the line between standard and non-standard house-types, the house-types used in regional offices are nearly always derivatives. The perceived corporate attitude has been that non-standards and variations were not as good as the national standard house-types. However, this attitude is changing as the role of the central technical department is expected to change, and the core of standard house-types which will be retained, may be used in a less prescriptive manner. The head office design team may become more involved in checking the validity of the designs produced in the regions in terms of legislative requirements, rather than themselves being involved in drawing designs. The company has just introduced some urban house-types which have been designed by external consultants, while such design work would in the past have been done in-house by the central design team.

6.4.2 Shared Access to Information, Design Portfolio

The company has to co-ordinate both housing schemes with standard / non-standard house-types and large schemes, in which external consultants are often used. In the summer of 1999, the group CAD manager, who was then design systems manager, became involved in a project to set up a web-server for use on some of the company’s larger projects. This has been set up to allow all participants remote access to relevant
design information, which is held on a central server, dependent on their security notification. This approach is intended to enable the house-building organisation to share all the design information from the regions and the head office.

Before implementation of the software, which is termed design portfolio software, the group CAD manager consulted with other construction companies about their experience of using such systems. A number of different software architectures were investigated. The system chosen was selected for its maturity, and also because of the company's relationship with the software developer, which had built up through previous information gathering and networking exercises related to the VR project. As the current version of the software is focused on the retail industry, discussion is taking place with regard to the production of a generic version of the software.

This project had taken a higher priority than the VR project by the end of the case study and active work with the VR package had stopped. However VR may be used with the networking capabilities in the future. It is possible that VR could be used through the design portfolio software, which has an option to import VRML data. This presents an opportunity for users to assess a house-type in a more visual form instead of just looking at the working drawings across different offices of the distributed organisation.

Having implemented the design portfolio software the group CAD manager wants to rethink the use of visualisation in the sales and marketing tools used by the company. At present sales and marketing is conducted in a showroom built on the site. This is usually the double garage next to the show house, which is converted by putting patio doors on the front. However this approach is seen as being inadequate for the range of schemes that are now being considered by the company. The company believes that the design systems they are using at present are not developed enough to present the quality of housing schemes that are being produced. Visualisation tools are used in an 'ad hoc' manner and they want a more considered approach. The use of visualisation to attract client interest is an area that the company expects to explore further. This would be of use particularly on the larger schemes that take about 4-5 years to finish.
6.5 Summary of Findings

The main findings can be summarised:

- *The lack of direct involvement by board level management has hampered the implementation process*

There has been a lack of direct involvement by board-level management in the development and implementation of the Visual Designer software although the initial incentive for introducing VR was the interest expressed by the Chief Executive. This has resulted in implementation problems, including a lack of co-ordination between different parts of the organisation, the linking of VR introduction to specific projects, a concentration on short term rather than longer-term benefits, and the lack of a project specific budget in terms of both time and money. Despite some dissatisfaction with the initial briefing and product development process, integration of the package with the business processes was seen as the most challenging aspect of the VR implementation. Here, it is argued that these organisational issues mean that the full advantage of the VR software is not yet realised within the company.

- *The time taken to implement the package has reduced the benefit achieved due to the problems of initial high cost, technical obsolescence and organisational change*

VR is a technology that is evolving rapidly with both software and hardware increasing in capability and falling in price. The time taken by the company to develop and implement the VR system was nearly two years and in this time the initial high cost of the software significantly reduced and the software purchased became obsolescent. Though the company was able to demonstrate benefits of the technology, this long implementation time reduced the practical benefit of the software. The company was unable to adequately incorporate the advantages of improvements in the VR technology during this implementation time, meaning that they did not get an adequate return on their early investment. The company itself was also undergoing a process of change, and the length of time it took to implement the system also meant that when implemented, the system did not adequately fit current and future practice.
• The company objectives were fulfilled in terms of the use VR to address design issues and to include non-technical staff in discussion of design ideas but not in terms of the use of VR in the early design process.

The case study has demonstrated the potential use of the Visual Designer software and the possibility of attaining the company objectives, as set out in section 6.2.3, to use VR to address design issues and to include non-technical staff in discussion in design ideas. For example the use of Visual Designer at a meeting in region C described in section 6.3.5 demonstrates the fulfilment of the company’s objectives. There is the potential for the by-products of modelling work undertaken for VR to be used at the presentation and marketing stages of the house development process. One of the CAD managers interviewed said, “We’d like to use it not only for the design process, we’d like to use it for planning but I’d also like to then go on and use it for sales and marketing”.

In-house expertise in 3D visualisation techniques is seen by the CAD managers to offer strategic advantage to the company, particularly as 3D visualisation becomes more widespread in the industry. However the introduction of VR within existing processes imposed an additional burden on CAD managers, who were learning and using the new software on top of their routine operations. It was difficult for staff to budget time for VR modelling due to heavy workloads and tight deadlines, which are exasperated by staff shortages in some of the regions. VR was not used in the early design stage as limitations of the software made modelling time consuming. There was no project specific budget and software purchases were made out of regional budgets and justified in terms of the projects they were initially used on. Introduction of the software into the regions is slow, as it is dependent on agreement in many sections of the company and approval of a scheme that the software can be used on.

However, using another part of the organisation as an external consultant to create models of a site was seen as a good method for introducing the software into a region, as it allowed staff at all levels within the company to experience the software at first-hand and see its benefits.

This case study shows a lead user of VR, extending and customising the basic VR functionality by creating a unique solution to the 3D interactive visualisation of
housing developments in conjunction with a software company. Despite the limitations of studying a single case, comparison with previous theory suggests that this VR package will show characteristics of benefit to other house-builders, and that the issues encountered in the implementation process may also be encountered by other house-builders.
Chapter 7 VR Use in Japanese House-Building

7.1 Introduction

7.1.1 Why study the Japanese experience?

The last chapters described VR use in the British house-building industry. This chapter enables a comparison with and further characterisation of the British situation, through consideration of VR in another innovative sector. The research question addressed is:

- How does a similar innovative sector use visualisation tools such as VR?


Though there has been some interest in VR for housing application in other countries, for example in Canada (Thurston, 1996) and the USA (Butterfield & Holmes, 1997; Hart, 1998) realisation has been at a small-scale and in the form of demonstration projects. In the USA a manufactured-housing company, Hart Housing, demonstrates a VRML model on its web-site (Hart, 1998). A US online house-building magazine advertises a QuickTime VR walkthrough (Butterfield & Holmes, 1997). However there is insufficient industrial use of VR for comparative purposes. No evidence of widespread or strategic use of VR by house-building companies was found. In contrast, as described in this chapter, there is continued research and development of
VR applications for house-building in Japan where some large house-builders have extensive use of VR and computer graphics.

**7.1.2 Method**

A two-week study visit to Japan was used to conduct case studies, investigating the use of advanced visualisation techniques and VR within three house-building companies. Semi-structured interviews and software reviews through demonstrations were used as the primary data collection technique and were supplemented by secondary sources of information, such as company reports, publicity and web pages.

The Japanese language was studied in evening classes for one year prior to the visit. Letters were sent and emailed to the top 10 house-builders and these led to three case studies being set up, with Sekisui House Ltd., National House Industrial Co. Ltd. and Mitsui Home Co. Ltd. A standard interview protocol was produced (Appendix C) to aid in the interviews, and an English-speaking student from Tokyo Metropolitan University’s Architecture Department assisted in cases where the host-company had little English expertise.

An understanding of the broader context within which Japanese house-builders use visualisation techniques was sought to allow meaningful interpretation of the case study data. Analysis of the Japanese industrial context was undertaken through interviews and consultation with a wide range of companies; research laboratories; computer companies and academics. Organisations consulted and a full timetable of all the visits made in Japan can be found in Appendix D.

**Section 7.2** draws on previous literature to describe Japanese house-building. Though not reported in full, interviews with Professor Matsumura at Tokyo University, and Paul Lynch at the British Embassy were used to clarify issues arising from the literature. **Section 7.3** describes the context in relation to the use of CAD and VR packages, reporting on interviews with Unisys, Matsushita Electric and CAD Center conducted during the study visit.

The three case studies are then introduced in the subsequent sections, **7.4, 7.5, & 7.6**, which introduce the three Japanese house-building companies studied: Sekisui House Ltd., National House Industrial Co. Ltd. and Mitsui Home Co. Ltd. **Section 7.7**
provides a cross-case analysis and section 7.8 presents a summary of the findings of the study.

To allow rough financial comparisons to be made an exchange rate of 185 yen to one pound sterling is used (the actual rate was 185.4716 yen/pounds on 05 August 1999).

7.2 Japanese House-Building

Some features of the Japanese house-building industry are briefly covered in this section to facilitate interpretation of the case studies. These are the Japanese companies’ membership of inter-firm networks, low time-efficiency in Japan, the market for land and housing, and customer care.

7.2.1 Inter-Firm Networks

Many Japanese house building companies belong to large conglomerates or inter-firm networks (keiretsu), the formation of which has been one of the characteristics of post-war Japanese business (Masaki, 1998). Consisting of ostensibly independent member companies, a keiretsu is a nebulous group of companies. It often has a bank and a trading company at the core and member companies are often linked through inter-corporate shareholding, investment and the exchange of personnel. Members of keiretsu provide preferential markets for each other’s products.

The organisation of these inter-firm networks has been described as ‘horizontal’ or ‘vertical’ (Edward & Samini, 1997). Member firms of horizontal keiretsu are involved in distinctly different industries and new firms are added to the group through progressive diversification (Edward & Samini, 1997). In vertical keiretsu there are two networks, one based on suppliers and the other on distribution, marketing and sales of finished products and after sales services. In practice members of keiretsu often exhibit both horizontal and vertical linkages.

By striving for scale and scope economies within inter-firm network structures, Japanese companies can transform some unusual products and markets into high-volume national industries (Fruin, 1992). The creation of large housebuilding companies in Japan is an example of such inter-firm adaptability. Until the 1950s and
60s, carpenters and builders built almost all detached houses with conventional wooden post-and-beam structures (Matsumura, 1988). Post-war housing shortage led to the creation of The Housing Loan Corporation and Japan Housing Corporation in the 1950s, which encouraged greater owner occupation through funding the construction and sale of public housing. Housing plans grew, from a 3-year plan for 180,000 units nation-wide in the early 1950s to a 5-year plan for 3,800,000 units in the late 1950s (Matsumura, 1988), this lead to government promotion of industrialised production.

Companies diversified into house-building as changes in other industries, such as the chemical and steel industries forced them to find alternative markets for their products. For example, Nippon Steel, (which at that time was called Yahata/Fuji) turned to industrialised housing production in its search for other markets for steel, as demand from the US army and navy had ceased with the end of the Korean War (Matsumura, 1988).

7.2.2 Low Time Efficiency

Large size firms offer stable employment ('life-time' employment) and the prospect of moving up through the ranks for male members of staff (Morris, 1996). As recruitment depends upon personal ties and recommendations there is no desire to reduce intake (Yoshimura, 1997) and companies try very hard to keep their employees. This practice may change as the service sectors face competition from abroad, however the practice continues to influence present employment patterns. Companies are not aiming to minimise the number of people, but to maximise output, thus there is little drive for time efficiency. Companies would like to achieve full time employment of their staff and also produce quality products so that their market share increases.

7.2.3 Land and Housing

In Japan the house-building companies are not involved in land development. Land is extraordinarily expensive in Japan. For example, the average price of residential land in Tokyo was 560,000 yen (£3027) per square metre in 1994, compared with 30,000 yen (£162) per square metre in London (Endo, 1998). Japanese people rarely move
and within a Japanese family, land is often passed down from generation to generation. Houses are not regarded as permanent structures and are rebuilt every 25 years approximately. A large percentage of new build housing is ‘rebuild’, built on brown-field sites already owned by the client. There is virtually no second-hand housing market.

Planners are not concerned with regulating the appearance of the developments, which are not considered permanent. Planning control by the Ministry of Construction and Local Authorities only concerns the volume/land-use capacity and some sanitation, health and structural stability conditions (personal communication with Prof. Matsumura, 1999).

7.2.4 Customer Care

As the landowners, customers can shop around amongst the house builders for someone to build a house on their land. They frequently demand changes at the design and construction stage specifying finish work to the smallest detail since there is no tradition of consumers maintaining their own homes. This means that the competition between the house builders is based on the quality of their housing and their ability to fulfil the customers’ requirements. There are five or six consultations before signing the contract, which includes a rough estimate of the cost based on proposed finishes. After the contract is signed the detail design is undertaken.

Showing technical ability is seen as important for customer satisfaction, with large companies usually paying around 30% of their income on advertising. There are more than 500 parks of show-houses built at full size in locations around Japan.
7.3 CAD and VR

7.3.1 Introduction

During the study trip to Japan, visits were made to obtain a contextual understanding of CAD and VR use in Japan to facilitate interpretation of the case studies. Some visits, not found to be of direct relevance to the objectives of this chapter, are not reported in detail here but can be found in Appendix D. The visits discussed relate to the use of CAD software, VR software and VR model building, and involved Unisys Japan, Matsushita Electric Works and the CAD Center. Exhaustive coverage of each topic is not attempted. This section simply provides a brief overview of general CAD and VR use in Japan to provide a context within which to interpret the case study data.

7.3.2 Housing CAD Software

An interview was conducted at Unisys Japan, a software developer that provides CAD to major Japanese house-building companies. Their customers include Sekisui House Ltd., Mitsui Home Co., Ltd. and Sumitomo Forestry Co., Ltd. Their web-site is http://www.unisys.co.jp/welcome-e.html.

The Group Manager for Housing Systems at Unisys explained that Unisys Japan see the house-building market as a pyramid, with a few larger house-builders at the top and many small builders at the bottom. Their target customer-base used to be the top 50% of the market because the cost of their software and the required hardware was out of the reach of the smaller business.

The first version of housing CAD software developed by Unisys was a custom made system for mainframe use. It was jointly developed with Sekisui House Ltd. This software was then revised to give Unisys a package that could be sold to other house-builders. It was released under the name ‘HCAD’ in 1984. In 1991 this software was ported to UNIX platform and sold as ‘HCAD/WS’.

In 1998 Unisys released an entirely new PC-based proprietary digital design system, called DigiD. It was released to run on the NT environment, with the aim of
increasing the company's customer base. DigiD has an easier graphical user interface (GUI) and its release made Unisys CAD software more affordable to the medium and smaller sized house-building company. The DigiD system design concept includes two parts: a sales support system; and a detail design system (Figure 7.1).

The detail design system allows the house to be detailed "down to the toilet roll holder" according to the manager. It has different modules for different methods of construction such as light steel construction and conventional Japanese timber construction.

It is the sales support system that had good visualisation capabilities, as was demonstrated during the visit. This system was designed for use by sales personnel when discussing house design options with the client.

Initially, the name of the customer is entered and stored in the customer management sub-system. First the house layout, including room sizes is then drawn on the computer screen. All the parameters are not required at this stage and can be added later as the design becomes more detailed. Thus the initial focus of attention is the size of the respective spaces rather than walls and other construction elements. Input
of further data can be done by clicking on the appropriate room. It takes between 15 and 20 minutes to create a 3D model of the house.

The sales support system allows high quality still images to be produced. The Unisys company uses Lightworks and Graphisoft rendering engines in the DigiD package, and has looked at the Informatix and Planedge rendering engines. In the last year, house-builders' focus in computer graphics presentation systems has been at the pre-contract stage, whilst it was previously focused on the detail design after contract.

7.3.3 Housing VR Software

A visit was made to Matsushita Electric Works' Advanced Technology Research Laboratory, which is internationally known for research on VR applications in the domestic environment (Virtual Housing, 1998; Nomura & Sawada 1998; Nomura & Sawada 1996; Sawada et al. 1996; Shinomiya et al. 1994). Better known in the West under the trading names, 'Panasonic' and 'National', this company has pioneered VR development. It created the kitchen system (Nomura & Sawada, 1996) described in section 2.3.6. It has a CAVE (CAVE Automatic Virtual Environment), which is a multi-person, room-sized, high-resolution, 3D video and audio environment, and is being used in a range of research projects, including the circulation of people through urban spaces.

The laboratory is currently involved in the House Japan project, a 7-year technical development program, funded by the Japanese government ministry, MITI. The total budget for this project, was about 10 billion yen (£54 million). It involves 40 large companies, including component manufacturers, house-builders and general contractors. Matsushita Electric Works is working on R&D theme 10, System to Support the User's Participating in House Design. The aim of the project is to develop a housing design advice system through which users can obtain information on housing using Internet technologies. Users can design a house themselves with the intention of building it. A life design support system is also being developed as part of the House Japan project. This would provide "a system to assist users in designing a clear life style program, which they may aspire to in their subconscious".
7.3.4 VR Model Building

An interview was conducted at CAD Center Corp. The company used to operate as a CAD drafting company, but is now working on about 50 advanced computer visualisation projects a year, producing video animations, photo-realistic still images and VR models of built environment projects.

When creating VR models, a CAD package FormZ is used to create the models, which are then shown in the modeller Multigen on a SGI computer and also under Windows NT. This software includes libraries of models of detailed furniture, house and garden plants. However adding all these details can make the resultant models become large. One of the models demonstrated contained approximately 200,000 polygons.

In a model of an urban development, interaction is performed by moving a mouse over a paper drawing of the plan, which is laid on the table. The movement of the mouse is calibrated to control the position of the viewpoint in the model: hence the user experiences a very tangible relationship between the realistic viewpoint in the computer graphic model and the more abstract data on the plan.

Although modelling of individual houses is fairly untypical for the company, house models were demonstrated. The first of these was a VR model of 6 individual rooms, created for a house-building company and designed to complement the two rooms that are constructed at real life size in a house-builder’s sales centre. Computer graphics can be used to show more choices than are available in real life display centres, with 6 different types of rooms available in the software presented. However, these VR models of rooms were not linked in a way that made it possible to walk through the entire house. In the model rooms shown in this software, the furniture is also moveable and different styles and colours of furniture can be shown, thus the model can be used as a sales tool by developers, to allow customers to make limited interior design decisions around a standard housetype.

Another VR model of a house showed the construction techniques used in putting together a house. The developer that commissioned this visualisation was also operating as the construction company and was keen to obtain competitive advantage by demonstrating good construction techniques.
Kizu is a new town located near Nara in the Kyoto prefecture, and developed by Kodan, the Japanese government developers. A visualisation model (Figure 7.2) was used for the opening ceremony in 1997 and also for public viewing and orientation in the train station. To aid navigation the interface to the model included a north-up map, which showed the field of view. As the model was designed to allow many people to view the scheme, free navigation through the model is only possible for 300-second before the viewpoint is reset.

The model took three people five months to produce, some of the streets and houses modelled already existed in the town when the model was completed. House elevation details were created using texture mapping, put on using PhotoShop from CAD elevation drawings, the aerial view of the site is a real photograph draped over a wireframe surface.

Another scheme, shown in Figure 7.2, shows a streetscape on which a range of different styles of houses can be shown. It took three people three months to develop this model, which is designed to sell the new development to existing residents. The user can compare different options for the built environment by substituting traditional or modern architectures and different road widths and spatial layouts. The model is demonstrated in a show-house on the site where the development is being built. It is hoped that the model will persuade the nearby residents that modern architecture is more appropriate than the traditional architecture to which they are familiar.
Figure 7.2 Views of the CAD Center Corp. VR models. Courtesy of and Copyright CAD Center Corp.

a) model of a streetscape

b) model of the Kizu new town
7.4 Sekisui House Ltd.

7.4.1 Company Background

The first case study was conducted with Sekisui House Ltd. In 1955 an employee of Sekisui Chemical Co. read about and was inspired by the creation of a plastic house by the American company, Montsanto (personal communication with Prof. Matsumura). At the time Sekisui Chemical Co. wanted to develop a new market for plastic leading to it establishing and became a major shareholder in the company Sekisui House Ltd. Sekisui House is now Japan’s largest house-builder, building 75,740 houses in 1997. It has 14,576 employees (Toyo, 1998) and a capital stock of 182,458 million yen (as of January 31, 1998).

In addition to its network of design offices, sales offices and show houses, the company owns six factories in Japan and has research laboratories, a publishing business and library. Facilities such as the Housing Science Hall, Institute of Housing Science, Tokyo SHIC (Sekisui House Interior Co-ordination) City, and the Comprehensive Housing R&D Institute ‘Nattoku Kobo’ are available for public access to allow the public to learn about the house-building process.

7.4.2 Housing Design and Sales

For operational reasons, Sekisui House divides Japan into three regions. There is a design centre in each region, and more than 200 branch offices across Japan. Customisation of a particular design is often done by the sales staff in the branch office, in liaison with the client, but the more difficult cases would be referred to one of the three regional design centres, which are based in Osaka, Tokyo and Hiroshima.

Data is not available on the percentage of houses that are built on brown-field sites but this may be largely due to the custom of rebuilding houses on the same site. It is unusual for the land and the house to both be purchased from Sekisui House, in most cases Sekisui builds houses to order on land owned by the customer.

The Sekisui House business is based on a policy of direct sales to purchasers. In its promotional literature it boasts that, “Every Sekisui home is custom made”. However
this is achieved through the customisation of standard house-types. Ranges of standard house-types are used as templates, and depending on the customer’s budget, these are customised to a varying degree of sophistication to suit the customer’s specific requirements.

7.4.3 CAD and IT use

Sekisui House was an early adopter of CAD technology in Japan and has used it for about 20 years. They use Unisys software that was developed to suit their house-building requirements. However, CAD is currently used only for drafting. The design is hand-drawn on paper and then put into a CAD system by a CAD operator. CAD drawings are used for presentation to communicate designs to the government, customers and the factory, rather than for design generation.

CAD packages are widely used in the company, each sales office has one or two CAD workstations, so there are between two and four hundred CAD workstations in Sekisui House sales offices across Japan. Packages are not however standardised throughout the company, with factories using a different CAD package to the sales offices. CAD drawings at the factory are translated into an appropriate format when they are received from the sales offices to enable a link to a specialised Computer Aided Manufacturing (CAM) software. The benefit of updating the CAD system to enable all systems to exchange data is now recognised and a 3D CAD system is under development.

Not all the staff employed by Sekisui House have access to network technologies. The company does have an Intranet, but only those members whose job function is seen as requiring its use have access to email and the Internet. Hence the sales staff have Internet access, whilst most design staff do not.

Sekisui House does however have an extensive Japanese and English language website (the English home page is at http://www.sekisuihouse.co.jp/english/index.html). This serves not only as a marketing tool, but also as a means of promoting trade between Sekisui House and component and material suppliers.
7.4.4 Visualisation: The COSMOS System

Since 1997, when the COSMOS (Customer Oriented Structural Modeling of Sekisui house) visualisation system was first introduced, more than 8,000 customers have experienced it. Images from the software can be seen in Figure 7.3. The software is used in the computer graphics room at the sales centre of Comprehensive Housing R&D Institute 'Nattoku Kobo' and in certain sales divisions of Sekisui House. In the company literature the objectives of using the system are described:

“In Japan, many people wish to own their house, but it is very difficult to buy or build a house twice and more times, because it is costly (sic). So, they are very sensitive for their house, and they would like to know anything before build: exterior, interior, convenience, design and so on. COSMOS is a computer graphics visualization system in order to realize these requests. Customers will be able to experience their house they decide to their planning (sic), so we can reduce many claims and dissatisfactions about our works.”

Figure 7.3 Images from the COSMOS software. Courtesy of and Copyright Sekisui House Ltd.
COSMOS 1.61 is a customised application based on software developed by Matsushita Electric Works. The software is easy to operate for planning, and is customised for the viewing of Sekisui House original components such as doors, sashes and textures, thus allowing detailed models to be created for simulation. The system is easy to operate and can be used to show the view from a human viewpoint and also from an aerial view of the house floor. Features include:

- Smooth-move cameras
- Interactive manipulation (replace objects, change textures)
- Libraries of furniture, which can be added to check the scale.
- Default setting of a realistic human eye-level - the operator can change the eye-level of the viewpoint, but the viewpoint is fixed to the realistic human eye-level for walkthroughs with customers.

However the software is not so easy to operate in terms of model creation. There is no easy way of translating CAD drawings into a format understood by the software. The models are currently fully built in the COSMOS software, by an operator using a paper drawing printed from the CAD model as a guide. Libraries of components are stored in the VR software and the operator selects the zone for the planning for example the living, dining or kitchen area, then adds the walls and uses codes to insert different types of door and openings into the walls. Inputting data into different systems is a time consuming process and the company is planning in future to connect the Unisys CAD system with COSMOS.

7.4.5 Use of the Computer Graphics Room in Nattoku Kobo

The customer care centre at Nattoku Kobo, which is called ‘The Satisfaction Studio’ in English, comprises 10 different zones on 4 floors (Figure 7.4). The computer graphics room is the final zone, and is used in the later stages of a highly choreographed and polished presentation of Sekisui House’s ability to fulfil customer requirements.
Customers are initially taken to the top floor of the show room where there is an orientation zone (1), in which there are displays about the history of housing and the different kinds of housing available in different parts of the world. As they pass through this, and the other zones, which look at housing quality and environment (2), structure (3), lifetime home (4), storage (5), equipment (6), space (7), kitchen (8) and interior and exterior co-ordination (9), they slowly build up a detailed picture of their new house. This may take place over more than one visit. There are interactive displays and maquettes that allow the house to be explored at different levels. For example, in the lifetime homes zone (4), it is possible to view the effects of reduced eyesight on visibility by looking through clouded glass, or to simulate the effects of reduced mobility, by strapping weights to your legs or sitting in a wheel chair and navigating through full-scale door openings and stairs. In the storage zone (5), it is possible to move full-scale storage units up and down the wall to determine the most suitable height. In the kitchen zone (8) it is possible to move units around in a 1:200
scale maquette. As the customer makes design choices these are entered into the CAD package.

In the final zone at ‘Nattoku Kobo’, VR is used to present the whole house to the customer (**Figure 7.5**). Thus VR is used as part of a larger narrative about the customisation of the design. It is also used at a stage where its use builds on previous discussion between the customer and the sales representative.

![Figure 7.5 Photograph of the computer graphics demonstration room. Courtesy of and Copyright Sekisui House Ltd.](image)

The computer graphics demonstration room resembles a boardroom, which has a large screen mounted on one of the walls. The customers meet with a sales representative, who discusses house design with them. VR is seen as a good means for reaching an agreement between the house-builder and the customer, reducing the risk of claims later. The display environment has been carefully tailored to be conducive to consensus building. An operator, sitting to one side navigates around the model, responding to the nature of the discussion but remaining unobtrusive. The auditory environment has also been tailored with barely perceptible background noise, such as the bird sounds heard in a country meadow, provided through the speakers of a sound system, to assist in creating an environment psychologically removed from the rest of the busy sales centre.
Chapter 7 VR Use in Japanese Housebuilding

The computer used for the presentation is a SGI OCTANE / MXIR10000 with 256MB RAM, 195 MHz, and 6GB hard disk drive. This is used with a JVC DLA-G10 SXGA Multimedia Projector, and a Mitsubishi Electronics True Color Printer. The data is input on a SGI computer O2.

7.5 National House Industrial Co. Ltd.

7.5.1 Company Background

In 1961, Matsushita Electric Works Ltd. initially created a Housing Business Division, which marketed its first house-type called Matsushita Type 1 House. Just two years later, in 1963, National House Industrial Co. Ltd. was established as the housing division of the Matsushita group. It is now the 4th largest builder of prefabricated homes in Japan. Major shareholders are Matsushita Electric Works, Co., Ltd. and Matsushita Electric Industrial Co. Ltd. The company has 3,782 employees (Toyo, 1998).

The trade name ‘Panahome’ is used by the National Housing Group, which comprises approximately 86 associated dealers in 8 regions across Japan, as well as overseas affiliates in New Zealand and Malaysia. The company owns 4 factories in Japan and 2 overseas, and has a human resources (HR) center for staff training. Each region in Japan also has an after sales service company.

7.5.2 Housing Design and Sales

National House Industrial builds different ranges of detached homes, these include dwellings customised to snow country and cold weather, urban three-storey homes, multi-family dwellings, and low rise buildings. The company also uses different ranges of standard house-types that can be customised to suit the customer through the addition of options. There are two types of structure available, dependant on climate and three ranges of housing, according to price.

Marketing is taken seriously with the first TV commercial aired in 1970, and a jingle “if we build a house” which became a popular hit in 1972. In 1990 the first Human Plaza, a showroom to disseminate information about the house-builder’s ‘Creation of
a New Way of Living” opened, since then, six other Human Plazas have been opened around Japan. A 24 hour 365 day per year consultancy service was introduced in 1999.

7.5.3 CAD and IT use

CAD has been used in the company for both presentation and design, for the last 10 years, in the form of the Fujitsu system. About 500 people in the company use CAD, 300 of these are CAD operators, and the other 200 are involved in the design process. According to the CAD manager, it takes about 1 hour 30 minutes to manually input the data for one house into CAD.

The company has an Intranet, some employees have email and some access to the Internet. “Discover New Life with PanaHome”, the company’s Internet homepage was launched in 1996, with the English language home page at:

http://www.panahome.co.jp/cam_t/english/cam_e.htm

7.5.4 Visualisation: Panahome Hi-soft Kantan CG system

The visualisation system Hi-Soft Kantan CG is used in National House Industrial and was introduced in 1996. The system is easy to use to enable staff without specialist programming or technical knowledge to operate it. The graphical user interface (GUI) on the computer screen is divided into three parts, which show a plan, elevation and perspective view. It is the perspective view that can be walked through in real-time. The interactive functionality of the system is found to be extremely helpful in house design, consultation with clients and with planners. During the interview the system was described as only fairly useful in street layout design and providing no benefit for marketing.

Before signing the contract, the house-builder shows the customer either a rendered picture or a rendered 3D model, that can be walked through in real-time, so that they both agree on the same design. The overall image or model is not very highly detailed. 1-2 hours are spent to create a rendered 3D model of the house when used for this purpose. According to company literature, the purpose of the VR system is presentation of design before the customer and the house-builder sign the contract.
The system ensures customer satisfaction by allowing the customer to view the house before completion. However investigation into the details is impossible with the present technique.

The main feature of the Hi-Soft Kantan CG system is the short time required to create a model. It takes about 1-2 hours to produce a model from the 2D CAD drawing. The system can even be used by customers who are not experienced or knowledgeable about VR and architecture. The system describes typical parts of their own design. The basic scale and design are input beforehand, but the information can be tailored to suit customers needs.

National House Industrial does not have a special computer-graphics presentation room: models are demonstrated on personal desktop computer, with the customers sitting around the desk and watching the presentation in one area of the show room. The system is used in showrooms all over Japan for VR presentations, on a total of 70 computers.

7.6 Mitsui Home Co. Ltd.

7.6.1 Company Background

Established in 1974, Mitsui Home uses the two-by-four (2x4) construction method originated in North America, and is the largest 2x4 housing manufacturer in Japan. 2x4 housing construction uses platform timber frames with structural components made in factories and is similar to what is known as 4x2 timber frame in the UK (Bottom, et al. 1996).

7.6.2 Housing Design and Sales

Mitsui Home has 20 design offices with 60 associated sales offices. The company is a house-builder and not a developer (although it has on occasion done development work). Mitsui Home doesn't buy land, and does not obtain planning permission as such, although each sales office has permission to build houses. Designs are produced in-house, but working drawings, which are used by the tradesmen on the site, are sometimes subcontracted to external consultants. The company builds on demand.
with 90% of houses designed and built to order for customers. It has 10 or more
standard house-types that can either be used as standard, or customised to suit the
customers’ needs.

7.6.3 CAD and IT use

CAD has been used in the company for the last 10 years, in the form of the
HCAD/WS software from Unisys. Each regional office employs designers and in
each office about 10% of these are CAD users. About 80-90% of design work is done
on CAD, but difficult forms like the lounge area are produced by hand.

The company has an Intranet though not every employee has access to email. There is
also some Internet access, and the company has an Internet web-site in both English
and Japanese, with the English homepage at:

http://www.mitsuihome.co.jp/INDEX/e_index.htm.

The company believes that an important consideration when choosing a software
package is that it must be easy to learn, as minimising the learning time is important.
A movie is used to teach employees new software.

7.6.4 Visualisation:

Mitsui Home uses VR that can be presented within the company offices and also
provides CD-ROMs and video presentations that can be taken home by customers.

The CD-ROM was made to order by an external company and contains 4 types of
houses, which are basic house-types. These are demonstrated using QuickTime VR
models. The computer screen is divided into three windows, showing a QuickTime
view, a 3D external view and a plan view. Full interactive 3D VR can be viewed at
the company offices in Tokyo at Mitsui Home Image Planning Square (Figure 7.6),
where it has been used for the last three years. Not all customers choose to view the
VR models. It is a service that the company offers if requested.
Sixty percent of VR use takes place before the customers’ decision to use Mitsui Home so that the house-builder and customer agree on an image of the house. The rest of VR use is introduced after the contract is drawn up and before construction starts on site. When the plan is decided, a 3D model is created and transferred onto video, which is then given to the customer. The video presentation is a walk-through of the three-dimensional model of a customer’s specific house design, and it is created from the VR model.

7.6.5 Mitsui Home Image Planning Square

Mitsui Home Image Planning Square (MIPS), is located in the heart of Shinjuku, a busy area of Tokyo, on the 37th floor in the Mitsui offices. The room itself is larger than the computer graphics room at Sekisui House’s ‘Nattuko Kobe’. The careful packaging of the presentation is however the same. The room appears to be a boardroom with a large screen (of approximately 1.5m x 2.5m) mounted on one wall. The images presented are therefore appearing at nearly real size. The sales representative sits with the customers and guides them through the presentation. The
operator is not in the same room, sitting behind a small glass window in the projection room. There are 3D glasses for use when viewing the house; these provide real 3D images although they have the disadvantage of causing a slight shadowing of the images.

The hardware used is a SGI based Onyx dVS system. It takes on average 2-3 minutes to load a presentation but corrections take about 3-4 hours.

7.7 Cross-Case Analysis

7.7.1 Introduction

In this section the characteristics of Japanese house-building companies and the use of VR and advanced computer graphics techniques found in the case studies are summarised, with the extent of the supporting evidence indicated. This is shown in tabular form in Table 7.1.
### Table 7.1 Similarities and differences between the Japanese house-building companies

<table>
<thead>
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<th>Company structure</th>
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<th>National House Industrial Co. Ltd.</th>
<th>Mitsui Home Co. Ltd.</th>
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</thead>
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<td>Design customised to customer requirements in regional offices</td>
<td>Design customised to customer requirements in regional offices</td>
<td>Design customised to customer requirements in regional offices</td>
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<td>CAD use</td>
<td>For drafting and not for design</td>
<td>For presentation and design</td>
<td>For design</td>
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<tr>
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<td>Comprehensive website</td>
<td>Comprehensive website</td>
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<tr>
<td>Sales staff have Internet access and email</td>
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<tr>
<td>VR and advanced visualisation use</td>
<td>For customer presentation</td>
<td>For customer presentation</td>
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<td>Used as final zone of customer care centre, Nattoku Kobo</td>
<td>Used as part of part of customer care centre, in Osaka</td>
<td>Available in customer care centre or on video/CD ROM</td>
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<tr>
<td></td>
<td>Used for 3 years</td>
<td>Used for 4 years</td>
<td>Used for 3 years</td>
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<td></td>
<td>Modelling - &quot;time consuming&quot; as no data transfer between CAD and VR</td>
<td>Modelling - 1-2 hours per house, from 2D CAD drawings (using library of components)</td>
<td>Modelling - about 1/2 day per house, including data transfer and manual corrections</td>
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<td>Presentation with a computer operator and sales presenter</td>
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<td>Presentation with a computer operator and sales presenter</td>
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<td>Hardware: SGI</td>
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</table>

### 7.7.2 Japanese House-Building Companies

As shown in Table 7.1, the structure of the house-building companies is hierarchical in all 3 companies, with a head office, regional offices, sales offices, and an infrastructure of supporting factories and research laboratories. House layout design
is customised in the sales offices, only being referred to a regional or head office in the case of difficulties being encountered. Some basic standard house-types, which are designed in the central office, are used but these are customised and altered according to customers' requirements.

In two of the three case studies CAD software is used for design generation as well as for drafting purposes, in the third case it is used for presentation only and not for design. In none of the cases is all design work done on the computer and all of the companies use computer operators for inputting designs into the CAD software. This may be a result of the lack of drive for time efficiency in Japan. When this research was conducted, in 1999, CAD had been used for more than 10 years in all three companies.

All three companies have comprehensive web sites, available in both Japanese and English, however none of the companies has all of their staff linked to the Intranet or to the Internet. Access is given selectively.

7.7.3 VR use

VR and advanced computer graphics techniques are used by all three of the Japanese house-building companies, considered in this study as shown in Table 7.1. Customer presentation is the main use for such techniques in all three case studies where VR is not used in isolation but with a suite of other computer and low-tech tools to present and explain the house design to the customer and allow design customisation.

In 1999 VR had been in use for 2-3 years and is often introduced before the contract stage. All three companies have presentation centres where customers can experience VR models. To present VR models two out of the three companies used both a computer operator, who did not contribute to the discussion, and a sales person, who led the presentation. Two of the companies use SGI computers for modelling and the third uses high end PCs.
7.8 Summary of Findings

In Japan, VR is being used extensively by some Japanese house-building companies, as one of a suite of techniques to present and explain the design to the house purchaser and to allow design customisation to suit that purchaser's specific requirements. VR complements other techniques used for describing forms, such as the use of small models or full-scale components. The narrative about design is started using conventional media and then followed in VR, which provides an interactive medium for exploring the whole design from a realistic human eye level.

VR is used in a dedicated area of the company offices usually as part of a sales center. It is often used before the contract stage, but can also be used in the detail design stage before construction starts on site. Japanese house-builders see VR as useful for presenting design at this stage so that the client and the house-builder agree on the same design and the potential for legal claims are reduced.

Japanese house-building companies were early investors in CAD and IT software, however effective translation of data from the CAD model to the VR model is not yet implemented. It may be that Japan's lifetime employment practice, which means that there is little need to use IT for time efficiency, leads to some inefficiency in computer use being tolerated. This may reduce the priority given to developing effective translation software for VR use in Japan.

The fact that Japanese house-builders usually build individual houses rather than streets combined with the lack of stringent aesthetic planning requirements makes house-builders less concerned with the environmental impact of new houses. VR is not used by house-builders for the visualisation of housing developments. However, VR is used by the Japanese government for the visualisation of developments such as new towns and new urban areas areas, as shown by the work at the CAD Center.

Some elements of the Japanese experience of VR use are felt to be relevant to the British house-building industry as many issues encountered by British house-builders have also been experienced in the Japanese context. Further discussion of the comparison between and lessons to be learnt from the Japanese experience is in the next chapter.
Chapter 8 Discussion and Conclusions

8.1 Introduction

This research has investigated the potential use of VR in the house-building sector of the construction industry. The research problem was introduced and justified in chapter 1. Government interest in modernising house-building practice (Egan, 1998) and introducing VR into the British construction industry (Cydata, 1998) was discussed.

The literature review in chapter 2 identified four major areas that had not been previously researched and questions were formulated to investigate these areas. The research questions cover the context, technical problems and implementation issues related to VR use in the house-building industry. The relationship between the different sections of the research was described in chapter 3 and the methodological approach and methods used were discussed.

Chapters 4, 5 and 6 presented the results related to the first three research questions, which between them cover VR use in the British house-building industry. The survey conducted to investigate the use of CAD and VR in the British house-building industry was described in chapter 4. Three modelling approaches and the problems of data transfer from CAD to VR, which were investigated through a practical modelling project, were presented in chapter 5 together with feedback obtained from British housing developers. A case study of VR implementation in a British house-building company was described in chapter 6. There is a narrowing and deepening of focus through these studies, from the questionnaire survey of the industry at large, through to the modelling work and an in-depth study with a single house-building company.

To allow comparison between the emerging VR use in Britain and more established VR use in Japan, chapter 7 presented an investigation of the VR use in Japanese house-building companies.
In this chapter, the main findings of the different parts of the research are summarised and discussed in relation to one another, the extant literature and the overall research problem. The main conclusions of the research are then presented and their implications for theory and practice are discussed. Scenarios for future VR use within the industry are considered and further work is identified.

8.2 Discussion of the Combined Findings

Three topics considered in this section are: the relationship between IT and the house-building organisation, similarities and differences between CAD and VR implementation, and the comparison between British and Japanese house-builders' attitudes towards and use of VR.

- The relationship between IT use and house-building is discussed and theorised with regard to empirical findings of the industrial survey (chapter 4), and case study of VR implementation (chapter 6), in the context of research on organisational IT use (section 2.4.3).

- Similarities and differences between CAD and VR are discussed by comparing the organisational impact of VR implementation and use, explored in chapter 7, and the literature on early CAD implementation and use (section 2.4.4). These findings are considered in the context of the wider literature on innovation (section 2.4) and the characteristics of the technologies and their use for model building (chapter 5).

- British and Japanese house-builders' attitudes towards and use of VR are discussed through a comparison of VR use in British house-building, researched in chapters 4, 5 and 6, and VR use in Japanese house-building, described in chapter 7. The use of the same instrumentation in between these two parts of the research was discussed in section 3.1.4. The findings are discussed in the context of the previous literature on house-building in Britain (section 2.2) and Japan, (section 7.2).
Building on the discussion of these topics the final part of the section considers the relationship between VR and British house-building policy and practice.

8.2.1 IT and House-Building

Levels of IT use within the British house-building sector of the construction industry were found to be significantly higher than previously recorded: companies had large IT departments (section 4.3.5) and a significant proportion had high levels of CAD use (section 4.3.1).

Automation of existing house-building processes is the main focus of IT use. Companies use CAD as a drafting tool to speed up the efficiency of producing and communicating site layouts for a large number of sites. The integrative effects of IT and the capacity of IT to informate (Zuboff, 1995) are not being widely utilised.

In construction, IT systems have in the past been purchased because of operational rather than strategic/business requirements (Aouad, et al. 1999). The VR implementation described in chapter 6, shows the continuation of this trend, with VR, like CAD, being implemented by a sub-set of the wider organisation. The CAD managers involved in implementation have a fractious relationship with the central IT department, and the introduction of VR was not found to be in step with wider corporate strategy.

The trials of VR systems found that libraries of standard-house-types were appropriate for rapid modelling of housing site layouts (section 5.8). However the attempt to implement such an approach within a British house-building company was problematic (section 6.5). Not only were there difficulties financing model creation, as finance was tied to construction projects, but the standard house-types themselves were often altered from one region to the next. In Japan libraries of components, were used to create models, this approach gives more flexibility than libraries of house-types and should be considered by British house-builders.

Though IT can be an enabling technology for such organisational change, it is unlikely that all house-builders will be able to use IT in this manner in the short term. Some large and mid-sized house-builders have a long history of investing in IT and CAD software, and use CAD packages for over 90% of design work. These house-
builders may gain competitive advantage by using advanced IT techniques, such as VR and network technologies. CAD managers in these house-building companies are networking with their competitors, through groups such as the CICUG volume-builders CAD group (section 4.3.5), and are also collaborating with software developers (section 6.2.3).

8.2.2 Similarities and Differences between CAD and VR

Housing developers have now started to see the benefits of using CAD although they were slow to implement it (chapter 4). The number of standard house-types used by the larger house-builders is increasing (Hooper, 1998), and this could be partly due to the ease with which standard house-types can be altered and amended on CAD drawings. VR provides a unique vehicle for some aspects of house-builders' work. Some house-builders may take advantage of VR to achieve economies of scope as well as economies of scale though a level of standardisation may facilitate VR introduction.

A comparison of the technical characteristics of CAD and VR has been given in section 5.3.2. VR packages are different from CAD in that they have a hierarchical structure and lack a modelling kernel, support for architectural data or sophisticated modelling aids. These differences arise from the need to optimise VR models for real-time viewing. Data is often translated from CAD to VR but there are no standard methods of creating VR models from CAD data. Three approaches to model creation have been identified and trialed in this work (section 5.5).

Despite the significant differences between the technical characteristics of CAD and VR, significant similarities were found between the early CAD implementation described by Schaffitzel & Kersten (1985), and the empirical observations of early implementation of VR. The similarities and differences are summarised in Table 8.1.
Table 8.1 Comparison of organisational use of CAD and VR

<table>
<thead>
<tr>
<th>Aspect of Implementation</th>
<th>CAD (Schaffitzel &amp; Kersten, 1985)</th>
<th>VR (case study)</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy</td>
<td>‘ad hoc’</td>
<td>‘ad hoc’ (section 6.3.1)</td>
<td>YES</td>
</tr>
<tr>
<td>Planning and Analysis</td>
<td>No formal methods used</td>
<td>No formal methods used (section 6.3.6)</td>
<td>YES</td>
</tr>
<tr>
<td>Position of Implementer(s)</td>
<td>Almost always a newly created position or department</td>
<td>Newly created position within the company (section 6.3.1; 6.4.2)</td>
<td>YES</td>
</tr>
<tr>
<td>Relationship of implementer(s) to IT department</td>
<td>Separate from the existing computing centre and systems department</td>
<td>Separate from the existing IT department, and central CAD department (section 6.2.1)</td>
<td>YES</td>
</tr>
<tr>
<td>Implementer involvement in software development</td>
<td>Participated personally in developing the systems</td>
<td>Participated personally in developing the systems (section 6.2.3)</td>
<td>YES</td>
</tr>
<tr>
<td>User involvement in software development</td>
<td>Future users were not involved directly in selecting the CAD system</td>
<td>Regional CAD managers were not involved at the VR product selection and development stage (section 6.2.3)</td>
<td>YES</td>
</tr>
<tr>
<td>Documentation</td>
<td>Not encountered (except in one developer organisation).</td>
<td>Not produced, although discussed (section 6.3.1)</td>
<td>YES</td>
</tr>
<tr>
<td>Relationship to work process</td>
<td>Did not supplement an organisationally perfect work process but offered integrative effects</td>
<td>VR did not supplement an organisationally perfect work process, offering further integrative effects by allowing different professionals to discuss design (section 6.3.5)</td>
<td>YES</td>
</tr>
<tr>
<td>Time-scale of Implementation</td>
<td>Several years</td>
<td>After 2 years VR was still not fully implemented (section 6.5)</td>
<td>YES</td>
</tr>
<tr>
<td>Background computing environment</td>
<td>Solutions involving centralised hardware in the form of mainframe computers.</td>
<td>PCs are widely used for design and were used for the VR implementation. (section 6.3.1) A network may be used in future to integrate software (section 6.4.2)</td>
<td>NO</td>
</tr>
<tr>
<td>Software purchase from developers</td>
<td>CAD systems, complete in their CAD-specific part, were always offered by developers in hardware/software combinations</td>
<td>Software developers and resellers offer VR systems with or without accompanying hardware and this allows the buyer greater purchasing flexibility.</td>
<td>NO</td>
</tr>
</tbody>
</table>
Neither CAD nor VR packages were implemented into existing work processes. Both offer integrative effects and thus their effective use necessitates change within the organisation. However implementation strategies were generated in an 'ad hoc' manner in their early industrial use. Formal planning and analysis tools such as UML (Ambler, 1998) were not used and top management was not involved. That implementation occurred outside established centres of IT expertise within the company, and the implementers were in newly created positions suggests that both CAD and VR use are both fairly radical innovations.

The time-scale of innovation, which for CAD was years (Schaffitzel & Kersten, 1985; Forslin et al. 1989) was also found to be long in the case of VR. With such an immature technology, there are resultant problems with technological obsolescence and the initial high cost of the equipment. The time required for development meant that company requirements had shifted before the software was fully implemented both in the case of CAD (Schaffitzel & Kersten, 1985) and in the case of VR (section 6.5). Whilst the implementers of both CAD and VR were involved in developing the systems, other users were not involved at this stage and documentation was not provided to the users.

Similarities between CAD and VR suggest that:

- User-developer communication may be a critical issue for the successful early implementation of VR in industry, as it was for the implementation of CAD as similarities were found between the procedures for system development and introduction reported by Schaffitzel and Kertsen (1985) and those found in the case study.

- Strategic decision making by top management may be of importance for successful VR implementation. As in the case of CAD, a forum between the technical managers and top management could be used for discussing strategic issues (Forslin, et al. 1989).

Despite the similarities between early CAD and VR implementation, there are significant differences in the technological environment of the implementation and characteristics of the technologies. The maturity of network technologies has changed
dramatically since the early CAD packages were being implemented in the late 1980s. The impact of network technologies for design visualisation on future strategies for VR implementation cannot be deduced solely from this comparison. Within the case study company the implementation of stand-alone VR packages in the regions was not successful in the manner originally conceived and it appears likely that VR may be more effectively used in a distributed manner.

8.2.3 Comparison between House-Builders’ VR use in Britain and Japan

As shown in Table 8.2, there are considerable differences between the Japanese house-builders’ attitudes towards and use of VR, as researched in chapter 7, and the British house-builders’ attitudes towards and use of VR studied in chapters 4 & 6.

These differences may be partially explained by the different operations of Japanese and British house-builders. Japanese house-building organisations have a more extensive infrastructure of customer facilities than their British counterparts and they may also have research laboratories, human resource centres and libraries. This infrastructure of facilities reflects the importance of design quality as an area in which Japanese house-building companies can obtain competitive advantage.

Few British house-builders felt that consultation with clients was an area of business in which VR could have benefit (section 4.3.4) but Japanese house-builders use VR to present the design to the customer and allow customisation of the design (section 7.7.3). British housing developers currently operate speculatively, building standard house-types for an unknown client however this may change as British house-building is changed by government policy and house-building initiatives (Barlow, 1998; Roy & Cochrane, 1999; Roy & Gaze, 1999).

Japanese house-builders build houses predominantly for customers who already own the land and thus are not concerned with site layout but operate in a manner similar to interior design stores such as IKEA or HABITAT, selling a life-style commodity product. In contrast, British house-builders act as developers as well as house-builders, selling the land and the house to the customer at the same time. Whilst in Japan design is customised in the regional offices to suit the customer, in Britain it is customised to fit local planning regulations.
Both Japanese house-builders and British house-builders have some web-presence, although the Japanese house-builders have more comprehensive web-sites than British house-builders. These are used for marketing and contact with customers and suppliers. Within Britain, the number of house-building companies with web-sites has continued to rise as indicated in responses to the questionnaire, section 4.3.5. This trend has continued with Wimpey reporting 750 sales leads a month from its web-site (Gow, 2000).

Table 8.2 Comparison between Japanese and British house-builders showing how Japanese house-builders are different from British house-builders

<table>
<thead>
<tr>
<th>Company operation</th>
<th>British House-Builders</th>
<th>Japanese House-Builders</th>
<th>Major Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head office and regional offices</td>
<td>Head office, regional</td>
<td>Customer / manufacturing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>offices</td>
<td>offices, customer</td>
<td>research facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facilities, and factories, possible research laboratories.</td>
<td></td>
</tr>
<tr>
<td>Operates as a developer and a</td>
<td>Operates as a house-</td>
<td>No land development</td>
<td></td>
</tr>
<tr>
<td>house-builder</td>
<td>builder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design altered in regional offices</td>
<td>Design customised in</td>
<td>Customisation for customer rather than planners</td>
<td></td>
</tr>
<tr>
<td>to fit planning regulations</td>
<td>regional offices to suit the customer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAD use</td>
<td>For drafting and design</td>
<td>No use of CAD for design</td>
<td></td>
</tr>
<tr>
<td>Less than 10 years</td>
<td>More than 10 years</td>
<td>Longer CAD use</td>
<td></td>
</tr>
<tr>
<td>IT</td>
<td>Web-site recently</td>
<td>Web-site</td>
<td>Longer web use</td>
</tr>
<tr>
<td></td>
<td>acquired</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet access and email was</td>
<td>Some staff have Internet</td>
<td>Sales staff more likely</td>
<td></td>
</tr>
<tr>
<td>being introduced with central</td>
<td>access and email in</td>
<td>than design staff to have</td>
<td></td>
</tr>
<tr>
<td>office design staff, followed by</td>
<td>each of the companies</td>
<td>Internet and access</td>
<td></td>
</tr>
<tr>
<td>the sales and marketing staff,</td>
<td>considered, with sales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>most likely to have network</td>
<td>staff most likely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>facilities</td>
<td>to have the facilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VR use</td>
<td>Seen as useful for</td>
<td>VR useful for customer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>explaining the site</td>
<td>presentation not for</td>
<td></td>
</tr>
<tr>
<td></td>
<td>layout, both within and</td>
<td>presenting site layout.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>without the</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>organisation, to non-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>technical staff, planners and customers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use beginning to be explored</td>
<td>Used for 2-3 years</td>
<td>Longer use</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Used as one of a range of techniques to describe design intent</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Model creation takes between 1 hour and 1/2 day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency in model creation</td>
<td>Inefficiency in model</td>
<td>Inefficiency can be</td>
<td></td>
</tr>
<tr>
<td>required</td>
<td>creation tolerated</td>
<td>tolerated</td>
<td></td>
</tr>
</tbody>
</table>
## Chapter 8 Discussion and Conclusions

<table>
<thead>
<tr>
<th>VR use</th>
<th>Computer operator uses</th>
<th>Use of computer operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presently used by CAD managers, who</td>
<td>navigates the model and</td>
<td>Used of computer operator</td>
</tr>
<tr>
<td>demonstrate it to other members of the</td>
<td>a sales presenter</td>
<td></td>
</tr>
<tr>
<td>organisation</td>
<td>discusses the design</td>
<td></td>
</tr>
<tr>
<td>Interest in VR for marketing, followed by</td>
<td>VR used for design</td>
<td>Used in house design</td>
</tr>
<tr>
<td>communication with planners and refining</td>
<td>discussion in collaboration</td>
<td>stage.</td>
</tr>
<tr>
<td>the design idea and the use of VR at the</td>
<td>with the client, often</td>
<td></td>
</tr>
<tr>
<td>early design stage</td>
<td>before contract</td>
<td></td>
</tr>
<tr>
<td>Hardware: PC computers used</td>
<td>Hardware: SGI and PC</td>
<td>SGI used</td>
</tr>
<tr>
<td>used</td>
<td>computers used within</td>
<td></td>
</tr>
<tr>
<td>Concerns about giving more information as it</td>
<td>Organisations</td>
<td></td>
</tr>
<tr>
<td>might lead to claims later</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of virtual reality to give more</td>
<td>VR as means of reducing</td>
<td></td>
</tr>
<tr>
<td>information seen as a way of reducing</td>
<td>claims</td>
<td></td>
</tr>
<tr>
<td>claims later</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Japanese house-building companies visited were all early investors in CAD and IT software. The Japanese companies visited had all used CAD for more than 10 years. This suggests that CAD was implemented in Japanese housebuilding companies before British house-building companies as there was little CAD use in British house-building in the late 1980s (Thorpe, 1992). There is good software support for the Japanese house-building industry, with companies such as Unisys Japan producing specialist software for the last 20 years. In Britain in the late 1980s there was very little software support from software companies (Ewin, et al. 1990) but there are now software companies specialised in providing for this sector (section 4.3.1).

VR has been used for 2-3 years by the Japanese house-building companies studied and is seen by them as useful for explaining the house-design to the customer, through customer presentation. This is in contrast with the situation in Britain, where VR is just beginning to be explored and is seen as useful for presenting the site layout. The contrast may be explained by the different competitive strategies of Japanese and British house-builders. Planning is not as important to house-builders operating in Japan, as houses are considered as temporary structures. Japanese house-builders are usually developing single houses rather than housing developments and it is the government, which develops new towns in Japan.
Obtaining planning permission for sites in the prime locations is more important to the British house-builder and thus in contrast to the Japanese situation, VR models have initially been considered by the industry as tools to facilitate the visualisation of site layouts. The importance of enabling the customer to visualise house design may increase however, as the basis for competitive strategies change (Barlow, 1999), and companies beginning to explore customer-focused product development techniques (Roy & Cochrane, 1999).

Issues of model building, discussed in chapter 5, were investigated in Japan. In contrast to expectations, the Japanese companies studied were not using sophisticated modelling approaches as modelling was a time consuming process. The Japanese house-building companies studied used little automatic transfer of data between CAD and VR software packages, with one company building the VR models from scratch within the VR package itself using libraries of components, whilst the other two used some data transfer and libraries of components. Some inefficiency in computer use is tolerated in Japan as life-time employment practice reduces the need for efficiency drives. This inefficiency is not appropriate in the British house-building context. At CAD Center, a specialist model building company, one urban model took three people five months to complete. Thus there was about 15 months, or about 2400 hours, of operator time required to create the model (section 7.2.4). These results are similar to the modelling times found in previous literature (Bourdakis, 1997; Counsell, 1997) but are far too great to allow widespread use of VR in the British house-building process, unless very significant advantages can be demonstrated to justify the modelling time.

Despite the differences outlined above British housing developers can learn lessons from the Japanese use of VR:

**VR is useful for explaining design to the customer** – Better visualisation tools may be required for customer-focused product development and to allow greater customisability. VR is used in Japan to allow the customer to visualise and participate in the design of the house by customising standard house designs through the choice of a range of components. Thus VR is used for customer-focused product
development in Japan and house-building and construction companies wishing to implement this technique should consider the use of VR to support it.

**VR is useful as one of a range of interactive techniques** – VR was used in Japan as one of a range of techniques used to describe the house design. It did not supersede or replace other techniques, such as the use of full-scale models and maquettes. This suggests that VR cannot be expected to provide a quick technological fix, but can be used to augment the effectiveness of traditional media. Different people may respond differently to different methods of presenting spatial data and providing a range of representation of design allows all customers to reach a shared understanding of the design decisions that are made.

**The interface to VR models should be intuitive** – In Japan the technical aspects of VR were not presented to customers, but were down-played allowing the customer to focus on the design. Navigation in the model was aided by a map, or overhead view, and/or was performed by an operator, thus the customer was unlikely to get lost in the model. There was also the possibility of juxtaposing plans and perspective views in the VR model, thus allowing the customer flexibility in the way that they used the software.

### 8.2.4 VR in House-Building Policy and Practice

Consideration of early CAD implementation (section 8.2.2) and previous literature (section 2.4) suggests that user-developer relations between house-building organisations and software developers will facilitate relevant software innovation. Intuitive professional design products for house-building do not yet exist despite the fact that consumer products have been developed that allow the intuitive creation of houses in 3D (Johnson, 1998). Professional VR products are generic in nature and have even less built-in support for house-building requirements than CAD products, but Japanese house-building have used collaboration with specialist software developers companies to successfully implemented VR into their businesses.

Organisations such as the cross-industry (CICUG) CAD forum discussed in section 4.3.5 have been set up to lobby large CAD manufacturers to produce building design products that are adapted to the house-building industry’s needs. Such a forum also
allows the exchange of ideas between house-building organisations. This trading of and cross-fertilisation of ideas between lead users is important for innovative action within an industry (von Hippel, 1989). The cost of unsuccessful innovation within the house-building industry is high (Hooper, 1998) and networking with competitors can be used to reduce the risk of VR implementation through uncertainty reduction. Networking both with CAD suppliers and competitors is important throughout the innovation process as there is a danger of companies becoming wedded to a state of technology or a product type that is rapidly superseded by a more appropriate technology or design.

Policy makers have discussed process change whilst ignoring the role of IT as an enabler (or inhibitor) of change in house-building processes. The successful implementation of customer-focussed product development and supply-chain management initiatives (Gann, 1996; Roy & Cochrane, 1999) could be facilitated by advanced visualisation techniques such as VR, which allow communication of design intent in discussion with customers or between members of inter-disciplinary groups. Though the VR model may never replace the show-house, it may increase the options presented to the customer by allowing them to see alternative house-types and to view street layouts in post-construction form, in 3D either at a sales centre or on CD-ROM, or across the Internet. Organisations such as the CICUG CAD forum could also encourage component suppliers to provide 3D representations of their components. Thus the house-builder selling a customised product across a network could link VR models of the house to a library of components, allowing the user to retrieve further information about the components directly from the component supplier.

Thus VR can be used to achieve simultaneous economies of scale with economies of scope. Standardisation allows for the efficient prototyping and use of VR, though it would be undesirable for companies to become locked into the use of a very small number of standard designs. In the practical modelling work (section 5.5) a library of standard house-types was found to be useful for prototyping site layouts. Standard house-types had regional variations, which were often introduced to mollify planners concerns about the national standard house-types and the house-building company studied in the case study (chapter 6) found it difficult to use libraries of standard house-types in their VR system, because of the wide number of variations. It may be
that a more appropriate level at which to build libraries for use in VR is at the level of the standard components, which can be combined to make individual customisable houses that are sensitive to their context. At this level there is still a large degree of standardisation that would facilitate the prototyping of a VR system.

Within the house-building organisation, top management support for IT initiatives may enable VR implementation to be aligned with broader corporate strategy. The similarities between CAD and VR implementation (section 8.2.2) suggest that a joint forum between management and users may also be useful. However it is unlikely that many British companies will be positioned to implement VR to enable customer use for house customisation, in the manner that is used in Japan, in the near future. Land development and the obtaining of planning permission are more important in the British context and site layout design is a far greater part of the British housing developers work than it is of the Japanese house-builders work.

VR is useful for the involvement of all members of the house-building organisation in the site layout design process. The trials of VR systems found that different modelling approaches were suitable for different purposes as housing developers had different requirements for models that were for external presentations and internal discussions. Abstract VR models have been found to be more suitable than highly photo-realistic models for early design though the current technology did not support the interactivity required by housing developers. The use of exocentric views as well as egocentric views was also found to be helpful.

VR could be of great use within the planning system and 3D models of cities and urban areas, such as the models of Bath (Bourdakis, 1997) and the LA basin (Liggett, 1997) may be potent tools for use by planners in the future. Situating VR models of new housing developments within the wider context of the urban environment may enable more informed planning decisions to be taken.

Whilst some planners are aware of the advantages of more versatile visualisation tools (section 4.3.3) the regional variation in planning authority requirements makes house-builders reluctant to experiment. Some planning authorities are technophobic to the extent that house-builders use packages to make their CAD drawings look hand-drawn before presentation to the planners (section 4.3.3).
At present British house-builders are wary about the use of visualisation tools because of the legal issues that arise when representations lack ambiguity and misrepresent detail design. Though Japanese house-builders saw the use of VR as a good way of reaching consensus on design, the British house-builders were concerned that they would be liable for matching the exact colouring and detailing on the VR model. Policy makers wishing to encourage VR implementation and use should seek to clarify the legislation in this area. One manner in which this issue may be resolved is through giving the VR model the same status as the hand-painted watercolour. This would enable a note declaring the representation as an artist's impression to be displayed with the model, to enable house-builders to give an impression of the scheme they intend to build without being legally bound to replicate exactly all of the details.

8.3 Conclusions about the Research Problem

The preceding section discussed IT in house-building, similarities and differences between CAD and VR use and the comparison between house-builders' use of VR in Britain and Japan. VR in housebuilding policy and practice was then considered. This section summarises the major findings with regard to the research problem:

*What is the potential for British housing developers to use virtual reality for the design and evaluation of housing developments?*

The research problem has been analysed at the level of the industry (through internal and external analysis), the technology, and the house-building organisation, the findings have been synthesised as discussed in section 3.3.4.

The three main conclusions are outlined in the following sections.

8.3.1 Conclusion A

- *Virtual reality is of use for explaining the design of housing developments to non-designers, both internally and externally to the house-building organisation.*
Respondents to the survey felt that designers were able to interpret abstract CAD drawings (section 4.3.4), which formed a kind of shorthand. They felt that VR could be of more benefit for explaining design to non-designers. The business areas in which VR techniques was perceived to have most benefit are areas in which it is desirable that non-designers understand design intent: marketing, followed by consultation with planners and refining the design idea.

The potential to use PC-based VR enables house-builders to use VR within the company rather than commissioning external consultants to create models. Trials of PC-based VR systems, described in section 5.5, found that VR models of housing development could be created from CAD data. Though there are some technical difficulties with data transfer from CAD to VR, three modelling approaches were identified and trials found that the usefulness of the different modelling approaches was dependent on the purpose of the VR model (section 5.5).

PC-based VR will enable companies to use VR for more purposes than just presentation. Through its capacity to informate, or explain design to all participants within the house-building process, VR facilitates innovation as proposed by Watts, et al. (1998). The first British house-builder to implement a PC-based VR system wanted to use VR to include non-technical staff in discussion about design ideas (section 6.2.2). This objective was fulfilled in the project and regional directors, land-buying, sales and marketing staff were included in design discussions using VR, though they may not have been able to understand the traditional plans and sections presented in CAD drawings (section 6.5).

Japanese house-builders did not use VR for the evaluation and design of housing developments, however this is due to differences between the operation of Japanese and British house-builders. Unlike British house-builders, Japanese house-builders do not act as developers. For the Japanese house-builder customer care is more important than planning regulations, thus their failure to implement VR for site layout design and evaluation cannot be seen as a sign that this application would not be relevant to the British housing developer.
8.3.2 Conclusion B

- *Housing developers’ use of virtual reality at the early design stages is hampered by the current state of the technology.*

The first British company to implement a VR system in-house saw design issues as a reason for implementing VR (section 6.2.2) and the survey found that the desire to use VR for refining the design idea was widespread (section 4.3.4). However trials of VR systems found that the technology did not support the rapid alteration of design required at the early stages (section 5.5). The creation of VR models is a time consuming process therefore CAD managers were found to delay creating the VR models until the design was nearly finalised (section 6.3.2). This was done to reduce the need to alter the models after their initial creation. VR models were not dynamically linked to the CAD data. This greatly reduced the potential for VR to be used in an interactive manner at the design stage. When designs changed the process of up-dating them became laborious.

Some CAD managers believe that VR should be the medium for design, with static 2D working drawings taken directly from the 3D interactive VR model (section 6.2.1). The use of VR in this manner could allow great flexibility in use and an evolution of uses throughout the house-building process. A model created for the evaluation of housing developments at the feasibility stage of the house-building process (described in section 2.2.2) could be used in later stages of the process for consultation with planners, marketing and sales.

Generic PC-based VR systems are not well adapted to the display and manipulation of architectural data, and the future of current standards such as VRML (ISO/IEC 14772) is uncertain. Developments in VR continue to be driven by flight simulation, computer games and ecommerce application. For VR to be a useful part of housing developers’ future building design tools, as discussed in section 5.3.4, software developers need to create VR applications that address the needs of the house-building industry. The CAD vendors, PTC (http://www.ptc.com), which produces the mechanical CAD software ProEngineer, have purchased the VR software Division, and this kind of alliance may allow the better integration of CAD and VR functions.
At present libraries of house-types, or libraries of components could be used to alleviate translation problems allowing VR to be used at an earlier design stage. This approach was found to be useful in the trials of VR systems (section 5.8) and was taken by the British company implementing a VR system (section 6.2.4) and the Japanese house-builders studied (section 7.7). However the database approach, used in conjunction with a library of common geometries would allow VR models to be created and altered at all stages of the house-building process.

8.3.3 Conclusion C

- **Organisational transformation is required for housing developers to implement and obtain maximum benefit from virtual reality.**

There are integrative effects of VR use, as there were in the case of CAD, and the use of VR can be seen as an enabler (or inhibitor) of change within the house-building industry. A radical rethink of the house-building process and organisational structure, such as that associated with the customer-focused product development techniques can be enabled by the use of appropriate technologies such as VR, and the co-maturation of process and IT (Aouad, et al. 1999). Information about design can be made available to all participants within the house-building process to allow greater organisational flexibility to be gained, with the integration of business functions (Allen & Scott Morton, 1994).

However technical change does not automatically lead to changed organisational patterns (Forslin et al. 1989). In the studies of CAD and VR implementation separate individuals voluntarily made technical innovations after which the development process took place within the functional line and with a minimum of cross communication either within or between functions. This greatly reduced the potential for success of, and the benefit gained from innovation.

For VR to be of benefit to house-building companies they need to see quality of design as an important aspect of their work. Implementation of the new software has little effect on bureaucratic organisation unless such change was included as a explicit objective of the implementation (Forslin et al. 1989). Thus it may be necessary to
align implementation strategy with wider corporate strategy from the outset of the project. At present housing developers compete using land-based strategies.

Within the top 100 British house-builders, the extent of IT use doesn’t correlate with the size of house-building company, though there is a polarisation between those companies which have high CAD use and those with low CAD use (section 4.3.1). The very largest house-builders or volume-builders have oligopolistic competitive strategies (Hooper, 1998) and smaller organisations may gain competitive advantage by bringing in radical innovation (Slaughter, 1998). Thus it may be the regional or mid-sized builders with coherent IT strategies, strong IT bases and clear business objectives that are first to use VR.

8.3.4 Summary

The findings regarding the research questions are triangulated to ensure the validity of the conclusions as discussed in section 3.3. Different parts of the research are compared to establish whether there are similarities. Convergence of findings from the different parts of the research strengthens their justifiability and can be used to confirm the conclusions about the research problem.

The relation between the findings of the research questions and the conclusions are shown in Figure 8.1. Different aspects of the findings on computer use in house-building (chapter 4), VR modelling (chapter 5), VR in a British house-building organisation (chapter 6), and VR use in Japanese house-building (chapter 7) are used to confirm the three conclusions.
### Findings regarding the research questions

#### VR Use in British House-Building

**Computer Use in the House-Building Industry**
- Extent of IT use doesn't correlate with company size.
- Polarisation of companies: high/low CAD use
- VR seen as useful for marketing, consultation with planners and refining the design idea.

#### VR Modelling
- Architectural data not adequately supported in VR.
- Translation from CAD difficult due to different structure of packages and no standards.
- 3 modelling approaches identified for PC-based VR: library-based, straightforward translation, database

#### VR in a British House-Building Organisation
- Lack of involvement by board level management hampered implementation.
- Time taken to implement VR reduced benefit due to problems of initial high cost, technical obsolescence and organisational change.
- VR used to address design issues and to include non-technical staff in discussion of design.
- VR not used in the early design process though this was a company objective.

#### VR Use in Japanese House-Building
- VR not used for design and evaluation of housing developments, as house-building companies do not operate as land developers.
- VR is one of a suite of techniques to present and explain the design to house purchaser before contract.
- Effective translation of data from CAD model to VR not yet implemented.

### Conclusions regarding the research problem

**What is the potential for British housing developers to use virtual reality for the design and evaluation of housing developments?**

- **A)** Virtual reality is of use for explaining the design of housing developments to non-designers, both internally and externally to the house-building organisation.

- **B)** Housing developers' use of virtual reality at the early design stages is hampered by the current state of the technology.

- **C)** Organisational transformation is required for housing developers to implement and obtain maximum benefit from virtual reality.

**Figure 8.1** Triangulation of findings regarding the research questions to validate conclusions regarding the research problem
8.4 Future Directions for VR use in British House-Building

Neither the empirical findings nor the conclusions give absolute certainty that VR will be used by British house-builders. Future prediction is not a subject that fits well with the requirement for methodological rigor in academic research as discussed in chapter 3. However it is often desirable to hypothesise about future phenomena. One approach taken by academics is to paint a set of pictures or scenarios (Maxwell, 1996). This approach is taken in this section to consider three scenarios for the future use of VR:

8.4.1 Scenario 1: VR created by Consultants

- VR models will continue to be made by external consultants and will not be created within house-building organisations.

In this scenario VR models are not created within the house-building organisation, but are created from CAD drawings by professional VR content creators.

An advantage of this approach is that the housing company’s staff time is not used up creating VR models as the professional VR content creators operate as external consultants. Also, the models that are created are highly optimised for use within the VR environment as many consultants do not translate the CAD models into VR, but use the CAD data as a basis on which to build a VR model out of primitive shapes within the VR environment. The VR models can be created to have a very high degree of realism. Model creation is not limited by the software and hardware packages owned by the house-building company, but can be created using the latest software and hardware packages on the market as the house-building company can choose which VR content creator to use as external consultants. Alternatively the house-building organisation can build up a working relationship with one particular content creator so that this external consultant becomes aware of the house-builders’ specific modelling requirements. This kind of content creator may already be working in the house-building sector, for example as a CAD vendor or as an engineering consultancy.
However the process has some disadvantages. It is expensive, limiting the number of sites on which such models can be used to a few key flag-ship developments. Also the use of the resultant VR models is limited to the presentation stage of the project. The model cannot be generated instantaneously and the company is dependant on the modelling timescale set by the external consultants. The models can be used for marketing activities, such as use on the company web-site, and in the sales office. It could be argued that these are the most important uses of VR, marketing was rated as the most important use for VR in the survey (section 4.3.4), and sales is an area expected to become more important as house-builders become more customer focused. However such VR models are useless for the customisation of design promoted by the British government, and witnessed in Japan (chapter 7). They have no additional benefits for aiding communication between staff at the design stage or for use in the planning consultation process.

8.4.2 Scenario 2: VR creation as a Specialist Job

- VR model creation is a specialist activity within the house-building organisation and VR models are generated at a centre of excellence within the decentralised house-building organisation.

This is an approach considered by the house-building company studied in chapter 6. The creation of VR models from CAD data is currently a time consuming process requiring specialist skills. The time required to adequately acquire these skills may be too great to justify all members of the house-building company that use CAD learning to create models in VR. Instead a specialist unit within one of the offices could create models. In this unit staff could be trained to use the VR package and produce optimised VR models. This unit could produce VR models both for projects within that office, and for projects within other offices of the same house-building organisation.

This scenario means that design staff do not have to learn too many packages, but can concentrate on using a few packages to their full potential. Whilst most design staff operate the CAD package, and are not concerned with the technical requirements of producing and optimising VR models, having staff that concentrate on the production
of VR and visualisations ensures that this is done to the highest possible quality. These staff can generate a library of the company’s standard housetypes in VR, allowing models to be reused and greatly facilitating the process of creating VR models of standard housing developments. All design staff and non-technical staff can use the VR models as end users. VR models can be used in the consultation process, being returned to the specialist unit when they require updating. The level of realism in the model can be optimised to the models purpose, with more abstract models containing simplified house-types being used in design and more highly detailed and rendered house-types being substituted when the model is displayed externally. Thus a problem with this approach is that the standard house-types have regional variations. Either the approach may lead to further standardisation of design, or it may inaccurately portray house-types to reduce the burden of modelling.

Also the company has to invest in the VR hardware and software, and this may be superseded and need replacing in a short period of time. The current cost of such hardware and software is about £10,000 but this may fall over time. The company also has to buy staff, or train existing staff to use the VR software to create models for the company.

If only a few sites are required to be put into VR then this approach is unlikely to be as cost effective as scenario 1, but if VR is to be used on many sites then there are many advantages of this approach over scenario 1. VR skills are learnt in-house, and these skills may be viewed as an investment for the future. The VR models that are created can be highly customised to the house-builders’ requirements, as the in-house staff will have a better understanding of the house-builders operation than external consultants will. Data can be translated from CAD, reducing the amount of modelling work that has to be redone, and filters can be set up to automate some aspects of this process. Over time organisational learning takes place with regard to optimising the creation of VR models for the house-building application. A library of house-types can also be used. Models can be updated and standard house-type models can be reused. Such an approach is possible with currently existing technologies.

A variant of this approach is used in Japan as discussed in chapter 7. VR models are created by CAD operators, who are not themselves directly involved in design.
8.4.3 Scenario 3: VR Available at every CAD Station

- VR is available at every CAD station. A VR viewing environment is integrated into the base CAD products, through the use of a database of representations.

In this scenario every designer within the house-building company has access to an updated VR model of the design as there is a dynamic link between the CAD model and the VR model.

Creating a VR model is not a time-consuming process and the VR model can be used to communicate the design to non-technical staff at any stage of the design process. Design can also be conducted in the VR model, and changes made are automatically propagated into the CAD model. Although this scenario is not possible with the currently available software, it has many advantages. This type of VR model facilitates concurrent engineering: VR can be used in the design process, as well as in consultation and marketing.

To implement this approach requires the resolution of many of the technical problems and this only seems likely if housing developers work with the software developers. Up to this point the development of VR technology has been driven by the interests of the military, in the development of flight simulation; computer graphics programmers; the entertainment industry and lately e-commerce (see for example the way that Superscape is developing). The needs of the building professional have had little impact on the development of VR software.

8.5 Limitations

Limitations of the research are:

- The research focused on the house-builders' perspective. To obtain a wider perspective of VR within the industry interviews were conducted with a local planning authority and with a CAD software company that specialised in providing solutions to the house-building industry. However, interviews have not been conducted with external consultants and companies in the house-building
supply chain to investigate the role of VR in facilitating communication between these organisations.

- interviews have not been conducted with all stakeholder groups within the house-building organisation. Extensive user feedback has not been obtained from the sales and marketing staff, land-buyers and regional directors using VR in the early design stage.

- The use of libraries of standard components, rather than libraries of standard house-types was not considered in the modelling work. A more appropriate level at which to build libraries for use in VR may be at the level of the standard components, which can be combined to make individual customisable houses that are sensitive to their context. At this level there is a large degree of standardisation that would facilitate the prototyping of a system.

8.6 Identification of Further Research

Several suggestions and recommendations for further research have been made in previous chapters of this thesis. These are summarised below:

The implications of VR use on the working practice of house-building companies within their supply-chain require further study. As VR enables non-designers to understand design, it may be used to enable greater customer involvement. A VR system could be created for use at the customer interface, from this rich data about customer preferences could be obtained to inform future design work. The potential for collaboration with component manufacturers should be explored. There may be mutual benefit in housing developers obtaining some VR data directly from component suppliers, in order to demonstrate components to their customers.

VR could be used as the front-end to a database of different components, enabling customer-focussed product development by allowing the customer to rapidly view alternatives in a manner that builds on Japanese house-builders' VR use. A project to develop these tools could build on recent research into object-oriented component databases and study of Japanese housing developers' VR use.
Also the use of external consultants for design in the private house-building industry should be researched. House-builders’ decisions regarding use of CAD and VR may be better understood within the context of their management of external as well as internal design.

The relationship between the use of IT and the structure of the house-building organisation requires further study. Hooper (1998) has suggested that the use of standard house-types is related to the internal structure of the organisation; whether dominated by the head office, or by regional offices that have a larger degree of influence. IT use may be related to both the use of standard house-types and the structure of the organisation. The change from a hierarchical centric organisation to a network organisation, observed in the house-building organisation studied in the case study, requires further study. This radical change into a flatter organisation was conducted at the same time as new web-based systems were introduced to support the organisation. The degree to which this phenomenon is widespread within the house-building sector and the implications of this new organisation for the use of design and visualisation tools should be investigated.

A visualisation tool could be developed that uses web technologies to allow discussion of site-layout within a multidisciplinary distributed team. The work could build on the work in this thesis and recent research into mixed/augmented reality systems, seen at Matsushita (Panasonic) Research Laboratories, Columbia University and Strathclyde University.

Implementation of IT systems can fail when the systems do not fit current practice or when there is a change in the needs of the organisation. Analysis of the visualisation needs of current and evolving construction processes is proposed using tools such as UML to allow research to be aligned with business strategy.
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References


References


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References


References


References


Appendix A:

Questionnaire sent out to the top 100 British house-builders.
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Appendix B:

Interview Protocols for the Case Study

Protocol for the 1st Interview with Future Users of the VR Package.

IMPLEMENTER:

Company Objectives
What are the reasons for implementing a VR system?
What are the company objectives in relation to the implementation?

Software Development
What is the procedure for software development?
Why did you decide to get involved in software development?
What is the timescale that this development took?
How many iterations of development and testing have been gone through before it was sent out to the regions?
How was the development managed and structured?

Housebuilding Processes
Is this an accurate description of the housebuilding processes (from the company perspective)?
How do you see VR impacting the processes?

IMPLEMENTER AND FUTURE USERS:

Technological issues and expectations
What is the task for which VR will be used?
What are your expectations of VR?

IT infrastructure
What is the company IT policy?
What are the roles within company in relation to IT purchase and implementation?
How is training conducted?
How many staff within the region are using CAD – for housetype/street layout design?
How many staff within the region are expected to use VR and in what context?

Region's operations
What are the different departments in the region?
How many staff are there in the region?
How many houses are built by the region?
Are working drawings produced in the region?
What percentage of standard housetypes are used?

Working routine
How many hours are worked on CAD per week (individually)?
What proportion of time is spent using CAD?

Hardware/software
What is the existent hardware/software for design and visualisation in the region?
What hardware/software has been purchased for the project?

Implementation
What are the predicted timescales for the implementation of VR?
What are the training provisions for the implementation of VR?
Who will manage the implementation process?
Is there a plan?
Appendix B

Protocol for the second interview with the CAD managers

**Housebuilding Processes**

Is this an accurate description of the housebuilding processes (from the region's perspective)?

How do you see VR impacting the processes?

**Region's Operations**

How many staff are there in the region?

How many houses are built by the region?

**Sites**

How many different sites are looked at by the Landbuying department in a year?

How many years is land kept in the landbank?

How many sites are in the landbank within the region?

Does the landbuying department/surveyors/technical decide the mix of housetypes?

**Schemes**

How many schemes are looked at by the Planning and Design department in a year?

How many of these will reach the planning approval (how is planning approval different from planning permission) stage?

How many of these will eventually be built?

**VR Project**

How big, in terms of units, is the project on which you are using VR?

At what stage in the development process is the project? (has the plan been finalised)

Are there external consultants involved in the project?

How is the VR being used in the project? (what function if the VR serving on this project?)

**Implementation Issues**

Has any VR modelling work been done for you by external agencies?

Who else, within the company, has seen the VR model/package at this point?

Have they had hands on experience, or has it been demonstrated to them?

Do you have plans for future VR use on another project at this stage?

How satisfied are you with the VR usage to date?

**Technological Issues: VR Experience**

How many hours experience with the software have you had at this point?
Do you find the package easy to learn?
What are the best features of the package?
What are the worst features of the package?
How would you change them?
Appendix C:

Questionnaire and Interview Protocol for Japan

COMPANY STRUCTURE

1) How many people are employed in the head office of the company? __________________

What are the functional departments of the head office of the company?  (Sales & Marketing, IT, Estimating etc) ... and how many people are employed in each department?

2) How many regional offices does the company have? __________________

How many people are employed in the regional offices? __________________

What are the functional departments of the regional offices of the company?

3) What research laboratories, and other subsidiary organisations does the company have?

How many people are employed in these? __________________

What are their functional departments?
4) How are large (multiple house) projects organised?

How are small projects organised?

HOUSEBUILDING OPERATIONS

1) Which housebuilding functions does the company undertake:

- Land purchase
- Obtaining planning permission
- House design
- Working drawings
- Site layout design
- Prefabrication in factory
- Assembly on site
- Sales
- After sales care

Reasons for operation methods

2) How many standard housetypes does the company have?
Appendix C

How can these housetypes be varied?

3) How many standard components does the company have? ____________________________
How are these standard components managed and specified? ____________________________

4) What size housing developments are undertaken?

5) What percentage of houses are built to order for a customer?

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<td>90-100%</td>
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What percentage of houses are built on brownfield sites (sites that have already had buildings on them)?

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IT (Computer) USE

1) How is IT managed in company? ____________________________

2) Which department/manager is responsible for IT strategy?
   IT purchasing? ____________________________
   IT maintenance? ____________________________

3) What network facilities do your company’s employees currently use?

   Email | Internet
   □     | □

Central Office Design Staff
Appendix C

Regional Office Design Staff
Sales and Marketing Staff
On Site Sales Staff

4) Does your company have a web site?

5) What are important considerations when choosing software for your company?

Well known trade names
One integrated solution for all functions
Separate packages which exchange data
Stand alone packages for different functions

Industry Standards
External software support
Custom made in house solutions
Other (please specify)

6) How is new software implemented in the company?

CAD USE

1) How long has CAD been used in the housing company? ______ years ______ months

What CAD software is used?

2) How many people use CAD for design (total)?

house design?

224
Appendix C

site layout design? 

3) What percentage of design work is done on CAD?

0-10% 
10-20% 
20-30% 
30-40% 
40-50% 
50-60% 
60-70% 
70-80% 
80-90% 
90-100%

4) Is 3D CAD used in the company? NO YES 

5) Is the CAD system customised for house-building? NO YES 

VISUALISATION USE

1) What other visualisation software is used in the company? 

2) In what areas do you feel that 3D modelling and visualisation tools can help?

house design extremely helpful / very helpful / fairly helpful / no benefit
street layout design extremely helpful / very helpful / fairly helpful / no benefit
marketing extremely helpful / very helpful / fairly helpful / no benefit
consultation with clients extremely helpful / very helpful / fairly helpful / no benefit
consultation with planners extremely helpful / very helpful / fairly helpful / no benefit
other (please specify) extremely helpful / very helpful / fairly helpful / no benefit

VR USE

1) Is virtual reality (VR) used in the company? NO YES 

If YES

How many years has VR been used in the company?

less than 1 box 
1-2 box 
2-3 box 
4-5 box 
5-10 box 
ever box
Appendix C

What is VR used for?

How was the VR package implemented?

If NO

Have you seen a demonstration of VR techniques in the construction industry?

YES / NO

Do you see VR techniques as potentially beneficial to your company?

YES / NO

In how many years time do you see Virtual Reality techniques in use in your company?

less than 1  □  1-2  □  2-3  □  4-5  □  5-10  □  never  □

2) How much impact do you see Virtual Reality techniques having on the following areas of business?

<table>
<thead>
<tr>
<th>Area</th>
<th>very high / high / medium / low / very low</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial design</td>
<td></td>
</tr>
<tr>
<td>refining the design idea</td>
<td></td>
</tr>
<tr>
<td>tendering &amp; construction</td>
<td></td>
</tr>
<tr>
<td>communication with planners</td>
<td></td>
</tr>
<tr>
<td>marketing</td>
<td></td>
</tr>
<tr>
<td>aftersales</td>
<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
</tr>
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</table>

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Appendix D:

Background information with regard to the visit to Japan. It includes a list of the organisation consulted and the timetable of visits.

Organisations Consulted

Sekisui House
Panahome (National House Industrial)
Mitsui Homes
CAD Center
Unisys Japan
Matsushita Electric Works (Panasonic)
Nippon VR Center
Mitsubishi Construction
Daiwa House Co. Ltd
Onuma & Associates
Kajima Corporation
Building Center of Japan
Shin-ichi Takemura
British Embassy
### Timetable of Visits

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Activity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friday</td>
<td>11th June</td>
<td>9.00am - arrive Tokyo</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.00pm - meet Professor Seiichi Fukao</td>
<td>TOKYO</td>
</tr>
<tr>
<td>Saturday</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday</td>
<td>13</td>
<td>10.30am - visit Sekisui House</td>
<td>OSAKA</td>
</tr>
<tr>
<td>Monday</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td>15</td>
<td>1.00pm – visit Panahome</td>
<td>OSAKA</td>
</tr>
<tr>
<td>Wednesday</td>
<td>16</td>
<td>1.00pm – visit Matsushita Electric Works</td>
<td>OSAKA</td>
</tr>
<tr>
<td>Thursday</td>
<td>17</td>
<td>1.00pm – visit Nippon VR Centre</td>
<td>GIFU</td>
</tr>
<tr>
<td>Friday</td>
<td>18</td>
<td>Industrial VR Show and Conference</td>
<td>TOKYO</td>
</tr>
<tr>
<td>Saturday</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>21</td>
<td>2.00pm – visit CAD Center</td>
<td>TOKYO</td>
</tr>
<tr>
<td>Tuesday</td>
<td>22</td>
<td>10.00am – visit Mitsui Homes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.00pm – meet Paul Lynch, British Embassy</td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td>23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td>24</td>
<td>10.00am – meet Professor Matsumura</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.00pm – visit Unisys Japan</td>
<td></td>
</tr>
<tr>
<td>Friday</td>
<td>25</td>
<td>visit Showhouses / Toyota showroom</td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday</td>
<td>27</td>
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<td></td>
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<tr>
<td>Monday</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td>29</td>
<td>11.00am – leave</td>
<td>Japan</td>
</tr>
</tbody>
</table>
Appendix E:

This appendix contains a complete publication list and selected publications:

Journals


Conferences


Paper:

From CAD to virtual reality: modelling approaches, data exchange and interactive 3D building design tools

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Accepted 30 April 1999

Abstract

Virtual reality has the potential to improve visualisation of building design and construction, but its implementation in the industry has yet to reach maturity. Present day translation of building data to virtual reality is often unidirectional and unsatisfactory. Three different approaches to the creation of models are identified and described in this paper. Consideration is given to the potential of both advances in computer-aided design and the emerging standards for data exchange to facilitate an integrated use of virtual reality. Commonalities and differences between computer-aided design and virtual reality packages are reviewed, and trials of current systems are described. The trials have been conducted to explore the technical issues related to the integrated use of CAD and virtual environments within the house building sector of the construction industry and to investigate the practical use of the new technology. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Virtual reality; CAD; Data exchange; 3D modelling; Visualisation

1. Introduction

Virtual reality (VR) has been used within the construction industry for design applications, for collaborative visualisation and as a tool to improve construction processes [9], but it is currently implemented in an ad hoc fashion [4]. At Loughborough University, the effective implementation of PC-based VR systems in the industry is being researched. A number of VR systems, including Superscape, VRML and World Tool Kit, have been tested to assess their suitability for integrated use in the house building sector of the construction industry.

VR forms a natural medium for building design as it provides 3D visualization, can be manipulated in real-time and can be used collaboratively to explore different stages of the construction process. In the future, it may be possible to generate and print 2D CAD drawings directly from the VR models that are being used for architectural design. However, in order for the use of VR to mature to such a level, the integration of its use with existing technologies such as CAD needs to become the focus of research [39], and appropriate standards and protocols need to be developed.

Although it is already possible to create VR models from within VR packages, for the use of VR in
construction industry, the transfer of geometrical data between CAD and VR is desirable to avoid repetitive work [2,10]. The trials undertaken by the authors have posed the question of how to transfer data from traditional CAD systems into VR, and have also assessed the suitability of different approaches to the creation of VR models for different situations.

After a description of the three different modelling approaches identified in the literature, the related technical issues of data exchange, VR systems and 3D graphical standards are explored. The trials of VR systems conducted at Loughborough University are then described.

2. Data translation and practical modelling approaches

2.1. Data translation from CAD to VR

The current process of translation from CAD into VR is normally a one-way or "downstream" process (Fig. 1). The CAD model is translated into VR, either directly, or through the intermediate stage of a rendering package. To facilitate the translation process, data on the CAD drawing is often reordered, usually in non-industry standard ways, to control features of the resultant VR model. The user relies on previous experience and prior knowledge of the translator and VR system to create a satisfactory model. Bourdakis [10] notes that there is a trade-off between the amount of time spent reordering the CAD model to suit the translator and the time spent optimising the resultant VR model and "It is normal to spend a few hours or even days, hand-optimising the translated file." [11].

Complex and highly detailed CAD data, common in the construction industry, translate into excessively large VR models, but the computational time required to run these must not slow user movement to an unacceptable level. Optimisation to allow real-time viewing is achieved by reducing the information to be processed and hence reducing the computational effort required during each simulation loop.

Three different approaches to the creation of VR models have been identified in commercial applications and VR research projects [39]; these are to build a library of standard parts, to rely on imperfect model conversion through translators, and to use VR as an interface to a central database.

2.2. A library-based approach

A library-based approach, where a library of components is archived for reuse within the VR environment (Fig. 2a), eliminates the need for repetitive data transfer and optimisation of common parts. Significant time and effort is initially required to build up the library, and the library components can be created from CAD data that has been optimised and had behaviours added.

Adeji-Kumi and Retik [1] and Retik [30] have taken this approach for research into the simulation of the construction sequence. As in the work of Op den Bosch and Baker [29], the interest is in the representation of construction activities. Direct translation of a whole model from CAD is inefficient as an item is simply a geometric description in CAD
and does not have associated information relating it to its construction processes. Instead a library of virtual elements is employed [30] to save and reuse information about both the geometrical nature of building components and the related processes. The time taken to create the library is compensated by the reuse of information about the complicated sequences of events.

A library of standard VR components has also been used in a networked system [32] to investigate the potential archival of manufacturers VR models of standard parts. It was proposed that each manufacturer would upload the latest versions of their products and these models could be used directly by building designers in their projects.

2.3. A straightforward translation approach

Complete CAD models can be used to generate VR models by straightforward translation of the whole model, sometimes in conjunction with algorithms for optimisation. A translation approach (Fig. 2b) has been used in research projects where there are few repeated elements, geometric data predominates and there are few activities associated with it, or the design process is completed and the design is fixed and unchanging [39]. Translation and optimisation can be used for the generation of highly rendered or optimised models for presentation to clients.

CAD models of entire cities that were created as student group projects have since been translated into VR urban models at Bath [11,16] and at Strathclyde, although extensive reorganisation and optimisation has been necessary to obtain suitable frame rates in such large VR models.

2.4. A database approach

A database approach to VR model creation utilises a central database to control component characteristics and both CAD and VR are used as graphical interfaces to that database [25]. The building model is created in the central database and viewed through the different applications [20], one of which is the VR package (Fig. 2c). A full implementation of such a system would allow updating of the model in both CAD and VR. Thus a two-way data exchange would be effected as opposed to unidirectional or downstream data transfer.

Whilst a database is used for internal organisation and for search and retrieval of information within the urban model of Los Angeles [25], the link between CAD and VR is not dynamic, and there is no central building model that can be viewed in both CAD and VR. Virtual Los Angeles has instead been created by the translation of models created in the MultiGen modeller and using GIS data.

A database approach has not been implemented commercially, but the Open Systems for Construction (OSCON) research project at Salford University uses case studies from real-life construction projects to demonstrate its usefulness [5]. This project, which builds on the earlier ICON project [14], has core modules that include process management, planning, CAD, estimating and VR. Thus, VR operates as the user interface for interrogation of an integrated project database. Whilst the OSCON project could not currently be used for real-time viewing and presentation of large complex building or urban models, it demonstrates the potential of such an approach to VR utilisation.
3. Data exchange issues

3.1. Formats for data exchange

The de facto standards for file transfer between different CAD packages, and between CAD and other design software are the DXF file format, developed by Autodesk, and more recently the native AutoCAD DWG format. Though such standards have often been more successful than the attempts to develop formal standards [35], their proprietary nature has been problematic, leading to incompatibility with different vendors' software, and with different versions.

The development of neutral formats for the exchange of CAD data first started in the 1960s with the Initial Graphics Exchange System (IGES) and out of this research the Standard for Exchange of Product model data (STEP) was developed [8]. STEP is the formal international standard adopted by the International Standards Organisation (ISO) and is concerned with defining product data, some of which is geometry. The pan-industry approach taken in STEP contrasts with the approach taken by a separate initiative, the International Alliance for Interoperability (IAI) to which STEP has made available technologies which support Computer Integrated Construction (CIC) [24].

There is an increasing awareness of the necessity of convincing industry of the business benefits [42] of standardisation initiatives. Founded in 1994 by a group of 12 companies in the US, the IAI is an industry driven standardisation initiative that is developing the Industry Foundation Classes (IFCs). These are a common set of intelligent building design objects that will enable the sharing of information at all stages of the construction process.

There is a need for standards that are straightforward in use and terminology [43]. Standardisation initiatives can become too large and unwieldy to be implemented, or too restrictive. Standard data exchange formats and methods would greatly help the development of protocols for the transfer of construction industry data to VR, but for this the standards would need to support the addition of behavioural information such as the opening and closing of a door.

3.2. Commonalities and differences between CAD and VR

Whilst 3D CAD has evolved from primitive 2D drafting packages that treated lines as simple graphical entities, VR has developed out of advanced work on flight simulators and computer graphics [6]. The construction industry user has not been active in the development of VR, and the computer graphics conventions, used in VR packages, are unfamiliar and often different from established CAD conventions. An example of such a difference is the right-hand coordinate system used in VR, which is different from the established CAD world-base coordinate system. Concepts such as levels of detail (LODs) are also used differently in CAD and VR. Architects have a concept of LOD based on the paper scaled representation of real space (1:5000, 1:1250, 1:500, etc.) rather than the visualisation of varying LODs at the same time. The specification of many values, such as colours and translations numerically (as RGB values, or quaternions), rather than graphically is not familiar to the user of the Windows graphic user interface (GUI) of the modern CAD environment.

Other differences between the packages, such as the hierarchical structure of VR packages, and the lack of a modelling kernel arise from the need to optimise VR models for real-time viewing. Differences such as the use of graphic primitives for modelling and the lack of sophisticated modelling aids such as layers, snap controls, and high precision detailed rulers to ensure the accurate placement of geometry allow for real-time viewing but make VR a less suitable environment for modelling in.

Whilst not themselves truly object-oriented, PC based VR systems use a scene graph to organise worlds hierarchically [44]. This is done as trees of different geometries, each of which inherit the translations and orientations of their parents and pass on their own translation and orientation to their children. Such an explicit hierarchical structure is not currently used by the traditional CAD packages widespread in industry, hence the translation of data from CAD to VR formats requires a fundamental restructuring of the data.

There are no standard methods for the translation of building data from CAD into VR. VR packages are generic in nature, and do not offer in-built sup-
port for complex domain-specific industrial information. Researchers have developed their own project-specific techniques for the translation of construction data to CAD and the structuring of construction data within VR. As the use of VR for design has not been widely researched, assessment of any particular system difficult [36] and standard methods for the management of architectural data in VR-based design systems have not yet been established.

3.3. Optimisation of translated VR models

Optimisation can be used with any of the modelling approaches described above. Techniques used to optimise models, though commonly used by both game developers and the VR community, are alien to the CAD environment with which the building professional is familiar [39]. Optimisation involves the reduction of the number of polygons to be processed in the VR model and it is done to increase performance, by increasing the frame rate and speed of reaction to user input. This can be achieved by simplifying the model, but such simplifications can be inappropriate and difficult to automate for the representation of building and construction data [22]. Optimisation requires a trade-off between speed on the one hand, and graphics quality and accuracy on the other, and can be achieved using the following techniques.

- The use of primitive solids — simple objects, such as spheres, cubes and cylinders, together with texture maps can simplify the amount of geometric data in a model.

- Distant dependant LODs — simpler geometry can be used to replace complex geometry at a sufficient distance from the viewpoint for the eye not to perceive the loss of detail. Techniques for the substitution of images, or imposters, for distant geometry are also being investigated [17,24].

- Selective loading — visibility sensors determine which part of the model is being viewed and therefore which geometry needs to be loaded and rendered and which behaviour scripts need to be active [31].

The rapid production of VR models of construction projects is hampered by the lack of standard protocols for the translation of data from CAD and the optimisation of the VR model. The unidirectional nature of the data flow from CAD to VR and the time taken for data translation and optimisation limit the effective utilisation of VR in the iterative design and construction process.

3.4. Interactive 3D building design tools of the future

Future CAD systems may use standard methods for describing building data, be semantically richer and based on the object-oriented paradigm. They could be based around intelligent building design objects that encapsulate both data structures and methods [18] and inherit properties from more generic objects.

Advanced 3D visualisation techniques, such as wireframe, solid modelling and quicktime VR are available in many contemporary CAD packages, as is the ability to export to 3D formats such as VRML.

Some VR capabilities are likely to be incorporated in the next generation of CAD tools. The 3D model may be used in the design process, with 2D views and sections being generated dynamically from it using sectioning tools. An early design package Sculptor [21], has been developed in which the architectural design is supported in the VR environment. Research is also ongoing into tools that simulate the construction process [26] within the CAD environment, using the spatial dimensions XYZ and time.

Thus many VR techniques can be incorporated into future building design tools for rapid prototyping of design, and the simulation of construction processes. VR packages will continue to be used within the AEC industries, when optimisation techniques are required to attain high frame rates, or when support is required for hardware devices.

4. VR systems and 3D graphics standards

VR systems range from a simple set up on a desktop PC, to high-end VR labs using silicon graphics (SGI) computers with additional hardware for stereoscopic vision and auditory and haptic feedback. Whilst the computational power available has an impact on the potential for achieving real-time viewing of complex data sets, the principles of modelling.
described in Section 3, are the same in both low
level and high level systems.

4.1. 3D APIs — Open GL and Direct 3D

VR packages are built on graphic Application
Programming Interfaces (APIs) that provide low-level
procedural models for 3D graphics.

At present many VR systems are built on the
Open Graphics Library (Open GL) or Microsoft's
Direct 3D. Open GL is a non-proprietary standard
API, the creation of which was initiated by SGI in
1992. Unlike Direct 3D, which is limited to the PC
platform, it is cross platform, and has been important
in the development of many high-end and commer-
cial VR systems. Such a low level API offers a way
to render a simple set of graphics primitives such as
points, lines and polygons, but further APIs are
needed to build on this and offer a greater level of
abstraction, and scene management functionality.

SGI's Iris Performer and Open Inventor APIs build
on Open GL, and are often used to provide further
functionality allowing the programmer to concentrate
on world creation. They have been utilised directly,
as well as indirectly, in building research. Iris Per-
former was designed for high-end visual simulation
on SGI computers and can support fixed frame rates.
It has been used for interactive visualisation of large
architectural models [22,25]. Open Inventor was de-
dsigned to be more general purpose than Iris Per-
former and is portable to non-SGI systems. It has
been used in building research projects, for direct
manipulation of designs within virtual environments
[41], and for design review [27].

4.2. VRML and 3D web technologies

Virtual Reality Modelling Language (VRML),
which in its first version was based on a subset of
Open Inventor, is now the international standard for
3D modelling (VRML '97 — ISO/IEC 14772) [37].
CAD packages, modelling applications, and propri-
etary VR applications export directly to it, and VRML
models can be viewed, either locally or distributed
across the Internet, through a plug-in in a web
browser such as Netscape or Internet Explorer.

Building research projects using VRML include
libraries of product data information [28], the VR
interface to an integrated project database [5], and
large-scale urban models [10,15] as well as a mul-
ti-user design environment [27].

4.3. Proprietary PC-based VR systems

As well as the standard for 3D modelling, VRML,
there are many commercial PC based VR packages
which contain in-built modelling environments for
world creation, and libraries of routines for the addi-
tion of behaviours. They are based on APIs such as
Open GL, and Direct 3D but offer some higher level
abstraction. Among the leading commercial VR
packages now available on the PC are Superscape,
WTK and Division.

Superscape is one of the early PC based VR
packages (originally running in DOS on a 386 pro-
cessor) and in the version used (VRT 4.0) in this
research, it was found to be difficult to import
large-scale 3D models from CAD into Superscape.
Building research which uses the Superscape soft-
ware includes construction scheduling in which a
library of standard parts are built up within the VR
environment [30].

WTK is a set of C functions with which cus-
tomised VR applications can be written. Applications
written with WTK can read AutoCAD's dxf files,
3DStudio's 3ds and VRML wrl files directly, as well
as reading and writing to WTK's own native ASCII
text based format, called neutral file format nff. It
has been used for building research by the Japanese
company, Matsushita Electric Works, in their Kitchen
Planning Support System (KiPs) [3,3], by the VR-DIS
design application developed at Eindhoven Univer-
sity [12] and in the ICON integrated building database
project D1.

One of the advantages of such a system is that
software development and VR model creation can be
separated into distinct activities, undertaken by sepa-
rate specialists, and that the software can be highly
customised to the specific task required by the con-
struction industry user.

The Division package is a family of product
simulation tools. It is one of the early VR packages
and, though it was not originally developed on the
PC platform, it has also been used in building re-
search projects and for engineering applications [18].
5. Trials of current VR systems

Trials were conducted to investigate the practical modelling approaches discussed above and further explore some of the technical issues.

5.1. Specific modelling requirements

The work is focused on the implementation of VR in the house building industry. Before the trials commenced, an in-depth interview was conducted with a housing developer to determine the nature of the house building process and the requirements for the VR model. Discussion established that house types were designed in the central office, and then sent to the regional offices where they were used on site layouts. The house building industry is standardised to an extent common in the manufacturing industries [23], and the number of standard house types used by any particular housing developer is relatively low. Unlike the rest of the AEC industry, house building is not concerned with one-off construction but has a semi-standardised and repeatable end product.

Work was undertaken to trial different modelling approaches and VR systems for their suitability in house building. The investigation of appropriate methods for an integrated use of VR as a design tool within the house building process benefited from the input from various regional and national housing developers who commented on the different models created.

5.2. Hardware and software used

This research was undertaken using computers similar to those found in industry today rather than a highly specialised academic VR research laboratory. The computers used are a 32 Mb RAM 133 MHz Pentium PC with a 4 Mb Matrox Millennium graphics card and a 128 Mb RAM 300 MHz Pentium II PC with a 8 Mb VRAM / 32 Mb DRAM Diamond Fire GL 3000 graphics card, and a 6 degrees of freedom Magellan Space Mouse.

Industry standard design tools such as AutoCAD and 3D Studio VIZ were used for model creation, and the PC based VR Systems used in the trials were VRML, Superscape and World Tool Kit. Cosmo-Player was the browser plug-in used to view the VRML models, in both the Netscape and Internet Explorer browsers, and VRealm Builder and Notepad were used to assemble and edit VRML models.

6. Models created in the trials

6.1. Library of standard house types for site layout appraisal

In the first VR trial [39,40], using the Superscape VR system, a library-based approach was taken towards modelling. After consultation with a leading UK housing developer, it was agreed that a library of house types, with their associated LODs and optimisations could be built up in VR.

The rationale behind the use of this approach was that, in a practical setting, a library of house type models could be built in the central office and sent out to the regions. In the regions this library could then be used for the rapid generation of detailed site layouts.

In the trial, 2D AutoCAD data was obtained from the housing developer. Attempts to build a 3D model in AutoCAD and then transfer this to Superscape met with only limited success. As the 3D data transfer was unsatisfactory, the 2D plan data was transferred to Superscape, and the 3D virtual model was assembled inside the package from the 2D AutoCAD data and the parts of 3D model successfully transferred. It was found that the translator was inaccurate and dimensions of the resultant model had to be checked.

The final model created was highly detailed and then it was instanced and simplified to create two other LODs. These could be substituted for the detailed model when the house type was at such a distance that the eye could not see the detail. Thus a sophisticated virtual model of a standard house type was created in VR from AutoCAD data.

This model of a standard house type was placed in different locations in a housing layout (Fig. 3) to demonstrate the potential use of a library of house types.

In this trial it was found that the data transfer between CAD and the VR package used was extremely cumbersome. The creation of the VR models
of the standard house types was time consuming. Although the library approach eliminates repetitive data transfer by reducing the amount of translation required, this early work led to the consideration of the potential of standard 3D formats such as VRML and the possible development of standards and protocols for data transfer to them.

6.2. Library of standard house type in VRML

Building on experience gained in the first trial, the second model also used the library based approach to model creation, but was built from CAD data of the house type that was translated into the VRML and assembled in an authoring tool (Fig. 4). First 3D models of the house types were created in CAD. These were taken into 3D Studio VIZ and then translated into VRML, using the in-built translator in the 3D Studio VIZ package. The site layout data, which in this trial was 2d, was also translated from CAD to VRML, via the in-built translator in the 3D Studio VIZ package.

The facilities for data transfer were much better but VRML was not very efficient at supporting complex geometry at near real-time speeds.

Using a VRML authoring tool, VRBuilder, the house type models could be duplicated and placed onto the site model. Various different house type models were produced, but difficulty was experienced with the accurate placement and movement of different models in the VRML world.

The VRML standard format was used for this model so that it can be accessed from any computer with a VRML browser plug-in installed. After viewing the model in the CosmoPlayer browser plug-in, some changes were made to the VRML code in Notepad. An applet was used to give the current
coordinates of the viewpoint, and this was found to be of great use for the setting up of cameras etc., but the VR environment was view only, and had insufficient support for sophisticated interactive manipulation of the data.

This model does however demonstrate the potential for VR models to be accessed through a browser, either remotely, or on the local computer. Technical data or photographic marketing images can be displayed when the user enquires about relevant parts of the housing scheme from within the virtual environment using hotspots. In this trial, this was achieved by creating HTML pages, to display the model in a HTML frame, and editing the VRML code, to add hyperlinks from the VRML house type models to further information which would display in another frame of the browser.

6.3. Straight-forward translation from CAD into VRML

In a further trial, a 3D model of a housing development was created in VRML [38,40], and then displayed in a web browser (Fig. 5). This was undertaken to further demonstrate the potential of 3D web technologies, such as VRML, to housing developers and other construction professionals. Because of the difficulty experienced in assembling models in VRML, and the need to create the model rapidly, a straightforward translation approach was taken with a simplified model. The model was built in 3D in the AutoCAD environment and then exported to 3D Studio VIZ, where it was structured hierarchically and further edited before being translated into VRML.

The VRML site model is not as refined as the initial house type models. It is a massing model, which just shows the general layout of the site.

House types were not modelled in detail, and a library of house types was not used, as excess detail would increase difficulties of bandwidth and hinder the attainment of real-time viewing.

6.4. Standard house types in a site layout

In the creation of later models the World Tool Kit software has been used (Fig. 6), and modelling approaches have been chosen to suit the different modelling tasks within the model. Housing layouts have been created by the substitution of detailed house type models, from a library of house types, into a simple model of the site that had been translated and filtered. As WTK can import models in VRML,
Fig. 6. 3D Studio models were created from 3D CAD models and were viewed in WTK, where they were positioned on the VRML site layout.

DXF and 3DS file formats, as well as the native NFF, modelling work undertaken for previous models has been reused. The simplified VRML model described in Section 6.3 has been taken into the WTK and then the 3D Studio models of house types described in Section 6.2 have been added to the model. The advantages of the library approach and the straightforward translation approach are combined.

7. Discussion of the different approaches

The library-based approach was found to be particularly suitable for this application of VR. Rapid generation of VR models is needed for the evaluation of site layout by housing developers during the design stage. The translation of all the house types with every site model would involve significant repetitive work and would increase the time required to produce the VR models. Archiving VR models of the standard house types allows users to rapidly generate detailed site layout models for use in discussions within the company and for presentation in planning proposals, without the need for repeated data translation. Additional information about standard house types, such as technical data or photographic marketing images, can be added to the VR models of standard house types in the library. This information can then be displayed when the user enquires about particular houses from within the virtual model of a specific housing development. A library of house types could be maintained by the central office of a housing developer and sent out to the regional offices for use in site layout design.

Straightforward translation was appropriate for the creation of a single model, for display over the Internet, or at the marketing stage, when the site layout design is fixed. For the use of VR during design and evaluation of housing developments, site data could be transferred from CAD to VR on a one-off basis and then the library-based approach could be used to add more detailed 3D models of standard house types.

A database approach would allow changes in VR to be seen in CAD, but would need to be sophisticated to allow the required optimisations and LODs...
to be associated with individual house types. The implementation of the database approach would require the creation of a central database for the building model using a neutral format accessible by both CAD and VR systems. This concept has been demonstrated through projects such as ATLAS [6], CIMsteel [12] and OSCON [5], however development of such scale is beyond the scope of the work presented in this paper. On the other hand, the models based on this concept required by software implementers in order to develop the software which would facilitate the process are not yet available.

8. Conclusions

Construction industry professionals, though potential users of advanced 3D technologies, have had little impact on the development of VR technology. This evolved from concepts laid out by computer graphics programmers developing flight simulators and military applications where the attainment of realistic real-time interaction is critical. Optimisation of VR models, through the use of primitive solids, distant dependent LODs, and selective loading, shows their concern with navigation of realistic environments rather than the accurate but interactive portrayal of geometric and architectural information.

Toolkits for the creation of VR environments, such as SGI's Iris Performer and Open Inventor, have been important in the development of VR, and have been used in building research projects. A subset of Open Inventor formed the basis for the first version of the Virtual Reality Modelling Language (VRML 1.0). This was designed as a file format for the interactive exploration of 3D models on the Internet and has now become the formal ISO standard for 3D modelling (VRML '97). VRML has made VR techniques more widely available, thus impacting low end PC-based VR, modelling and CAD packages, which now export to this format.

Whilst many VR techniques can be incorporated into future building design tools for rapid prototyping of design, VR packages will continue to be used within the AEC industries, when optimisation techniques are required to attain high frame rates, or to provide support for hardware devices.

VR is currently used in the construction industry and building related research for design applications, collaborative visualisation and as a tool to improve construction processes. In the future the use of VR techniques will mature, as some techniques are incorporated into interactive 3D building design tools. The translation of building data to specialist VR packages will be facilitated by the increased similarity in the structure of the packages and the adoption of formal standards for data organisation such as IFCs and 3D formats such as VRML.

Three different practical modelling approaches for VR applications have been reviewed as part of the work presented in this paper: the library-based, straightforward translation and database approaches. These were explored within the context of house building highlighting the potential use of the new technologies in different practical situations within this sector of the industry. It was found that different modelling approaches were more appropriate for different tasks.

- A library-based approach is useful when straightforward data transfer is cumbersome, when complicated activities or extensive attributes are associated with the sets of geometric data, and when standard parts are frequently used.
- A straightforward translation approach is more suitable when geometric data predominates and there are few activities associated with the data. It can also be used when the design process is completed and the design is fixed and unchanging.
- A database approach can be used for rapid prototyping, where a central database controls component characteristics and both CAD and VR are used as graphical interfaces to that database.

These trials show the potential of PC-based VR systems to facilitate visualisation of building models. The use of library-based approach was time consuming at the outset but offered the possibility of rapidly producing models with a high level of detail. This also demonstrated that such a system could be used by housing developers to produce alternative housing layouts for discussions within the company and for presentation in planning proposals.

A straight translation offered a faster option for producing the initial VR site layout model and could be used for the creation of a single VR model.

A database approach to VR model creation, though not commercially available today, may arise out of developments within the CAD and VR communities.
References


Paper:

A survey of CAD and virtual reality within the house building industry

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Abstract A survey of computer use in the British house building industry was conducted by means of a postal questionnaire to 100 house builders followed-up by in-depth interviews. The research shows widely variant levels of computer use and expertise in different house building companies amongst both regional developers and the nationwide volume builders. Some housing developers have sophisticated information technology strategies and are well placed to successfully implement advanced techniques whilst many have very little or no computer use for design and visualization and rely more on traditional competitive strategies.

Keywords CAD, design process, house building, industry survey, IT strategy, visualization

INTRODUCTION

The work described here forms an early part of a research project on the use of virtual reality (VR) within the British house building sector for the design and evaluation of new residential development. In this paper, the characteristics of current computer use are investigated through the presentation of the results of a recent survey. The extent and nature of the use of CAD software, 3-D modelling and visualization, and general computing and network strategies are considered. To gain an overall picture of the opportunities for implementing VR in house building companies, an investigation has also been conducted into practitioners' attitudes towards IT and their current IT use to support design processes.

The hypothesis, suggested by Freeman (1998), that larger British housing developers will adopt an IT base using advanced computer techniques to improve their competitive edge whilst regional housing developers will continue to operate on a traditional land-oriented model is tested. The survey confirmed the latter part of the hypothesis but did not show a significant correlation between the size of house building firms and the level of uptake of IT.

The British house building industry

The private housing developer in Britain is responsible for all stages of the house building process, from land acquisition to estate and house design, production and marketing. The process is speculative, with houses built in anticipation of demand and then marketed to prospective clients.

Though there are many companies registered with the National House Building Council (NHBC) in Britain, most of these build infrequently, and it is a few large companies that dominate the market. It can be seen from Table 1 that there were 17,620 builders on the NHBC register in 1997, but the majority of these built no houses at all during that year. By focusing on the top 100 housing developers, the survey presented here encompassed both the mid-sized regional house builders building a few hundred houses and the larger nationwide volume builders, but small and occasional builders were not considered. The housing developers included in the survey build the large majority of new houses in the UK, with the top 25 alone producing 55% of the total output of new houses (NHBC 1997).

The regional house builder uses local expertise to compete within one area of the country and operates a co-ordinating office that undertakes all in-house design work and consultation with planners, and on-site sales offices. The large nationwide volume builder would typically have a central office in which most of the standard house type design work is undertaken and regional offices that co-ordinate sites in their area (Gillen 1994). The regional offices, which in some volume builders have a large degree of autonomy, are also involved in site layout design, design of variations on standard house types, consultation with local planning officers and liaison with the on-site sales offices that market the finished products.

Many, but not all, of the nationwide volume builders are subsidiaries of national or international general contracting and construction consortia and they may retain some links with their parent companies.
Table 1 Number of house builders in different size categories, from those registered with the NHBC in 1997*

<table>
<thead>
<tr>
<th>No. of units</th>
<th>0-1</th>
<th>1-10</th>
<th>11-30</th>
<th>31-100</th>
<th>101-500</th>
<th>501-2000</th>
<th>&gt;2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of house builders</td>
<td>11320</td>
<td>5199</td>
<td>677</td>
<td>291</td>
<td>21</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

Source: Private House Building Statistics, NHBC.
* To accurately portray the overall distribution across different ranges, this represents the number of companies (range as a percentage) x 10.

Innovation in house building

British housing developers with land-oriented competitive strategies have been reluctant to invest in innovation and house design. The quality of house building compares unfavourably with that in countries such as Japan and Holland, where market conditions allow more innovative approaches to housing. A recent government report, *Rethinking Construction* (Egan 1998), devotes a chapter to improving house building.

Lower rates of inflation and a tighter planning and legislative environment than before (Asibong & Barlow 1997) mean that land-oriented strategies may be increasingly inappropriate and may lead some house builders to experiment with new building techniques (Gann & Senker 1993; Asibong & Barlow 1997).

A company’s computer strategy can operate as a facilitator (or inhibitor) of change in internal firm organization and operational procedures and there is a need for IT/process co-maturation (Aouad et al. 1998). Thus, the quality of computing strategies may facilitate or frustrate attempts to improve house building processes.

IT use in house building

There is almost no data relating to the development of IT strategies across the British house building industry during the 1990s, making extrapolation of future IT usage from secondary sources difficult. Previous work that has been done in the late 1980s and early 1990s is mainly in the functional areas of estimating and cost control (Skilton & McCaffery 1984; Ewin et al. 1990; Thorpe 1992), rather than computer use for design and visualization.

From this work, a picture of the fragmented and exploratory nature of IT use within the sector in the late 1980s can be drawn, and the following points are noted:

- House building companies generally lacked formal explicit strategies with respect to computers and information management (Thorpe 1992).
- The house building industry had received little attention from software developers (Ewin et al. 1990).

Recently, there has been research on a particular case of more advanced computer use for design at Westbury Homes in the late 1980s and early 1990s (Counsell 1998), but no industry wide data exists. In the late 1980s, this speculative house builder set up a CAD research department. Three-dimensional models were used in order to maximize the competitive advantage through visualization (Day 1997) and since 1989, some advanced work was done on the use of component library delivery and management (Counsell 1998).

**SURVEY METHODOLOGY**

The survey investigated the IT systems used for product design, development, modelling and sales in the British house building industry. It took the form of a postal questionnaire to 100 major British house builders, followed by in-depth interviews with 10 of these housing developers, a software developer and local planner.

Postal questionnaires

The postal questionnaire covered use of CAD, 3-D modelling and visualization software, and general computing and network strategies. After piloting and refinement, the questionnaire was sent out to the CAD managers of the top 100 house building firms, as identified by the market report, *Housebuilders—Major* (Business Ratio Plus 1997). After a second mail shot, and subsequent telephone follow-up, 42 completed questionnaires were obtained and formed the basis of the data analysed and presented in this paper.

In-depth interviews

The postal survey was followed up by more in-depth interviews with 10 housing developers. These semi-structured interviews were used to provide information about the business context for IT strategies within...
A survey of CAD and virtual reality within the house building industry

Figure 1 Percentage of design work done using CAD in the British housing development industry. * To accurately portray the overall distribution across different ranges, this represents the number of companies (range (as a percentage) X 10).

RESULTS

For clarity, the results are broken down into the areas that were addressed in the questionnaire and interview recording covering: current use of CAD software, 3-D modelling and visualization, and general computing and network strategies.

Current use of CAD software

Proportion of CAD use for design

Responses to the question "How much design work is done using CAD (as opposed to manual drafting)?" ranged right across the spectrum. More than one-fifth of the housing developers in the survey had over 90% CAD use for design (Fig. 1), however, no significant correlation was found between the extent of CAD use and macro-indicators such as turnover or the number of units built.

The questionnaire results showed that the general tendency was to either use manual drafting with a small proportion of CAD (or no CAD) or to computerise the majority of design work. In numerical terms, this meant that most of the respondents had either below 10% or over 90% CAD use in their companies.

Follow-up interviews revealed that some of the regional developers with little or no CAD use did little design work in-house, relying on external architects to design new house types and provide drawings.

One of the top housing developers, building more than 5000 houses a year, returned a questionnaire claiming to have no in-house CAD. However, a follow-up to the questionnaire showed that some CAD was used in one of the regional offices as a drafting tool but the developer in question had no plans in investing in visualization systems. This company did not feel that acquisition of CAD skills would add to their competitive advantage and the investment of time required to adequately acquire the new skills was seen as too great.
Basic CAD product used

Of the questionnaire respondents using CAD, 65% used AutoCAD, whilst 25% used Microstation and only a small percentage used other systems such as StarCAD (Fig. 2). Although other packages were mentioned, most of these were add-on packages such as MBA and Speedikon, which offer libraries of routines specific to the house design process, or Panterra, MOSS and PDS for road layout design, and which are not in themselves base CAD packages.

CAD training

CAD support and training is taken seriously by both housing developers and product vendors. The specialist CAD vendor interviewed aimed to undertake a solution sell rather than a product sell, as they recognized that the product they are introducing is a complex one. In the first few weeks, they undertake a review of current practice and business process within the client organization. They then identify and recommend solutions and demonstrate the different aspects of their product. After this stage, they lend the software to the company, but insist that they buy training for the software. The training can be for about 8–10 days over a 2–3 month period if the company has no previous experience of CAD, and the whole sales process can take between 6 months and 2 years.

It was found that many of the housing developers with a long experience of CAD have had significant difficulties with the implementation of earlier CAD systems and have had to alter and refine their CAD strategy in the light of this experience. The interviews showed that one of the housing developers, who had various experiences of CAD over the last 15 years, had only successfully implemented CAD across the company and seen the benefits in the last 3.5 years.

In those companies with longer experience of in-house CAD, there were also more established methods for training staff. For example, a large housing developer with 13 years CAD experience, building more than 4000 houses a year, has a dedicated training section in their IT department with an AutoCAD trainer in-house.

It can be postulated that the companies with a greater experience of CAD use in-house are able to attract the more experienced CAD operators who have a familiarity with the base product and are better able to train staff and push forward innovative computer use to increase their competitive edge. For large successful house building organizations with low IT and CAD use, the initial investment in staff training and equipment may not be worth the competitive advantage obtainable whilst competing with other companies who have many years of CAD experience.

![Graph showing CAD product usage in British housing development industries](image_url)
Many house building organizations are having difficulty implementing standard methods of working across the different branches of their own organizations, and the rigorous use of more global standards for organizing CAD data is not widespread. Housing developers find the use of the British Standard Layering system for CAD (BS 1192, part 5) too clumsy to implement for such a small and specialist design application. Two of the housing developers interviewed had implemented their own in-house layering system for organizing CAD data, each with less than 10 layers. The CAD manager from another housing developer stated that they tried introducing protocols for the use of CAD, but found this to be restrictive. Ultimately, they plan to have a standardized system but prefer the bottom-up approach, rather than it being imposed from above.

3-D modelling and visualization software

Use of 3-D modelling and visualization tools

When asked "In what areas do you feel that better 3-D modelling and visualization tools can help?", respondents rated marketing top out of the areas suggested, then house design and consultation with planners, before street layout design and consultation with clients (Fig. 3). In the follow-up interviews, it was found that there was a clear differentiation between the techniques perceived as useful for internal design discussion and those for external presentation.

Many housing developers use 3-D modelling systems in design work, as specialist CAD packages allow the user to work in 2-D and have a 3-D model built in the background. Constraints of manpower and time limit the extent to which 3-D modelling and visualization tools can be used. CAD managers expressed the desire to attain high levels of detail and felt that the 3-D nature of the modelling could be particularly useful for specific areas such as staircase design or for working out awkward details. However, detail was seen as less important for external presentation as housing developers tend to only want to give an overall impression of the development, leaving something to the imagination of planners and potential clients. Choreography of the presentation was important, as was a clear narrative structure. They wanted to create an overall representation without an in-depth discussion of insignificant particulars avoiding the inaccurate portrayal of detail that can lead to legal difficulties. Although concern was raised that computer presentations might be seen as too slick and technical, alienating some sectors of the community, the desire to use multimedia to seem up-to-date with the new technologies was considered as important. Some housing developers also use 3-D animations to supplement other material for planning consultation and for marketing.
Virtual reality

Just over half of the questionnaire respondents had previously seen a demonstration of VR in the construction industry, and 82% thought that it was potentially useful to their company. Seventy-six percent of respondents said that they thought it would take less than 5 years to see VR techniques used in their company (Fig. 4).

Marketing, followed by communication with planners and refining the design idea were seen as the areas in which VR techniques had the most to offer (Fig. 5). The communication of ideas to nondesigners, both outside the company and within, was seen as a major use of VR. Most interviewees said that designers could interpret the abstract 2-D plans and sections, which formed a kind of shorthand, and VR was of no direct benefit to them. However, they felt that VR could be useful for the presentation of design ideas externally and to allow input from nontechnical staff at the earlier design stages.

In-house, developers would want to allow staff total freedom to navigate a site. If accurate models can be produced at reasonable cost then VR could be useful for preprototyping house types. However, some of the housing developers interviewed felt that accuracy, down to if a light switch crosses the border tiles, was absolutely crucial, but the question was the amount of effort required to achieve it. One respondent thought that 3-D modelling should be introduced early in the design stage where VR, for example, could be used as an integral part of the conceptual design process, and the construction drawings could then be generated from the model.

a) to show the Proportion of the Respondents who had seen Demonstration of Virtual Reality techniques in the Construction Industry

For external presentation, housing developers were opposed to giving total freedom of movement to users when operating their computer generated walkthrough models. They preferred to limit what people see to valid human viewpoints for the purpose of preventing the exposure to sensitive angles, especially if these were using heights above that of a realistic eye level. Conversely, they also wanted to be able to provide bird's-eye views. Two housing developers said they would like to produce a video that could be taken home and viewed by perspective buyers. Selling from plan would be a big advantage that VR could offer.

One of the interviewees felt that VR and advanced visualization techniques must be used with care with Local Authorities, as there is the risk of it raising other issues.

General computing and network strategies

Company IT strategy

The IT department in most UK-based house building companies is larger than the central design department. In the case of one company interviewed, the IT department had just been increased fivefold in the preceding 2-3 months to 40 staff looking at the network and the automation of bills of quantities.

Although it was company policy to have a single IT strategy, it was found that amongst the larger housing developers, different regions had different, and sometimes incompatible, strategies for IT use in design. Regional CAD operators sometimes feel that the IT department in the central office lacks the hands-on experience of some CAD packages.
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The situation is not, however, homogenous, and it was found that the extent of CAD and general IT use did not correlate significantly with the size of the operation. The propensity to invest in IT seemed related to the overall business strategy and the company culture rather than macro-indicators such as turnover or units built. Some housing developers continue to have very low levels of IT use for design, whilst others undertake more than 90% of their design work on the computer. Whilst the results of this survey do show a polarization between those housing developers with a strong IT base and those without, they do not show the simple picture of volume builders embracing IT use, whilst smaller regional developers retain land-oriented strategies, as predicted by Freeman (1998).

Companies that are likely to move towards an early adoption of emerging technologies, such as VR, are those who:

- Have a coherent IT strategy and a strong IT base—invested in training staff to use CAD, visualization and modelling software and have an experience of what characteristics of computer software are important for house building design tasks.
- Have clear business objectives to be fulfilled through the use of VR—such as the involvement of a range of construction professionals and sales and marketing staff in the design process or facilitation of change in operational procedures.

Finally, this study clearly shows that most house builders are moving towards an increased use of IT in various sectors of their business. This is mainly driven by the widespread recognition of the potential of IT has in achieving innovation in house building which has been highlighted in the Egan report (Egan 1998). CAD and VR are an important component of this drive for innovation offering scope for improved quality and customer satisfaction through prototyping and feedback from sales and marketing teams.

Further investigation, in the form of longitudinal studies, should be undertaken to determine whether there is an increasing polarization between how developers with significant IT use and those with a smaller IT base think about and use IT.

Consideration

Figure 6 Considerations that respondents thought were important when choosing software.
REFERENCES


**Paper:**

THE PROMISE AND PROBLEMS OF IMPLEMENTING VIRTUAL REALITY IN CONSTRUCTION PRACTICE

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ABSTRACT

Virtual reality (VR) can be used as a powerful tool to extend the possibilities of visualising the built environment before construction.

This paper describes work conducted at Loughborough University in collaboration with a leading British housing developer, and highlights the need to balance the differing agendas of academic research and the competitive modern workplace. Through consultation with our industrial partner the potential of VR to contribute to design generation, consultation with planners and product marketing was identified. A prototype project raised important issues relating to the smooth transfer of VR techniques from research into practice in the building industry.

The major technological issue, addressed by this paper, is the inherently different structure of CAD and VR models. As CAD packages often determine the way in which three dimensional geometric data is stored in the building industry, the present differences between CAD and VR systems lead to both implementation and data transfer problems. Construction companies are inhibited from using virtual reality as the overlap between CAD and VR skills is insufficient, with building professionals remaining unfamiliar with VR concepts.

Transfer of data from CAD to VR systems is problematic. Three different strategies for overcoming this problem are described. These are: to build a library of standard parts within the VR system; to rely on imperfect model conversion from CAD to VR through translators; or to use VR and CAD as interfaces to a central database.

Advances in CAD technology and the emerging standards for data transfer will facilitate integration of CAD and VR data. Whilst our prototype project demonstrates the potential of Virtual Reality in practice, further work on improving the compatibility of CAD and VR systems is necessary before widespread industrial acceptance and commercial viability are attainable.

Keywords: Virtual Reality, CAD, VRML, design generation, product marketing, housing developer.

1. INTRODUCTION

In Britain, most new housing is built speculatively by private housing developers, using standard housetypes (Nicol, 1997). Research is taking place at Loughborough University into the use of desktop virtual reality (VR) to evaluate and improve the quality of new residential development.
The potential for housing developers to use VR in the design, consultation and marketing phases is being investigated. This paper discusses some of the practical considerations relating to the creation of VR models of buildings from CAD data, and describes a pilot project, undertaken in collaboration with a leading British housing developer.

2. VR MODELS AND CAD DATA

In the construction industry, geometric building data is stored in CAD systems, such as AutoCAD, and Microstation. Whilst it is possible to build up VR models from scratch within VR packages, it is widely agreed that transfer of the geometrical building data from CAD is desirable for applications of VR within the industry (Bourdakis, 1996; Alshawi, 1994). One reason that transfer of data is desirable is that it reduces the repetition of tasks in both CAD and VR. Another is that the tools provided for model creation in VR packages are not as sophisticated as those provided in CAD packages, as the production of construction and architectural models has not been the main objective of the programmers who have developed VR packages.

Differences between CAD and VR.

Whilst 3D CAD has evolved from primitive 2D design packages, VR has developed out of advanced work on flight simulators and computer graphics (Bertol, 1997) hence differences in CAD and VR systems are arise out of their different evolutions. The different nature of CAD and VR models, and the lack of overlap between CAD and VR skills can be seen as major barriers to the introduction of VR in the building industry.

Organisation of models

Most VR systems organise their worlds hierarchically, as a tree of different geometries, each of which inherit the translations and orientations of their parents and pass on their own translation and orientation to their children. Superscape and VRML are examples of VR packages structured in this way. Such an explicit hierarchical structure is not currently used by the traditional CAD packages widespread in industry.
Figure 2 Simple diagram showing the hierarchical structure of VRML, a desktop based VR modelling language. Transform nodes hold translation and orientation information.

Because CAD was originally developed as a 2D drafting package, X and Y are the default horizontal plane, with Z describing the vertical. However in VR, X and Z are the default horizontal plane with Y describing the vertical (Bourdakis, 1997).

Established versus emergent technology

CAD is an established technology: high functionality is achievable without resorting to scripting and programming languages, routines can be automated, and systems can be easily customised as there are many third party plug-ins and libraries of routines already in existence.

In contrast VR is an emergent technology and there is often a need to use programming languages to provide greater functionality. The necessity to interact with VR by programming or entering points and color values numerically is due to the evolution of VR out of work on simulators and advanced computer graphics. As VR authoring tools become more established and sophisticated, they may well develop more user-friendly interfaces.

Transfer of data from CAD to VR.

The current process of translation from CAD into VR is normally a one-off one way or “downstream” process. A CAD model is translated into VR, either directly, or through the intermediate stage of a rendering package. The resultant model is then optimised and behaviours are added.

Figure 3 The current process of translation from CAD to VR is a one way “downstream” process.
This process of translation requires an expert user as users often need to structure data on the CAD drawing by creating blocks and organising layers to facilitate the translation process. There is no recognised standard method for organising this data and translator specific optimisations are all too common, as are non-industry standard methods. There is a trade-off between the amount of time spent reordering the CAD model to suite the translator, and the amount of time optimising the resultant VR file (Bourdakis, 1997). Also the translation process often includes inefficiencies or, worse, wild inaccuracies.

The geometry of the VR model that the construction industry user creates from CAD data is likely to be complex, and the translation process itself often creates files that are unnecessarily large and ‘bloated’.

3. OPTIMISING PERFORMANCE

For PC based VR systems to allow a viewer to participate in complex 3D virtual environments in real time, optimisations must take place. The environment must be realistic and convincing, but the computation time required to run it must not slow user movement to an unacceptable level.

Techniques used to optimise are unnecessary within the CAD environment, with which building professionals are familiar. Their use requires a trade-off between speed on the one hand, and graphics quality and accuracy on the other. Common techniques, used by both games developers and the VR community are the simplification of geometrical data, the use of distance dependant levels of detail and selective loading.

Primative objects, such as spheres, cubes and cylinders; and tiled texture maps, are used to simplify the amount of geometric data in a model. This reduces the number of polygons and hence increasing the speed at which the world can react to user input. Such simplifications can be inappropriate to the representation of building and construction data, apart from the massing models used at the early design stage.

An alternative is to replace complex geometry with simpler geometry when it is far enough away from the viewpoint for the eye not to perceive the loss of detail. Multiple models are produced, and up to 10 levels of detail can be created to optimise the speed with which the user can experience the virtual environment. For complex buildings the generation of different levels of detail is difficult to automate (Funkhouser et al., 1996).

Visibility sensors can be used to determine which part of the model is being viewed and therefore which geometry needs to be loaded and rendered and which scripts need to be active (Roehl et al., 1997; Funkhouser et al., 1996).

Illegibility of VR files translated from CAD often increases the difficulty of optimising a VR model after translation. "It is normal to spend a few hours or even days, hand-optimising the translated file" (Bourdakis, 1997). If the original CAD file is subsequently changed, the processes of translation and optimisation will need to be repeated.

4. BUILDING VR MODELS

Three current strategies for building VR world are presented. These are to build a library of standard parts, to rely on imperfect model conversion through translators, and to use virtual
reality as an interface to a central database.

![Diagram showing A library-based approach, b) simple translation, c) a database approach.]

Figure 4 a) a library of standard parts b) simple translation and c) a central database approach.

**A library-based approach.**

A library-based approach is where a set of reusable components, for use within the VR environment, are generated. This approach has been used for construction sequence simulation (Adejei-Kumi, 1997; Retik, 1997) where much information is about processes rather than geometric objects, and research has been undertaken into its use in networked systems (Scott Howe, 1997) where the library of standard parts would come directly from manufacturers. This approach eliminates the need for repeated data transfer and file optimisation, but time is initially required to build up the library of parts. The components in the library can be built up from CAD data or modelled completely within the VR system. The approach is particularly successful when standard parts are frequently reused or when complicated activities, which cannot be represented in CAD, are associated with the sets of geometrical data.

**A straightforward translation approach.**

A straightforward translation approach is more appropriate when geometric data is predominant and there are fewer activities associated with the data. CAD is more refined as a 3D authoring tool and this approach is often taken for urban models (Bourdakis, 1996, 1997) and can be used in conjunction with algorithms for optimisation.

**A database approach.**

A database approach is where a central database controls component characteristics and both CAD and VR are used as graphical interfaces to that database (Aoaud, 1997; Alshawi, 1995). The building model is created in the central database and viewed through the CAD or VR applications. Thus a change made through either application, CAD or VR, changes the central building model in the database and is instantly viewable through other application. Whilst this approach allows the designer to make alterations quite easily, it does not allow for any optimisation of the VR model and therefore may be inappropriate for real-time viewing of larger complex building or urban models.

**5. APPLICATION OF VR TO HOUSEBUILDING**

In the work at Loughborough University, housebuilding has been taken as a case study for the application of virtual reality in construction. Residential development currently accounts for seventy percent of all urban land (Ball, 1996), and the demand for housing is growing. Therefore the ability to assess housing developments before construction is of great interest to urban
planners and housebuilders as well as to potential customers.

After initial discussion with the housing developer it was agreed that the project would investigate the use of VR for design generation, consultation with planners and product marketing. Design is an iterative process and the use of VR for design generation will necessitate either some upstream translation process, or the repeated translation of CAD into VR. For design generation, the VR model does not need to be as well optimised, as it does for the presentation of ideas to planners and clients. A VR model for consultation could be an optimised VR model with the option of interactively substituting different housetypes onto the site layout. A VR model used for marketing purposes, must be highly optimised and rendered, but it shows a final product and there is less need to interact with and change the model in real time.

![Figure 5 a) CAD drawing to show the new development in context. b) 3D CAD model. c) VR model of a single housetype. d) VR model of the streetscene with a single housetype.](image)

The housebuilding industry is standardised to an extent common in the manufacturing industries (Gann, 1996). The number of standard housetypes used by any particular housing developer is relatively low. The housing developer involved in this project used fifteen basic layouts, with variations to the facade and detailing bringing the total number up of house types to about forty.

Experimentation was undertaken to ascertain an effective method of creating and optimising a VR model for the housing developer. The housing developer wanted to use the VR system to rapidly create and evaluate proposed developments, in order to assess the appropriate usage of different housetypes.

**A pragmatic approach to model creation.**

The standardisation of housetypes within the housebuilding industry lends itself to the production of a library of reusable forms. The library-based approach is more appropriate than straightforward translation as it eliminates repetitive transfer of data. The database approach would allow changes in VR to be seen in CAD, but would not allow optimisations and levels of detail to be associated with individual housetypes.
After consultation with the housing developer, it was agreed that a library of these standard housetypes, with their associated levels of detail and optimisations could be built up. The advantage of this approach is that the speed with which a mock up street layout of any prospective site could be produced is much greater, once the library has been created. The site data can be transferred from CAD to VR on a one-off basis and the 3D models of standard house types can be placed in the appropriate positions directly from the library.

6. FUTURE DEVELOPMENTS

As Object Oriented CAD systems are introduced into the building industry the difference in the structure of CAD and VR models will be significantly diminished and the overlap of CAD and VR skills will be increased. Emerging standards for data transfer may also have an impact on the integration of CAD and VR data.

The VRML community, which is leading the development of PC based VR, is currently working on VRML 3.0 which will further enable multi-user worlds. Although their mandate is wider than the concerns of the building industry user, the direction that they take will have considerable effect on the viability of desktop VR in the industry in the short term.

7. CONCLUSIONS

In the pilot study a library-based approach to building the VR model was used, as the standard housing types are reused on different sites, and this approach would allow the rapid creation of site models. From our work, we have found that a greater overlap between CAD and VR skills would greatly facilitate the adoption of VR within the industry.

Whilst a one-off, one-way process is acceptable for the application of VR for product marketing, design is an iterative process. For VR to be an effective tool in design generation there needs to be the potential to propagate changes made in the 3D CAD model, into a pre-existent VR model, or to register changes made to the VR model “upstream” in the CAD model.
8. REFERENCES


Scott Howe, A. (1997) A Network-Based Kit-of-Parts Virtual Building System Proceedings of CAAD Futures Munich, 4-6 August.