A Telepresence Environment for Concurrent Life-Cycle Design and Construction

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A thesis submitted in partial fulfilment of the requirements for the award of the degree of

Doctor of Philosophy of Loughborough University.

March 2001.

Abstract

Construction projects normally involve transient 'virtual organisations', where a multi-disciplinary project team works together on the design and construction of a facility. Many of these participants often work independently while taking decisions that inevitably affect others. The research described in the thesis involved examining the adoption of concurrent engineering (CE) principles by the construction industry as a way to reduce the problems posed by the fragmentation of the industry, and to enhance its competitiveness. An important aspect of concurrent engineering in construction is the need for effective communication of design information between all members of the project team and across all stages of the constructed facility's life-cycle. The thesis describes the development of a communications infrastructure for Concurrent Life-Cycle Design and Construction.

A communications infrastructure for virtual construction project teams could greatly benefit from the application of Telepresence. Within a collaborative communications setting, Telepresence can be viewed as 'the facility which enables collaborating parties to be virtually located within a given (3D) environment, in which they are able to interact with one another or with virtual objects that are also present in that environment'. The intended aim of this being to create the illusion of 'being there'. An approach to implement a Telepresence technology in construction was developed as part of the European CICC (Collaborative Integrated Communications for Construction) project and this is described. Building upon this, a conceptual architecture for an advanced Telepresence Environment is developed. This architecture is used as the basis for a concept demonstrator that illustrates how the environment would be used. An evaluation exercise with the aim of determining how appropriate the adoption of systems such as that which the demonstrator illustrates is then described. The evaluation established that:

- the environment and the features within it do support Telepresence;
- the methods used to deliver information about people and project data are both appropriate and suitably well implemented;
- the environment provides communication tools that are useful and well integrated;
- the user is supported in fulfilling their project role with an improved awareness of project participants and activities;
- the adoption of the environment would improve the prospect of a project achieving, at least, some of the goals of Concurrent Engineering; and
- the environment would be widely used by design and management teams.

It is concluded that the Telepresence Environment is a unique and innovative approach to enabling communication on construction projects. The use of Telepresence technology is an effective way of facilitating communication within a Concurrent Life-Cycle Design and Construction environment. Its use within a communications infrastructure for Concurrent Life-Cycle Design and Construction projects will transform the industry, enabling the goals of Concurrent Engineering to be achieved. In particular, it will facilitate collaboration on projects by making it easier to access both project information and project participants.

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Acknowledgements

I would like to acknowledge the tireless support of my supervisor, Chimay Anumba. I am extremely grateful to him for all his help throughout the research and writing up process. I would also like to thank my director of research, Tony Thorpe and the Department of Civil and Building Engineering at Loughborough University.

I am also grateful to:

- Those who participated in the evaluation exercise, providing valuable feedback;
- Jerry Bowskill, formerly of BT, for his encouragement and guidance;
- Michael Jewell of BTexaCT for his support and guidance on the use of VRML;
- Scott Kerr of WS Atkins for providing the 3D building model and drawing files; and
- Robert Amor of the BRE for assistance with project document classifications.

Finally, I would like to thank my fiancée, Kellie, for her endless understanding, support and encouragement.

Chapter 1 Introduction

This chapter presents background to the research project and the problem that it seeks to address. It briefly introduces the three main subject areas on which this thesis is based. The first area is the Construction Industry - the problem space. The second is Concurrent Engineering - an approach that proposes major change in the industry and hopefully vast and wholesale improvement. The third area is Telepresence - a technology that could enable the successful adoption of Concurrent Engineering techniques and improve collaboration in the industry. The chapter goes on to state the research objectives for this work. This is followed by a description of the methodologies employed in addressing these objectives and a justification for the choice of these. Finally the structure of the thesis is introduced.

1.1 Background

1.1.1 The Construction Industry

The construction industry is highly fragmented. A typical construction project involves many disciplines collaborating for a relatively short period of time. A virtual organisation is formed, often with many of the parties non-collocated. The participants have divergent goals and objectives resulting in adversarial relationships developing which make co-operation, communication and integration difficult [Love & Gunasekaren, 1996]. Many of these parties work independently, taking decisions that often impact upon others. This level of fragmentation has resulted in several problems identified by Evbuomwan & Anumba (1996). These include:

- inadequate capture, structuring, prioritisation and implementation of client needs;
- the fragmentation of the different participants in most construction projects;
- the fragmentation of design, fabrication and construction data (data generated at one stage are not readily reused downstream);

- the lack of integration, co-ordination and collaboration between the various functional disciplines involved in the life-cycle issues of the project;

- the lack of true life-cycle analysis of projects (including costing, maintenance, etc.); and

- the lack of communication of design intent and rationale which leads to unwarranted design changes, unnecessary liability claims, increased design time and cost, and inadequate pre- and post- design specifications.

Evbuomwan and Anumba (1996) also recognise that the traditional product development process used in the construction industry has inherent problems. This compartmentalised approach, illustrated in Figure 1.1 is often called the 'over the wall' approach. The key disadvantage is the inadequate communication between each of the players involved in the process. Other disadvantages include:

- elimination of viable design alternatives due to pressure of time;

- characterisation of the design process with rigid sequence of activities;

- constructability and supporting issues are considered late in the process;

- fragmentation of design and construction data and difficulty in maintaining data consistency;

- the occurrence of costly design changes and unnecessary liability claims;

- loss of information about design rationale and intent; and

- inappropriate estimation of construction costs.

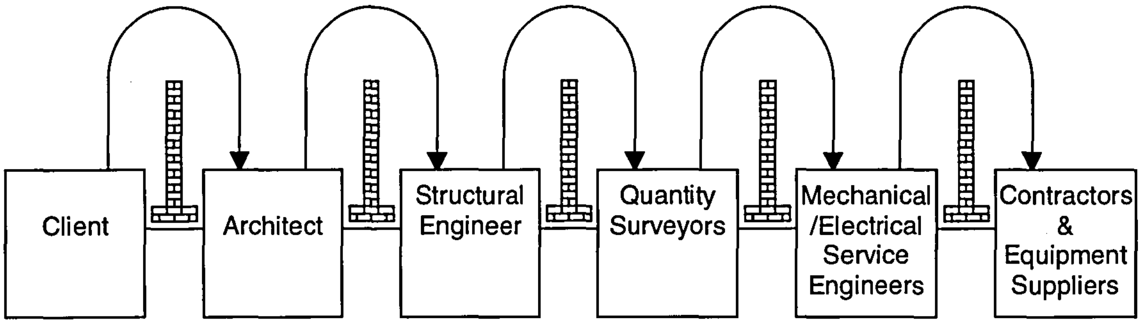

Figure 1.1. 'Over the Wall' approach

The Latham report [Latham, 1994] and the subsequent Egan report [Egan, 1998] have been catalysts for change in the industry. Latham criticised well-proven industry practices and concluded that cost savings of 30% could be made if techniques such as concurrent engineering, just-in-time supply, customer supplier partnerships and Total Quality Management were introduced into the construction sector. He called for a re-appraisal of procurement and contractual relationships, to create a more open industry that is happy to share information, when in collaboration, for the good of the industry as a whole.

Egan identifies that 'there is deep concern that the industry as a whole is under-achieving. It has low profitability and invests too little in capital, research and development, and training. Too many of the industry's clients are dissatisfied with its overall performance'. Egan also draws on the key factors behind the manufacturing renaissance in the UK by identifying 'five key drivers of change which need to set the agenda for the construction industry at large: committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda, and commitment to people' [Egan, 1998].

As stated above, collaboration between different parts of a virtual construction organisation can be problematic, particularly when the length of the project or the length of an individual's involvement with the project is short. Coupled with this is the problem of the huge amounts of information generated on a construction project. Gaining access to the correct information and to the people responsible for that information can be a time-consuming process. Studies have identified that construction managers can spend as much as half of their time collecting and analysing data [Oliver & Betts, 1996].

Clearly, the appropriate use of the emerging technologies that enable collaborative communications and information retrieval could help overcome many of the industry problems identified above. The construction industry has come under criticism for its failure to adopt new technology and analysis of the current use that the industry makes of IT shows it to be limited compared with other sectors [Oliver & Betts, 1996].

In recent years there have been major advances in the field of Information Technology. IT includes computer hardware and software, network technology and multimedia communications. The price of entry level PCs has largely been maintained while their power has continually increased. Similarly, the price of high powered graphics workstations is continually falling. These advances in hardware have enabled software to run faster and with greater functionality, together with improved user interfaces. Network technology in the form of LANs and WANs has enabled the transfer of data between computers. People can access data from anywhere in the world including while they are on the move. Internet technology is rapidly becoming a powerful business tool with many different uses in a wide variety of industries. The multimedia communications enabled by these advances provide a far more natural means of collaboration between remotely located people. Communication via video, voice, electronic mail, graphics and the ability to share applications and data overcome many of the problems associated with traditional forms of communication such as the telephone.

Egan states that, on its own, the introduction of technology will not 'provide the answer to the need for greater efficiency and quality in construction'. He advocates the approach of 'first sorting out the culture, then defining and improving processes and finally applying technology as a tool to support these cultural and process improvements' [Egan, 1998].

An interesting view of the use of information and communications technology in the industry is Hannus's Islands of Automation [Hannus, 1996], shown in Figure 1.2. This shows both the current state of play and an indication of what the future will hold.

In Chapter 3, a series of collaborative communications technologies that could be applied to the Construction industry are introduced. A number of studies that examine the usage of IT in the industry are also reviewed.

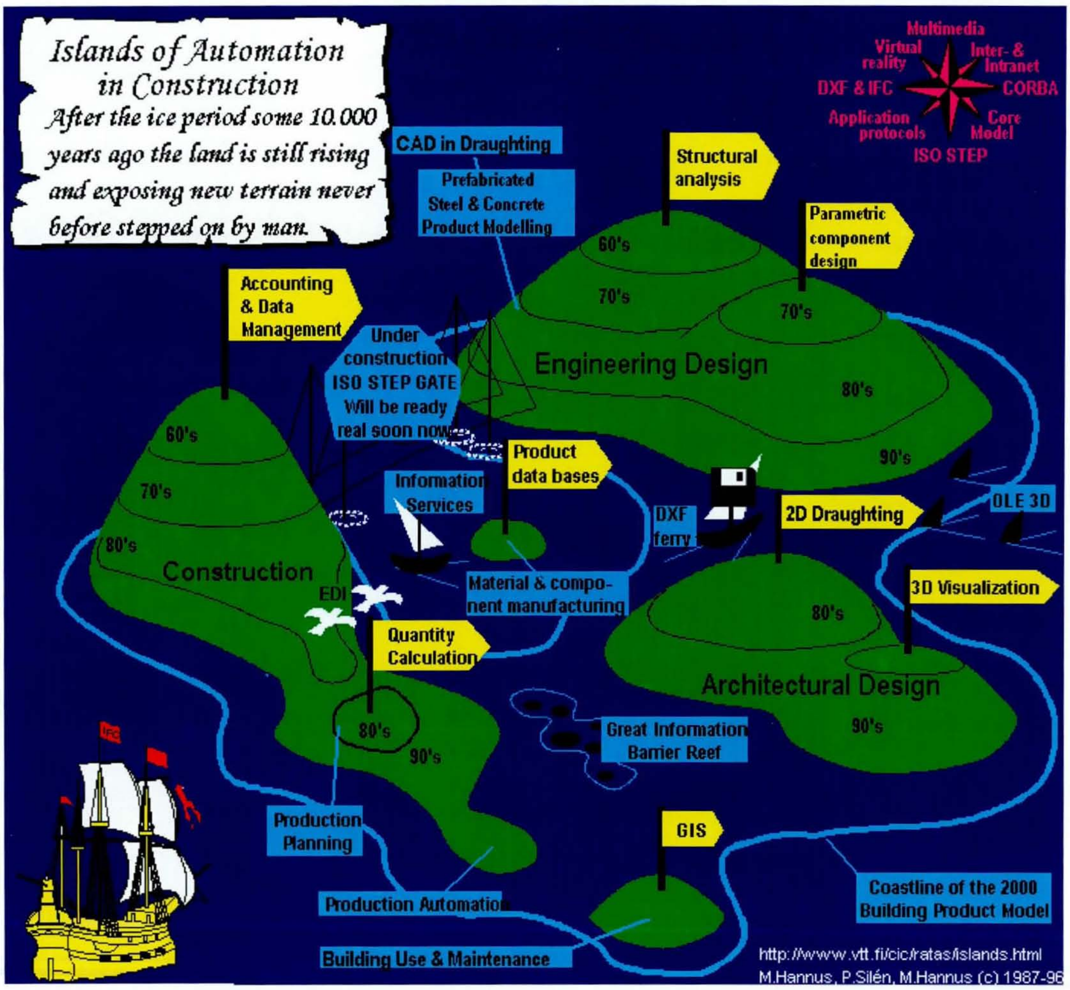

Figure 1.2. Islands of Automation.

1.1.2 Concurrent Engineering

Many of the issues identified in the previous section are now being tackled by the industry as a whole in response to the various studies that have been carried out. One approach that is gaining in stature is the adoption of concurrent engineering principles by the construction industry.

In the 1980s, in an attempt to respond to world-wide competition, the manufacturing industries of the United States began to adopt an approach called concurrent or simultaneous engineering. The concept of Concurrent Engineering (CE) was initially proposed as a 'potential means to minimise the product development and delivery time' [Prasad, 1997], by replacing the 'over the wall' form of engineering identified in Section 1.1.1 with one where a product team considers the whole process. The most popular definition of CE is by Winner et al, (1988) who state that 'Concurrent engineering is a systematic approach to the integrated concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through to disposal, including quality, cost, schedule and user requirements'. The principles and goals of Concurrent Engineering and the potential for its adoption in the construction industry are considered in greater detail in Chapter 2. However, it will suffice to state at this point that a key aspect of CE is the provision of an effective collaborative communications infrastructure. In this regard, Telepresence offers major scope and is briefly introduced below.

1.1.3 Telepresence

Telepresence may be defined as 'the ability to operate a device by remote control, including perceptual data and sensory feedback transmitted from the operator, such that it appears to the operator as if the operator were present at the site of the remote device and operating it directly' [Morris, 1992]. This is a rather broad definition and it is important to define more clearly the context within which the term is used in this thesis. Within a collaborative communications setting, Telepresence can be viewed as the facility which enables collaborating parties to be virtually co-located within a given (3D) environment, in which they are able to interact with one another or with virtual objects that are also present in that environment [Anumba & Duke, 1997]. The intended aim of this being to create the illusion of 'being there' [Cochrane et al, 1993]. This is perhaps Telepresence in its purest sense.

From the above definitions, it can be seen that Telepresence systems have significant potential for improving communications in a variety of settings. In particular, there is major scope for enhancing construction project team communications through the use of Telepresence. This is explored further in Chapter 3.

1.2 Aim and Objectives of Research

In the light of the foregoing, the aim of this research project is to determine the potential of a Telepresence Environment for Concurrent Life-Cycle Design and Construction (CLDC). It is proposed that the adoption of Telepresence technology within a CLDC environment will greatly improve the likelihood that the goals of Concurrent Engineering will be achieved.

The specific objectives of the research project are:

- to review the collaborative communications requirements of the construction industry within a CE context;
- to investigate the applicability of Telepresence to collaborative communications in construction;
- to develop an architecture for a Telepresence-based collaborative communications system for construction project teams;
- to develop a prototype or concept demonstrator that illustrates the goals of the infrastructure; and
- to evaluate the prototype using appropriate scenarios.

1.3 Methodology

Each of the objectives identified in the previous section was addressed with the use of appropriate methodologies. These are identified and briefly discussed in this section. In addition, further discussion and justification for the methodologies are included in subsequent chapters as appropriate.

1.3.1 Review of the Collaborative Communications Requirements of the Construction Industry

The review of the collaborative communications requirements of the industry within a CE context relied on a literature review process. This enabled the current 'state of the art' to be determined but also provides vital information about what has gone before, what has been tried and has or has not been successful. This literature review process involved establishing the nature and problems of the construction industry, the efforts to improve its efficiency via the adoption of CE and the resultant requirements of a CE organisation for improved collaborative communication (both amongst project participants and project data).

A wide variety of material is available including Government reports, studies on IT usage in construction companies or disciplines, long-term academic research and reports on technology adoption or trials by companies. Documents cited in the Inspec and Compendex databases, or published on the Internet and in conferences proceedings were reviewed. The documents themselves were also a source of related material through the citations that were made within them.

In addition to the literature review, the communications requirements of the industry were also gained via involvement in the CICC (Collaborative Integrated Communications for Construction) project. The consortium of this project involved members of both the Telecommunications and Construction industries and was founded with the recognition that Construction was one industry that could greatly benefit from advanced communication technologies. The construction parties involved were able to provide requirements to the consortium based upon their experiences. In addition they provided access to construction projects, allowing a series of pilots to be carried out. These pilots allowed further requirements to be captured from a wide variety of organisations and projects.

1.3.2 Investigation into the Applicability of Telepresence to Collaborative Communications in Construction

The literature review process was also employed in determining the level of application of Information and Communications Technologies (ICT) to the Construction Industry and also activities within the research communities concerned with collaborative communications (specifically Collaborative Virtual Environments and Telepresence). This process partly allowed the second objective to be met i.e. to investigate the applicability of Telepresence to collaborative communication in construction. In order to do this, the capabilities of the technology needed to be determined. As stated, this was partly carried out by literature review but additionally, working in a research department in a relevant field allowed a both a broader and deeper awareness of the field to be developed. The CICC project provided essential exposure to construction practitioners and projects allowing a measure of the applicability of collaborative communications to be determined. The project also proposed an integrated approach to the delivery of information and communications services to the user as the way forward. This approach was adopted and developed within this research project.

1.3.3 Development of an Architecture for a Telepresence-Based Collaborative Communications System

Once the applicability of Telepresence had been determined it was then necessary to develop an architecture for a Telepresence-based collaborative communications system for construction project teams. This required a definition of what exactly the system was to do and specifically how the communications requirements would be addressed. This is basically a system specification process. Once this was determined, the process of breaking down the overall system into individual functions that can satisfy the sub-goals of the overall system could take place. For each of these functions it was considered appropriate to consider existing products or systems that could potentially be included as components. It was also necessary to identify appropriate technologies that could be applied to fulfil a function where something did not already exist. This process again relied on knowledge of the field gained either through literature review or relevant experience. The relationships between these functions were also considered at this stage. This step was deemed necessary in order to ensure that the interfaces between existing components were adequate or to highlight that they should be appropriately considered in the following phases of development. The end result of this process was the production of a system architecture that would provide a basis for the development of a Telepresence Environment.

1.3.4 Development of the Prototype

The system architecture was then used as a basis for a prototype that would illustrate the goals of the infrastructure. Since this work is fairly long term and deals with concepts that are quite new to the industry it was deemed appropriate to first test out these concepts with potential future users of the technology who would also have a good understanding of the relative need for them. Prototyping is a technique that certainly allows this process to be carried out. It also allows those carrying out the development to assess the suitability of concepts and functions at an early stage. The actual development of the prototype consisted of a software development process using Java and VRML. Microsoft J++ was used as the development environment. Microsoft Access was used to provide the various database elements that were required. This was linked to the Java code via the Java Database Connectivity (JDBC) interface. Wherever possible, existing software was used to provide components of the architecture. These were integrated as part of the software development process. The methodologies applied in the prototype development stage are discussed in greater detail in Section 5.1.

1.3.5 Evaluation of the Prototype

The final objective was to evaluate the prototype using appropriate scenarios. The nature of the prototype influenced the type of evaluation that was carried out. It consisted of a demonstration of the prototype to a group of industry practitioners who were then asked to complete a questionnaire. This method was chosen over, for example, a 'hands-on' approach as the evaluation of the proposed concepts was considered to be of more importance than other assessments, such as the quality of the user interface. In addition, time constraints meant that a more in-depth study on a real construction project was not possible. The responses to the questionnaires were analysed and the results then used to assess the evaluation objectives. The methodologies applied in the evaluation process are discussed further in Section 6.2.

1.4 Structure of the Thesis

This thesis contains seven chapters. This, the introductory chapter presents a background to the research project and briefly introduces the Construction Industry, Concurrent Engineering and Telepresence. It states the research aim and objectives and identifies and justifies the methodologies used in addressing these.

The second chapter contains a much more detailed explanation of Concurrent Engineering including a full definition, a description of the principles and the goals, and its potential benefits. Concurrent Engineering was originally developed as an approach to address issues in the Manufacturing Industry, however, its use is now being advocated in other areas including Construction. The important relationship between CE and communications technology is also discussed in this chapter.

Chapter 3 introduces emerging technologies in the field of communications that could be appropriate for industrial applications. These include general collaborative communication technologies, Virtual and Augmented Reality, Telepresence and Collaborative Virtual Environments. This is followed by a picture of what the current situation is with regard to Information and Communications Technology penetration in the Construction Industry.

At the start of Chapter 4 a proposal for the adoption of collaborative environments in the Construction Industry is made. This focuses on the potential of such environments for improving communication and collaboration on Construction projects. This is followed by a description of work that was carried out on the CICC (Collaborative Integrated Communication for Construction) project. The aims of a Telepresence Environment, building upon work already carried out in the CICC project, are introduced. A conceptual architecture is then presented together with an explanation of the components involved. The proposed functionality of the environment is then given with appropriate scenarios of its intended use.

Chapter 5 is concerned with the development of a concept demonstrator. This was developed in order to illustrate the potential of the environment. The rationale and methodology related to the demonstrator are presented. This is then followed by a description of the architecture and components employed. A full description of the development process is provided including an explanation of design decisions, significant techniques employed, notable algorithms, and code fragments. A summary of the system operation and intended functionality is also provided.

The evaluation carried out on the use of the demonstrator is described in Chapter 6. The objectives of the evaluation and the methodology employed are discussed. The evaluation involved a presentation and demonstration to a group of potential end-users who were then asked to complete a questionnaire. A full description of this process is given and the results obtained from the questionnaires analysed and discussed. This is followed by a summary of the advantages and disadvantages of the demonstrator and the proposed Telepresence Environment.

The final chapter contains a summary and conclusions of the work and a discussion of possible further development.

Chapter 2 Concurrent Engineering and Collaborative Communications

This chapter introduces concurrent engineering (CE), firstly defining it and exploring its origin. Following this, the general principles and benefits are identified. Strategies for the application of CE to project teams are then introduced. This is followed by a description of how CE could be (and is being) applied to the construction industry. The important link between communication and CE is then explored, particularly with respect to Information and Communications Technology (ICT). This identifies the important communication issues that require addressing.

2.1 What is Concurrent Engineering?

2.1.1 Definition

Concurrent or simultaneous engineering is an approach that was developed by the manufacturing industry and is now widely used in that field. It was developed to address issues such as the rapid advancement in technology and new materials, increased creative product innovation, increased reliance on automation, and increased complexity, performance and reliability of products. Above all it is intended to allow manufacturers to respond to world-wide competition [Evbuomwan & Anumba, 1996]. There are many definitions of the approach which has many constituent principles. The most popular definition is by Winner et al, (1988) who state that 'Concurrent engineering is a systematic approach to the integrated concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through to disposal, including quality, cost, schedule and user requirements'.

Another definition is that by Broughton (1990) who defines simultaneous (concurrent) engineering as 'an attempt to optimise the design of the product and manufacturing process to achieve reduced lead times and improved quality and cost by the integration of design and manufacturing activities and by maximising parallelism in working practices'.

Evbuomwan & Anumba (1998) have modified the above definition in the context of the construction industry: 'Concurrent engineering attempts to optimise the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction and erection activities and by maximising concurrency and collaboration on working practices'.

2.1.2 Principles

Kamara et al (1997) have compiled, from a variety of sources, the key goals and principles of CE. These CE principles are now discussed. One of the most fundamental principles is 'the use of multi-disciplinary teams involving all of the parties in the product development process' [Kamara et al, 1997]. It is the establishment of these teams at an early stage (and their subsequent preservation) that enables a second important principle to be fulfilled i.e. 'early or up-front consideration of all life-cycle issues affecting the product which determine life-cycle costing, and provides for effective utilisation of resources - this facilitates early problem discovery and early decision making' [Kamara et al, 1997]. It is certainly the case that if CE is to be successful is must have wide support within the organisation implementing it. There is little point in attempting to implement CE at a local level. The decision to do so must be strategic in order to facilitate the formation of teams and support the flow of knowledge across the organisation. A further principle that is enabled by the planning activities of the multi-disciplinary team is the adoption of 'concurrent or parallel processing wherever possible as a result of work structuring' [Kamara et al, 1997].

As well as ensuring that an appropriate culture is in place to support CE it is also important to provide adequate communication and information management mechanisms. Kamara et al (1997) propose the use of 'Information Management to facilitate the flow of timely, relevant and accurate information, within and between teams, and across the stages of the product development process'. In order to allow this to take place a further principle must be adhered to i.e. the 'Integration of all the technologies and tools that are used to enable concurrent product development by simultaneous product and process design' [Kamara et al, 1997]. This integration will allow the various parties within the organisation to share information effectively.

A further principle is 'continuous process improvement by incorporating lessons learned' [Kamara et al, 1997]. One way in which continuous improvement can be enabled is via the effective implementation of information management. Understanding the rationale behind decisions it a useful way to learn from experience. Thus, the capture of rationale in information management could promote continuous improvement. The final principle proposed is 'continuous focus on the requirements of the customer' [Kamara et al, 1997]. It may be appropriate to include the client in the design team as a way of ensuring their requirements are satisfied.

2.1.3 Benefits / Goals

The successful application of the principles discussed above is intended to enable Kamara et al's (1997) following list of goals to be achieved:

- The reduction of the product development time;
- Getting rid of waste;
- Reducing Cost;
- Increasing quality and value;
- 'Right first time' design;
- Simultaneously satisfying the requirements for functionality, produceability and marketability; and
- Fully satisfying the customer.

The majority of these goals rely upon a more effective decision making process with input from many more sources than is commonly the case in a traditional environment. Although this may well lead to higher costs being incurred at earlier stages of development, the overall cost and time incurred should be reduced as a result of the improved decisions made.

2.1.4 Strategies for Concurrent Engineering in Project Teams

In order to realise the proposed rewards of Concurrent Engineering, a number of strategies are proposed by Katz et al (1994). These include both organisational structures and technology tools:

- An ad hoc approach;
- Design reviews;
- Constraints management systems;
- Multi-disciplinary teams; and
- Product modelling and management.

Katz et al (1994) state that 'Concurrent Engineering principles can be applied with varying degrees of commitment'. The benefits differ depending upon the size of the organisation that the principles are applied to. This approach is summarised in a paper by Duke et al (1998) and is included here along with the figure from the original paper (Figure 2.1). The model is intended to facilitate the understanding of the ways in which CE can be applied.

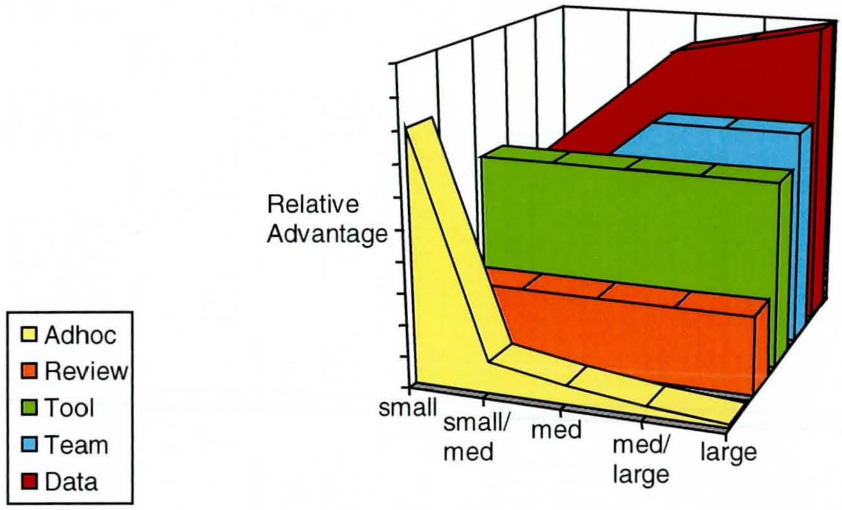

Figure 2.1. Efficiency of CE strategies when applied to organisations of differing sizes.

2.1.4.1 Ad hoc concurrent engineering based on small company structure and good personnel communication

This is the simplest case concurrent engineering scenario which can often be found in small organisations. In construction it may exist in a small company self-performing small projects or carrying out a largely self-contained part of a larger project. It can exist wherever engineering teams are small and communications between employees are good. Often, in small manufacturing companies, designers and production engineers will share a common work place; thus informal feedback exists during the design process. Also, when the project team is small, any previous issues relating to the product development process will be 'common knowledge' (although perhaps not documented). This state of affairs, although not formalised as concurrent engineering, does indeed display concurrent engineering features:

- Centralised knowledge (perhaps in the head of a single person); and
- Application of constraints during design, via informal feedback mechanisms.

Although successful in many instances, this informal arrangement lacks structure and is thus prone to collapse. If employees change, or personal relationships break down, then the experience is lost and the feedback destroyed. Also, since the number of employees is small, personnel quality and proficiency is of paramount importance. All knowledge pertaining to the product life-cycle must be encapsulated within the few team members. While an *ad hoc* approach to the adoption of concurrent engineering can be successful, as the company size increases then the effectiveness will decrease dramatically.

2.1.4.2 Rigorous sub-system review meetings with representatives from all disciplines

In conventional organisations of all sizes, the design review has been the traditional method of identifying potential problems. Here, the sub-system or component design must be evaluated from many perspectives before being signed-off as complete. In the construction industry, this takes place at project team meetings which are often held at irregular intervals and do not include all the necessary team members as some of these are appointed late in the design and construction process. While ensuring design quality, review meetings can still be regarded as a downstream solution, which results in many wasted hours of design time. For the review system to be successful, reviews must be held frequently. This becomes more complex to organise as the project team size increases or in situations where the members of the project team are geographically distributed. While, perhaps, placing more emphasis on engineering standards and documentation, in order to formalise an approach, much emphasis is still on the integrity of the designer. Furthermore, unless all the key members of the project team are represented at the review meetings, its effectiveness cannot be guaranteed.

2.1.4.3 Multi-Disciplinary Teams (MDT)

This is perhaps the classic approach to implementing CE practices. Historically, companies have been structured around a departmental regime. The MDT approach, while not destroying departments, attempts to orientate production around the product and not the department. Teams are assigned to manage projects, where each team is composed of representatives from all areas of the business. Thus, multi-perspective decisions can be made more frequently than with the design review process established in isolation (and without the organisational overheads). Although Multi-Disciplinary Teams have existed in construction for a long time (and are indeed essential due to the high degree of specialisation in the industry), most still operate in the 'over the wall' fashion. In CE terms, they are not true MDTs. Early on in the project life-cycle the lack of physical co-location accentuates any lack of coherence in the team. Also, in construction, the downstream appointment of project participants whose perspectives may have an influence at the early stages of design negates the full benefits of team working.

2.1.4.4 Design verification via automated constraint management

Since design normally involves collaboration, it is generally found that each different design, skill or responsibility aims at a different goal and that one individual's objective is another's constraint. In order to apply constraints to the designer early in the life cycle, and to reduce the impact of informal feedback mechanisms, design verification tools are necessary. Constraint management tools can give design assistance and ensure that design decisions are supported with knowledge of many perspectives. Thus, design integrity can be assured before the review stage. Any constraints system must have a rule base, by which design input can be interrogated [Katz et al, 1994].

Tools, such as those highlighted above, can provide the advantages of multi-discipline teams, i.e. the combined knowledge of professionals from all company disciplines. However, the knowledge engineer could never model the totality of the professionals' skills, therefore the maximum efficiency that tools could provide will always be less than that delivered in the multi-disciplinary environment. Tools can, however, deliver many of the benefits of the MDT knowledge in small companies where the MDT environment cannot be implemented due to personnel limitations. In larger companies, constraint management systems (CMS) can still perform a key role, allowing non-subjective and automatic constraints verification, and more productive use of MDT members (by checking all 'trivial' design decisions).

2.1.4.5 Integrated data including design and production rules to allow consistent tool automation

Computer systems and applications have evolved in isolation, utilising separate data formats. The full potential of concurrent engineering cannot be realised unless an integrated product model (PM) can be developed for use by MDTs. The PM contains *all* data associated with a product, including design, test, documentation, etc., in a single unambiguous form. Around this integrated database of product information, file and access tools are required to manage the data integrity. Although integrated product models are now common in manufacturing, they still require considerable development before they become widely accepted in construction. It is also being recognised that product models need to be integrated with process models (which describe the steps required to translate the design of an artefact or facility into a physical reality), communications protocols, project participants, organisational issues, and other considerations which have a bearing on the delivery of the project.

Each of these strategies is applicable in construction organisations. Indeed, the wide variance in size of such organisations certainly highlights the need to adopt appropriate strategies - as advocated by the model. The application of Concurrent Engineering to the industry is discussed in the following section.

2.2 The Application of Concurrent Engineering to the Construction Industry

The issues identified in Section 1.1.1 suggest that there is certainly much room for improvement in the construction industry. Construction is often compared unfavourably with the manufacturing industry as a whole which has reportedly undergone a 'technology revolution that has transformed the manufacturing process' [Powell, 1995]. Many studies [Powell (1995), Latham (1994), Deasley & Lettice (1997)] have examined the similarities between the construction and manufacturing industries and advocate the modelling of construction as a manufacturing process. Many of the goals and principles of Concurrent Engineering are clearly appropriate in the construction industry as well as in manufacturing. However, Kamara et al (1997) do not advocate a wholesale emulation of the processes of the manufacturing industry. Instead they support a strategic and targeted application of manufacturing principles to specific construction processes. Deasley & Lettice (1997) agree stating that 'manufacturing is fundamentally and culturally different from construction and applications of new techniques in the former are not obviously relevant to the latter'. However, given this they also state that 'there is sufficient similarity to presume that, with care, significant improvements can be achieved'. Kamara et al (1997) list the following as relevant areas that can be enhanced by the use of concurrent engineering:

- Process integration from design to manufacture;
- A collaborative approach to product design and manufacture;
- A pro-active approach to the utilisation of new technology (particularly information technology) to improve existing processes;
- Greater standardisation and automation;
- Improved abstraction and satisfaction of client requirements;
- Improved levels of safety; and
- Better communication between design and production teams.

Love & Gunasekaran (1996) have identified that the following are essential constituents of CE in construction:

- the identification of associated downstream aspects of design and construction processes;
- the reduction or elimination of non-value adding activities; and
- the multi-disciplinary team.

In the early identification of downstream aspects, a 'design team composed of participants from differing professions, brought together to partake in the design process' [Love & Gunasekaran, 1996] is advocated. Love and Gunasekaran (1996) go on to suggest that 'by using the knowledge of these participants in how downstream issues can influence the design and construction process, a reduction in the amount of redesign and development design and cost can be achieved'. They also state that a 10% reduction in costs can be made by improving design and building processes, suggesting that either a good client or a well-integrated design team is required and that the real way to reduce cost is to improve communications. This is further supported by the statement that 'the responsibility for the implementation of Concurrent Construction ultimately lies with the client' [Love & Gunasekaran, 1996]. The adoption of processes such as partnering by large industry clients e.g. BAA [Duncombe, 1997] have gone some way towards allowing this to occur.

Evbuomwan & Anumba (1998) have developed an integrated framework for Concurrent Life-Cycle Design and Construction which supports the concurrent development of a project and the associated construction process. The framework proposes a number of strategies for integration i.e.

- integration of functional disciplines involved in the project;
- integration of the design process and design tools; and
- integration of the textual and geometric project data.

The integration of disciplines is one of the most important principles of concurrent engineering. Evbuomwan & Anumba (1998) see this as the means by which 'the knowledge gap between design decisions made and the performance of the project downstream is reduced, as decisions are made based on more available knowledge and information'. The integration of design involves both an integration of the various design stages (from client needs elicitation through to construction planning) and an integration of the CAD tools used in those stages. The final strategy will integrate the total information about a project into one common format and environment. This will 'ensure that the information about the project is consistent, with each participant in the project having access to the same information' [Evbuomwan & Anumba, 1998].

These strategies underpin the framework of Evbuomwan & Anumba (1998) which proposes an integrated environment. The framework shown in Figure 2.2 is developed in three levels. These encapsulate the concurrent life-cycle design model, the associated design tools and techniques used in performing the various design activities at each stage of the design model and necessary knowledge / databases supporting these design modules.

The first level in the framework consists of six different stages of the integrated design and construction planning model for the framework and acts as an overarching structure over the supporting design tools and associated knowledge and databases. Level two represents computer aided design tools and techniques including codes of practice and industry standards that can be used in performing design activities at any of the design stages of level one. Some of the tools are used to support the various life-cycle analyses and evaluation of the project. Level three consists of necessary knowledge/databases that augment the design tools represented in level 2. They can act as repositories for design codes and standards, design rules, and information on construction techniques, processes and operations as well as the evolving project model and other corporate design data [Evbuomwan & Anumba, 1998].

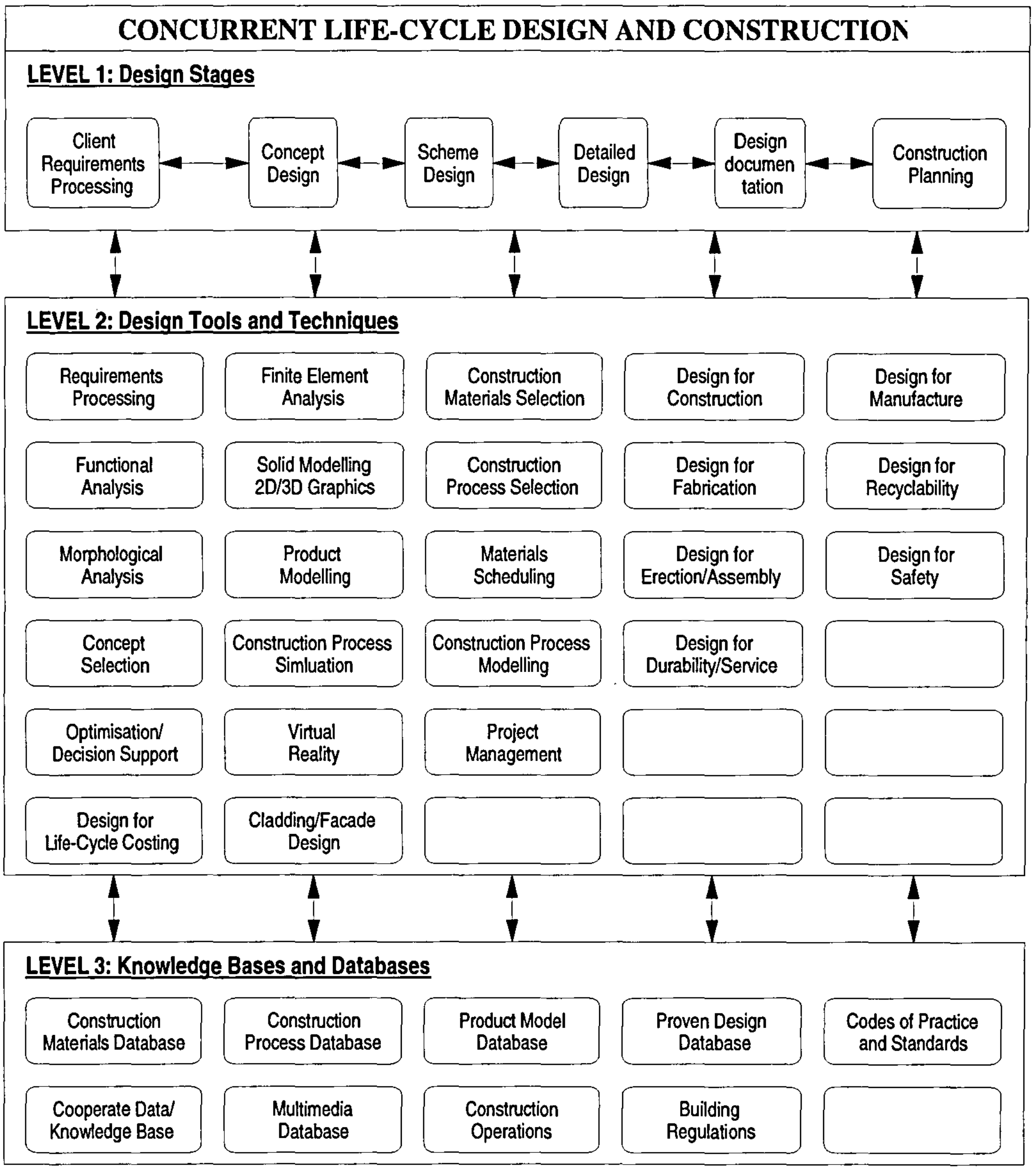

Figure 2.2. The structure of the integrated framework for concurrent life-cycle design and construction

The design model for concurrent life-cycle design and construction consists of six stages. These are:

1. client requirements processing;
2. preliminary conceptual design;
3. design of schematics;
4. analysis and detailed design;

5. design documentation; and
6. construction planning.

The client requirements processing stage focuses upon identifying, analysing, prioritising and translating into solution-neutral specifications, the requirements of the client. These requirements form the basis for tenders by prospective contractors or consortia.

Once the specifications are determined, the functional requirements of the design facility can be established. This allows possible conceptual solutions to be developed and critically examined and evaluated against the specifications to see if they satisfy the originating client needs. Factors such as economic viability, performance, functionality, aesthetics and constuctability can be assessed to determine the most viable concepts for further development in the next stage.

Those concepts selected from the second stage are then elaborated into feasible schemes. Schemes can represent, for example, 'different structural framing systems, structural materials as well as mechanical and electrical systems' [Evbuomwan & Anumba, 1998]. The schemes are developed until they represent what can be called the 'design solution space'. Again, the most viable schemes are selected via evaluation against the specifications from previous stages.

At the detailed design stage, the most feasible scheme is further refined. The design team carries out an extensive elaboration of each detail in the structure. Various forms of model are constructed and further issues such as: 'the definition of actions on the structure such as load, temperature difference, corrosion, etc.; analysis of the effects of these actions; and comparing these effects with a criterion of adequacy based on design codes, government regulations, industry guidelines and national / international standards' [Evbuomwan & Anumba, 1998]. These issues will require the use of design software and analysis tools such as those identified in Figure 2.2.

The design documentation stage involves the communication of the design to others involved in the construction project. This entails the production of documents such as drawings, equipment and materials schedules, specifications for the functional disciplines and contractual documents.

The final stage is that of construction planning. This forms the link between the detailed design stage and the eventual construction of the project. Construction methods are decided at the detailed design stage. For these, the construction process steps and operations are then established. Further activities include materials scheduling and management, construction sequence planning, project management and the modelling and simulation of the construction process using appropriate computer tools. An important requirement is that 'the integrated team should examine all these issues concurrently as the design of the project is being developed' [Evbuomwan & Anumba, 1998].

The benefits of the concurrent life-cycle design and construction model are summarised by Evbuomwan & Anumba (1998) as follows:

- the client is saved the cost of a set of design consultants at the early stages of the construction process;

- a formal framework for identifying and prioritising client requirements ensures that these are clearly defined at an early stage, and helps clients to clarify their vision of the facility to be constructed;

- the large amount of rework and duplication involved in the conventional procedure can be dispensed with, thereby shortening lead times and reducing cost; delays, disputes and claims inherent in existing procedures can be drastically reduced or eliminated, saving time and money;

- teamworking and group dynamics are enhanced under the new process, with better coordination of the efforts of team members;

- ensuring concurrent design and construction in an integrated project model will improve the technical capability of the project team through an enhanced knowledge base, thus better informed design decisions can be made, thereby narrowing the gap between design knowledge and cost committed at the design stage;

- early conflict resolution is enabled, ensuring the incorporation of buildability, safety and risk analyses at an early stage;

- the new process model allows for improved communication and coordination between members of the project team, which is vital for the construction industry.

The CLDC framework advocates a greater level of integration between the parties and processes involved in the project. Coupled with this, many of the areas and constituents of CE identified by Kamara et al (1997) and Love & Gunasekaran (1996) advocate or rely on an improvement in communication between the parties involved. Since the co-location of all the parties involved in the project is not feasible throughout the project life-cycle there is a resulting increased requirement for the use of Information and Communications Technology. Communication and the application of the associated technologies in a Concurrent Engineering setting are discussed in the following section.

2.3 Concurrent Engineering and Communication

In the previous section, various approaches for the adoption of Concurrent Engineering to the construction industry have been identified. As a result of many of these approaches the level of collaboration between the parties involved in projects will increase. Anumba & Duke (2000) state that 'one aim of concurrent engineering is to address downstream issues early on in the project life-cycle. This calls for the involvement of all parties (including specialist subcontractors) at a much earlier stage than would be the case in a traditional construction project environment. It is not feasible for all these parties to be co-located during this period of design and hence the reliance of the project group upon information and communications technologies will increase. The deployment of these technologies throughout the project life-cycle will be beneficial for effective collaboration'. Bowles (1994) goes further to identify the primary objectives for information technology and communications to support concurrent engineering as follows:

- To reduce the effect of distance so that team members can interact as if co-located.
- To enable cost-effective, flexible applications to have a visual object representation.
- To manage the generation, storage and distribution of data.
- To facilitate the integration of applications so that the human-machine interface solves the business problem and not vagaries of implementation - in particular, to provide smooth transfer between design, modelling, test and production.

In order to achieve these objectives it is important to understand the nature of communications in a concurrent life-cycle design and construction (CLDC) environment. The key communications issues that need to be addressed within this environment are identified by Anumba & Duke (2000):

- Concurrency in an integrated design and construction process requires greater discipline in the production, manipulation, storage and communication of project information.
- Project information necessarily consists of both graphical and non-graphical information, which must be communicated between members of the project team.
- The greater the level of concurrency in a process, the greater the level of co-ordination required. This entails an increased level of communications between the various stages and activities in the process, as well as between the project team members.

- Paper-based communication of project information is now inadequate to cope with the high level of functionality (in terms of speed, accuracy, usability, ease of modification, enhanced visualisation, improved co-ordination, etc.) required in a collaborative working environment.

- The increasing 'globalisation' and complexity of construction projects means that project teams often involve partners from widely distributed geographical areas, sometimes on different continents. Face-to-face meetings in such circumstances are expensive in terms of time, money and personal inconvenience [Rogers, 1994]; effective communication protocols able to collapse time and distance constraints are therefore necessary.

- The very fast pace of technological development, particularly in computing and telecommunications dictate that, for the construction industry to remain competitive, it must take advantage of new and emerging information and communication technologies such as the Internet, multimedia, virtual reality, broadband communications networks, etc.

Anumba & Evbuomwan (1999) have developed a model that identifies the distinct groups of people, tools and project phases across which communication has to take place. This is illustrated in Figure 2.3.

The figure shows the seven main facets of communication that need to be addressed in concurrent life-cycle design and construction. These have been discussed in detail by Anumba & Evbuomwan (1999) and Anumba & Duke (2000) and include:

- Intra-disciplinary Tool-to-Tool Communication (F1)
- Designer-to-Tool Communication (F2)
- Project Team Communications (F3)
- Discipline-to-Project Model Communication (F4)
- Communication Between Stages in the Project Life-cycle (F5)
- Project Team-to-Third Party Communication (F6)

- Inter-disciplinary Tool-to-Tool Communication (F7)

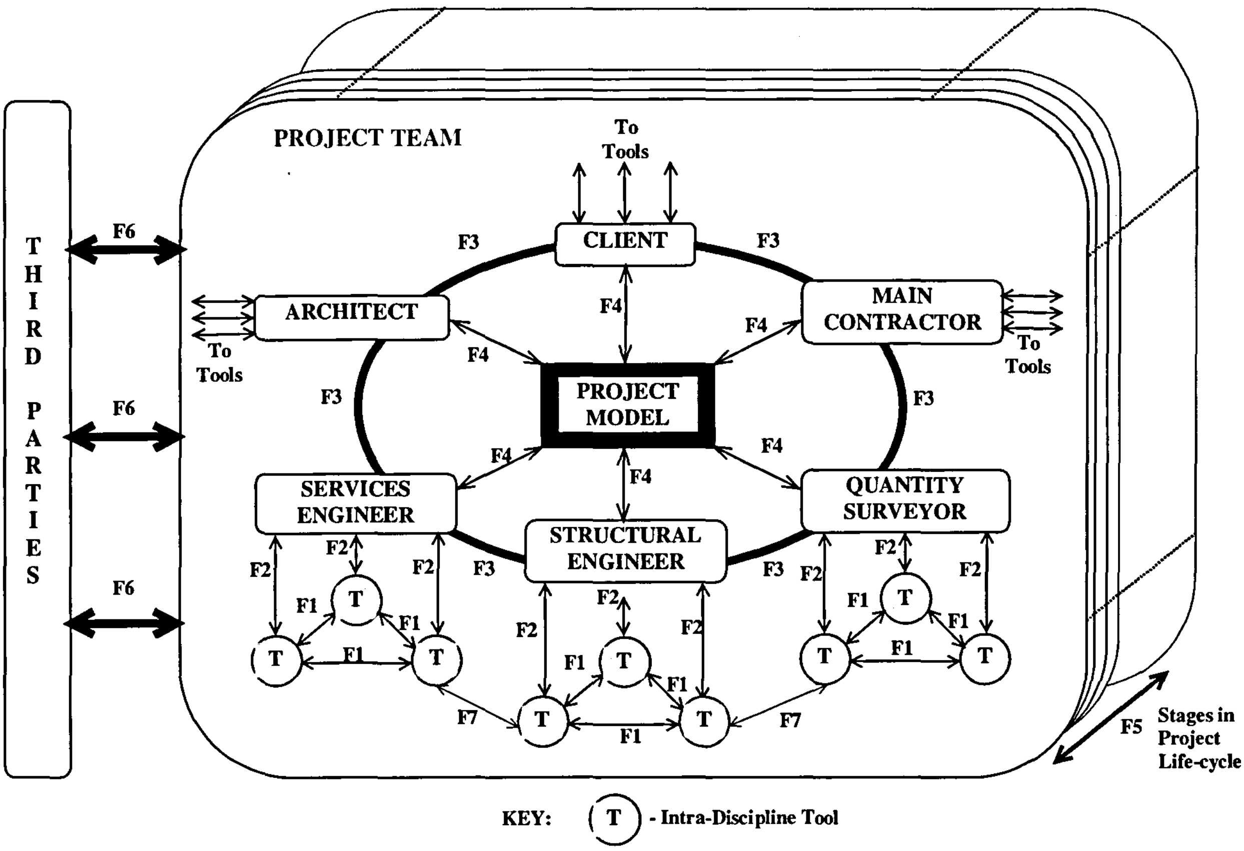

Figure 2.3. Facets of Communication in CLDC.

2.3.1 Intra-disciplinary Tool-to-Tool Communication (F1)

This refers to the communication between the various design and other software tools within each discipline. For example, the structural engineer's finite element (FE) analysis model needs to be able to communicate with the elemental design and detailing packages or with a knowledge-based conceptual design system. This facet of communication is essential to integration within a given discipline and will, in addition to minimising data input and rework, ensure that all design information from each discipline is mutually consistent.

2.3.2 Designer-to-Tool Communication (F2)

It is important that the designer is able to communicate effectively with the design tools at his/her disposal. This facet of communication is often a function of the user-interface design, and is necessary for the effective deployment of the tools. In this regard, it is essential that CAE tools are designer-oriented [Anumba & Watson, 1992], providing the designer with the flexibility to structure design information in accordance with individual, project and/or corporate requirements, and to configure the user-interface to suit individual preferences. This will entail taking advantage of emerging technologies such as multimedia, voice/motion recognition, and virtual reality.

2.3.3 Project Team Communications (F3)

This relates to communication between the various members of a given project team. There is a need to provide an appropriate communications infrastructure which will facilitate multi-lateral communication involving all members of the project team or a subset thereof. Concurrent project development requires that all appropriate team members participate in meetings, agreeing the basis for design decisions, and resolving potential downstream safety, buildability or other problems. This facet of communication should provide support for both synchronous and asynchronous 'meetings', as well as both co-located working (such as within a multi-disciplinary practice or in a face-to-face meeting) and distributed working (within a single organisation, and/or between an extended network of partners). In addition, enhanced visualisation tools based on the 'What You See Is What I See' (WYSIWIS) philosophy [Maher, 1994] (but also allowing for multiple views of design information [Anumba & Evbuomwan, 1996]) are necessary to support concurrent project development.

2.3.4 Discipline-to-Project Model Communication (F4)

At this level, each discipline should be able to communicate interactively with a common project model. A common project model is considered vital for 'seamless inter-working' between several disciplines. Each discipline should, therefore, have facilities to insert and abstract information from the project model, as well view (and comment on) changes to the model instigated by other disciplines. It is also essential that, where appropriate, intra-discipline design tools are compatible with the hardware and software platforms on which the common project model is based. This will facilitate bi-directional co-ordination. The common project model also needs to support concurrent multi-user access, and provide appropriate mechanisms for integrity and consistency checking.

2.3.5 Communication Between Stages in the Project Life-cycle (F5)

An integrated framework for concurrent life-cycle design and construction developed by Evbuomwan & Anumba (1995) provides for six key design stages - client requirements processing, preliminary/conceptual design, design of schematics, analysis and detailed design, design documentation, and construction planning. There is need for communication of both design information and design rationale between these stages as well as the subsequent stages of construction, utilisation, maintenance, and disposal. It should be borne in mind that the configuration of the communication facets will change from one stage of the project life-cycle to another as the communication requirements (and project team composition) are liable to change from one stage to another. This is discussed in greater detail elsewhere [Anumba & Evbuomwan, 1999]. Ensuring effective communication between stages in the project life-cycle will not only facilitate the re-use of project information at the later stages of a project's life-cycle, but also ensure the traceability of design rationale and decisions to explicit and implicit client requirements. This can be provided for within the common project model, and will prevent ill-advised late changes, and limit disputes and claims.

2.3.6 Project Team-to-Third Party Communication (F6)

In construction, third parties are often introduced into a project and, while they are not full-time project team members per se, there is a need for adequate communication links between the project team and such parties. Third parties may include specialists (e.g. geotechnics experts), regulatory bodies (e.g. local authority building inspectors, Health & Safety Executive safety inspectors) or others. The involvement of some third parties, although transient, may involve a high level of communication with the project team. In such cases, it may be necessary to allow third parties limited access to the project model (or parts thereof) and/or the project team's communications network.

2.3.7 Inter-disciplinary Tool-to-Tool Communication (F7)

This is the communication between the CAE tools used by the different disciplines. For example, there may be a need for the structural engineer's CAE system to exchange information directly with the architect's CAD modelling system, or the services engineer's design system. This level of communication is sometimes useful and can readily be undertaken where the relevant disciplines utilise the same or mutually compatible systems. However, where disparate systems are in use, necessitating numerous interfaces, this level of communication would be best carried out via a common project model.

Various technologies are now being employed to address the above communication facets and new ones are emerging. These are identified and discussed in Chapter 3.

2.4 Summary

This chapter has introduced CE as an approach that has been successfully implemented in the manufacturing industry. It discussed how CE could be applied to project teams. The proposal and rationale for the introduction of CE techniques in the construction industry was then introduced. Although the wholesale adoption of CE is not advocated, situations where it could be most successfully applied were identified. These included the formation of a multi-disciplinary team, early in the project life-cycle with the intention of tackling downstream issues. The Concurrent Life-Cycle Design and Construction framework was introduced as a model that could be employed to improve the business processes of the construction industry.

The adoption of CE principles in construction will increase the reliance of organisations upon information and communications technology. The issues surrounding this were identified and the key communications facets that need to be addressed in CE were presented. Appropriate technologies that could be employed to do this are introduced in the next chapter.

Chapter 3 Advanced Collaboration Technologies

This chapter introduces a series of advanced communications technologies that are being or could be applied to the construction industry. This includes both a number of established communication technologies, such as e-mail, electronic document management and conferencing, and also technologies such as Virtual and Augmented Reality, Telepresence and Collaborative Virtual Environments that are expected to have an impact in the future. The expected applications for each of the technologies within the industry are identified. The focus is primarily upon person-to-person communication (or communication between groups of people) rather than upon communication between tools although the latter is included in the context of the former. The communication facets introduced in Section 2.3 are considered with respect to the technologies and an appropriate mapping between the two is provided. The current usage of communications technologies within the construction industry is then assessed. A number of surveys, reports and papers that provide a picture of both the current situation and trends are cited.

3.1 Established Communication Technologies

In this section a series of communication technologies are introduced. Although all of the technologies in this chapter could be classified as such, those in this section are widely used in either the consumer or business setting and can readily be applied to a concurrent engineering in construction environment. A distinction has been made between those technologies supporting asynchronous communication and those supporting synchronous communication.

3.1.1 Asynchronous Communication

3.1.1.1 Electronic Mail

Electronic mail (e-mail) is now widespread and provides a cheap, fast and effective means of communication between two or more people linked together on a computer network. Transmission of messages usually takes place in seconds or minutes, and there is the facility to 'attach' files (in any mutually acceptable format) to the basic mail message. Information transmission is reasonably secure and most electronic mailing systems provide facilities for delivery confirmation, auto-reply, mail filtering and priority setting [Anumba et al, 1997].

3.1.1.2 Discussion Forums

Discussion forums, like e-mail, are a very popular means of communication amongst communities on the public Internet. Known as 'newsgroups', these forums cover a multitude of topics and allow users to start or contribute to a discussion thread. Threads are commonly centred around particular issues or requests for advice on particular topics. The ability of discussion groups to provide a means for the sharing of knowledge as well as the resolution of issues means that their use is becoming increasingly common in a business setting. This can either be via allowing employees to access Internet 'newsgroups' or by providing internal forums for the discussion of business issues.

3.1.1.3 Electronic Document Management

Electronic document management (EDM) systems are sets of software and services through which business-critical information is managed by enabling the creation, assembly, control, reuse and distribution of this information. The information managed may be in different electronic formats - text, graphics, images, CAD drawings and models, video, audio, etc. EDMs help to improve communications both within and between organisations by improving accuracy, retrieval and flow of information [Anumba et al, 1997]. EDM systems are also sometimes referred to as Workflow Management Systems. This describes the way in which documents and data are managed by the system in accordance with defined processes. This can involve, for example, the distribution of data to individuals who are required to provide approval. This can be carried out using integrated e-mail as well as other forms of messaging.

3.1.1.4 Internet / Intranets

The Internet is an international network of computers that are geographically distributed but are able to exchange and communicate information. It was originally developed in the early '70s by the United States military as a resilient network but quickly expanded into the educational, personal and finally business communication arenas. In the first two decades of its existence the primary usage areas were e-mail (using the Simple Mail Transfer Protocol -

SMTP) and file transfer (using the File Transfer Protocol - FTP). However, the '90s saw the development of the World Wide Web (WWW), a global collection of linked multimedia pages, made possible by the Hypertext Transfer Protocol - HTTP. The WWW (or simply 'The Web') is certainly the fastest growing repository of information available. Several 'browsers' are available to enable users to navigate the Web; examples include Microsoft Internet Explorer and Netscape Navigator. Organisations and individuals have the facility to create their own Web sites containing whatever information they wish to place in the public domain. Most Web sites have links to embedded information within the site or to other related sites. These are known as 'Hyperlinks' and are created using HTML (Hypertext Mark-up Language) which also determines the way in which the pages are displayed in the browser.

Although the Internet can be seen as an enabling technology for collaboration tools such as e-mail, increasingly the web is being seen as a collaboration tool in its own right. The Web has moved on from its early static nature and is becoming truly dynamic. Distributed, client-server and multi-user applications are becoming 'Web enabled' (i.e. the Internet browser is being used as the user interface and HTTP as the communication mechanism). This has the advantage of removing the need for installed applications on the end-user's computer. Such applications obviously require installation before they can be used and also require maintaining and upgrading.

The other asynchronous communication technologies identified so far in this chapter i.e. e-mail, discussion forums, and document management have all become Web enabled to some degree. However, it does not stop there. Real-time or synchronous communication technologies are also becoming Web enabled as is shown in the next section.

Intranets are networks that are built upon Internet technology but are broadly inaccessible from the Internet itself. They are set up by companies and organisations to provide internal information and communication services. Access and connection between Intranets and the Internet is controlled by devices known as 'Firewalls'. In general these allow access to the Internet from within an Intranet but restrict access in the other direction.

3.1.2 Synchronous Communication

The most widely used synchronous telecommunication technology is of course telephony. In recent decades, the use of mobile telephony has also become widespread, particularly in Construction. In addition to telephony, many other synchronous technologies have recently become popular. The most widely used of these are now discussed.

3.1.2.1 Instant Messaging

Instant Messaging is another technology that has become popular among communities on the public Internet and that is now beginning to be used in business applications. One form of instant messaging is the 'chat room'. These are similar to 'newsgroups' in that they are generally focused around a particular topic but differ in that they are real-time. Users contribute to the discussion or conversation by typing and sending text messages that are then distributed to all the other users.

A further form of instant messaging is that used in applications known as 'buddy lists'. These applications allow users to maintain an awareness of whether friends or colleagues are currently on-line. A small user interface with a list of people together with a status indicator for each allows the user to see at a glance who is currently online. Users can then invite others to join them in a text chat session that they can launch from the user interface. Unlike the chat rooms, these sessions are private. Other users can request to join the session or can be invited in by those already involved. Popular examples of this technology include ICQ[1] and Microsoft Network (MSN) Messenger[2]. These rely on proprietary protocols for communication, however, a current initiative by the Internet Engineering Task Force entitled Instant Messaging and Presence Protocol[3] (IMPP) is seeking to define a protocol that will allow these applications to interwork with each other.

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[1] http://www.icq.com/
[2] http://www.msn.com/
[3] http://www.ietf.org/html.charters/impp-charter.html

3.1.2.2 Video Conferencing

Video Conferencing is now fairly well established and is already being used to facilitate collaboration in many business settings. It involves the provision of a video and audio link between two or more parties who are generally geographically distributed. Early systems were room-based facilities that utilised dedicated communication links or ISDN (Integrated Services Digital Network) lines. However, more powerful computers and cheaper cameras have meant that video conferencing is feasible on the desktop possibly using IP (Internet Protocol), LANs (Local Area Networks) and WANs (Wide Area Networks). This shift towards the desktop PC enables data sharing facilities to be integrated with the conference. Such facilities are text chat, electronic whiteboard sharing, file transfer and application sharing. Microsoft NetMeeting[4] is one popular application that allows desktop video conferencing (although currently only point-to-point video is possible unless an additional video mixer is used).

3.1.2.3 Audiographic Conferencing

Audiographic Conferencing is an emerging technology that is attempting to enhance the audio conference by integrating it with the computer desktop and by providing a graphical representation of the conference. One example of an audiographic conferencing system is BT's Conference Call Presence[5]. The user interface for this service (see Figure 3.1) shows a conference table surrounded by representations of the conference participants. This interface allows the user to control their audio, view information about other participants and launch the integrated data tools. The service uses Microsoft NetMeeting to provide these data tools.

3.1.2.4 Internet / intranets

As stated earlier, the Internet and IP technology is an enabler for many forms of collaboration. Increasingly, real-time communication is taking place over IP based LANs and WANs. IP audio calls and conferences have become popular amongst Internet users as low cost communication when compared to public telephony services. IP video calls and conferences

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[4] http://www.microsoft.com/windows/netmeeting/

[5] http://presence.conferencing.bt.com/presence/home.htm

are also becoming popular. The quality experienced in IP based communications over the Internet is certainly not high but this situation is expected to improve as bandwidth is increased and measures to guarantee quality of service are introduced. These measures will also make IP conferencing feasible in the business setting. The attraction is in the inherent savings that result from the same infrastructure being used to provide data and voice services.

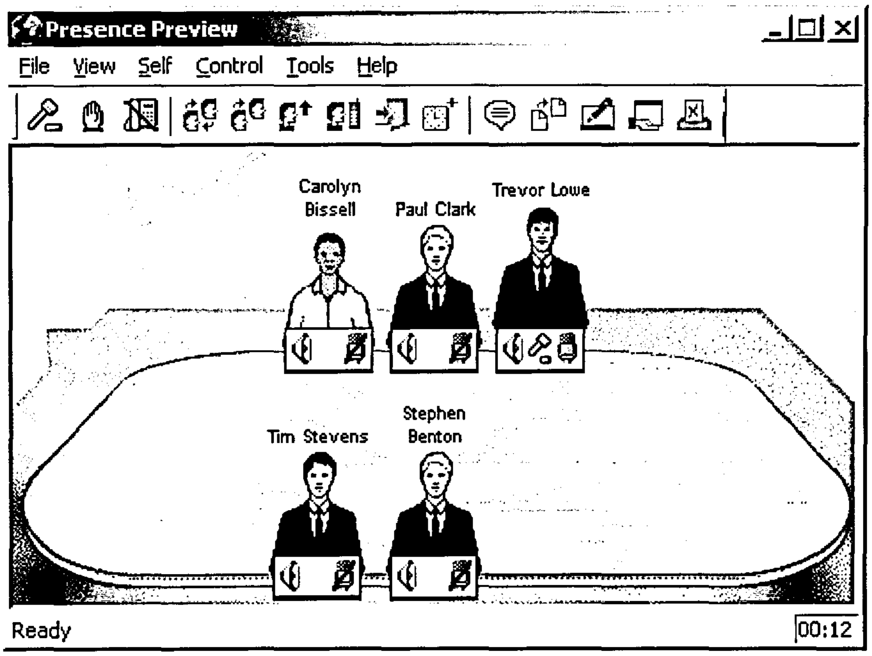


Figure 3.1. Conference Call Presence.

As is the case for asynchronous communication tools, synchronous ones are also becoming Web enabled. The Internet browser is being used as the user interface for real-time communication services. The advantages of doing so are similar to those stated earlier. Users can navigate to a Webpage that includes communication components required to join a conference. If these had not previously been down-loaded this process can be carried out when the page is loaded. In addition to this, communication through a fire-wall is made possible. Fire-walls generally block Internet traffic other than that on a particular port associated with Web browsing. By 'tunnelling' services through this port into the Web browser, users on different sides of fire-walls can collaborate.

It is widely predicted that massive growth will soon occur in the field of mobile Internet. So called 'Third Generation' mobile networks will enable portable devices such as telephones, Personal Digital Assistants, and laptop computers to be connected to IP services. This growth, together with further adoption of Wireless LAN technology could enable site-based Construction personnel to be as well connected as their office based counterparts. Conversely, office-based personnel could be permitted some of the benefits of being located on site with the use of this technology. One example of this is the BT and Loughborough University RealView system [Miah, et al, 1998]. RealView used a video camera in conjunction with a wireless LAN or radio-based communication system and an ISDN video system to provide a wide-area connection. The system allowed people remote from the construction site to join a conference with a video feed from the camera controlled by someone located at the site. Participants of the conference would be able to discuss issues aided by the visual information. RealView can be seen as a Telepresence technology as it provides people with a sense of being present at a remote location. Telepresence and further examples of its potential application are identified in Section 3.3.

3.1.3 Collaboration Technologies Research

The technologies identified in this section have been adopted in many industrial settings and are beginning to make an impact in the construction industry. Numerous research projects have been carried out that involve trials of collaboration technologies followed by an evaluation process. Many of these are summarised in a study carried out by Munkvold (1996). The aim of the study was to assess the effects of using electronic communication on the process and outcome of teamwork. A synopsis of the study results is included here to give an indication of the expected impact of the application of collaboration technologies in a Concurrent Engineering environment.

The empirical studies on computer-mediated communication (CMC) were examined for results that could be transferable to virtual teams. Munkvold uses the term computer-mediated communication as a 'catch all' for technologies such as e-mail, computer conferencing, bulletin boards and (group) decision support systems. None of the studies were concerned with technologies offering multiple communication channels. The majority of the studies carried out consisted of 'laboratory experiments involving three to five member groups of students, engaged in short-term tasks, mostly decision making' [Munkvold, 1996].

Munkvold states that many factors affect the general applicability of the results to new contexts. These include the research setting of the studies, the short-term nature of the tasks, the use of students as subjects and the lack of continuity and interdependency between the tasks used. Given this, however, the following findings were deemed to be of relevance to the use of CMC to support distributed teamwork in CE.

There was no evidence of any negative impact on performance and quality of the outcome as a result of the use of CMC. Some studies found improved levels of quality and depth of analysis. This was particularly prevalent in those studies where the use of e-mail was frequent. Other studies found that there was little difference between 'face-to-face' groups and CMC users. The level of experience with technology was identified as having a large effect on team performance but this effect quickly diminished once experience levels increased. Users were found to be capable of quickly adapting to the use of new technology for communicating.

Several studies experienced an increased level of participation amongst team members and a reduced occurrence of domination by a few members. This is coupled with an increase in uninhibited behaviour. Participants were observed to be less concerned about status or social conventions when contributing to discussions. This could be perceived as having a negative impact upon harmony within the team, however, the increased level of participation, and possibly creativity, in the team should be seen as a positive outcome, particularly as one of the goals of CE is to increase communication in a multi-disciplinary team.

The perception of the team members as to group performance was also examined by many of the studies. Some found that an increased confidence in decisions resulted. Others reported a decrease in the level of co-ordination and satisfaction with the group process. This could be attributed to the uninhibited behaviour but weaker bonds for member support were also reported by some of the CMC groups compared to 'face-to-face' groups.

All of the studies that examined decision time as a variable found that an increase in the decision time of CMC groups occurred when compared to 'face-to-face' groups. This is consistent with the findings that the depth of analysis and level of team member participation were increased in CMC groups.

Munkvold provides some contingencies for each of the negative effects, stating that technologies providing multiple communication channels may improve the performance and perception of the group process, that in real situations face-to-face communication might not even be an option and lastly that the uninhibited behaviour might not necessarily be a bad thing.

The studies show that the use of CMC may have both positive and negative impacts upon team performance and process. These impacts should be considered when applying collaboration technologies to a CE environment. It may be appropriate to ensure that the technologies attempt to address the possible negative impacts such as the lack of co-ordination and satisfaction with the group process and the length of decision time.

3.2 Virtual and Augmented Reality

The origins of Virtual Reality (VR) are often attributed to the authors of Science Fiction novels such as William Gibson who coined the term 'Cyberspace' to represent an alternative reality sustained by computers and networks [Gibson, 1984]. The term Virtual Reality was launched in 1989 by Jaron Lanier, chairman of VPL, a major manufacturer of VR systems in the United States. The word virtual had previously been used in the late 1970s by computer scientists involved in simulation systems and interactive environments resulting in terms such as 'Virtual Cockpit' and 'Virtual Environment' where the interface between user and computer was extended beyond the traditional screen and keyboard [Mantovani, 1996].

VR systems provide users with a three-dimensional view of a computer-generated world [Rogers, 1995]. It can be described as both immersive and non-immersive. Non-immersive VR involves the user interacting with the environment via traditional devices such as computer monitor and a mouse or keyboard. Immersive VR, on the other hand, seeks to place the user within the same space as the data being visualised and/or manipulated. It requires more sophisticated devices including head-mounted viewing equipment and hand tracking devices [Anumba et al, 1997].

Virtual Reality on the Internet is enabled by VRML (Virtual Reality Modelling Language). As well as allowing the developer to model and animate 3-D worlds it allows elements within them to be linked to further 3-D worlds or any other Web page. VRML models or worlds are viewed by downloading VRML files into a Web browser with an appropriate plugin (although Java viewing applets now exist that remove the need for an installed plugin). The VRML files themselves primarily consist of a 'scenegraph' which is a description of a series of visual elements each with data about size, colour and location in the world with respect to a datum. In addition to the scenegraph there is data about animation, viewpoints and other interactive features.

VR is seen by many as just one end of a mixed reality continuum [Milgram & Kishino, 1994] shown in Figure 3.2. The field of Mixed Reality seeks to combine the best features of real environments with those of virtual environments. There are perceived benefits in this mixture, with the two main types of mixed reality environments being augmented reality (where reality is augmented with additional virtual information) and augmented virtuality (where a virtual world is augmented with information from the real world).

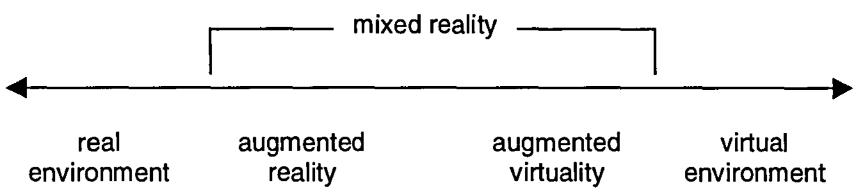


Figure 3.2. The Virtuality Continuum

There has been major interest in the potential of VR in the construction industry. The fact that the industry is involved with the production of complex physical 3-D structures that are often 'one-of-a-kind' make it attractive to try to model a building before it is built in order to understand what it will look like and what might be involved in building it. Traditionally, this modelling process has been carried out using scaled physical models. This, together with a series of 2D drawings is often used to illustrate the nature of a facility before it is built. However, the ability to carry out the modelling process on a computer has a number of advantages. Firstly, a computer or VR model allows an understanding of the scale of a building to be conveyed. Secondly, proposed design changes can be incorporated much more easily into a computer model. Finally, the model can be used as in conjunction with simulation tools to model the effects of, amongst other things, lighting, heating and ventilation.

3.2.1 VR and AR Research in Construction

In addition to the examples given above where the technology is used in earnest, there are also a larger number of research initiatives involving VR and AR. A number of these are now briefly discussed.

The potential for the use of 3D or VR technology as a better illustration of a planned facility than a set of 2D drawings was mentioned above. An architectural practice has built a prototype Web facility to disseminate design data as VRML models and HTML text to the design client, contractor and fabricators [Campbell, 2000]. The models were used as an interface to further, more detailed models and textual data via the use of hyperlinks. The results of this study highlight the long length of time that it currently takes to 'author' models in VRML when compared to standard CAD packages. This is attributed to the current lack of sophisticated VRML modelling packages. The alternative of using software capable of translating CAD models to VRML was found to often produce accurate polygonal and textural data but to be incapable of translating primitives such as text and line sets necessary for creating dimensions in VRML. The insufficient capability of the computers available to end users was also seen as a barrier. Shortcomings of VRML itself were also identified. These included the lack of a facility for the inclusion of qualitative and descriptive data resulting in a need to link to separate 2-D information, a lack of icons to aid navigation into and out of detailed data and the lack of a facility allowing the querying of dimensions or spatial relationships.

Despite these shortcomings, the users were found to be positive about the potential of VRML in communicating design data. The use of the model as an interface to access more detailed models was seen as an appropriate metaphor. In particular, the use of the Web to provide links between these types of data was seen to be of benefit. Other positive results were concerned with the ease of checking for conflicts and inconsistencies in 3-D and a reduction in the requirement for multiple views of a space to be printed and distributed.

The approach of utilising VRML as an interface to underlying data has also been adopted in the OSCON project [Aouad et al, 1997]. Here, a VRML model is used as a means for remotely interrogating information stored within an object-orientated integrated project database. Visual objects in the VRML model are linked to objects in the database. Users can select these objects to interrogate the database for information about their properties such as geometry, cost and time data. The data returned could also be tailored to suit the requirements of a particular participant in the construction process. In evaluating the system, Aouad et al (1997) found that 'direct interaction with a VR environment has many advantages over the use of a CAD package. Changes in CAD are costly and time consuming as new images are re-generated from sequences of fixed frames. In a VR environment, changes are handled efficiently by the technology'. They also received feedback that 'navigation around a VRML model is not an easy-task'. An alternative suggestion was to provide users with a number of pre-determined views of the model.

In the architectural prototype mentioned above, one of the reported issues was the fact that the models took a long time to create. A further problem was that changes in the design were not automatically reflected in the VRML model. Re-work on the model is required if it is not to become out of step with the design. An approach adopted in the SPACE (Simultaneous Prototype for an Integrated Construction Environment) project [Faraj & Alshawi, 1997] attempts to address this by 'linking the VR application with the project model where all the data of a project is represented. Hence, enabling the automatic generation of a virtual environment that supports the project from design, construction, to maintenance'. A system called CONVERT is used to create a link between the building elements defined in CAD (including low-level elements that make up the elements) and all the data associated with them in the project model. Thus the visual objects in the VR system are linked to data in the project model. Appropriate data types can be returned depending on the application carrying out the query. The continued development of the approach adopted in the SPACE project could remove one of the main obstacles associated with the application of VR technologies to construction i.e. the level of effort required to build and maintain accurate VR models.

There are many further examples of how VR technology is being applied to construction. These include the visualisation of a construction schedule [McKinney et al (1998), Adjei-Kumi & Retik (1997)] (often called 4D visualisation due to the addition of the time dimension). This could be used to improve 'workspace logistics and the utilisation of resources and equipment in space and over time' [McKinney et al, 1998]. Further examples include the visualisation of residential developments [Whyte et al, 1998], road building projects [Lee et al, 1997] and building interiors [Li & Love, 1998]. The common goals in all of these work areas are improvements in understanding what a facility will look (and feel) like and what is required to build it.

As well as developments in the VR field there have also been some in the field of AR for construction. A simplistic form of AR that is often applied is the artist's impression or computer generated image of a facility super-imposed onto a photograph of its intended location. Parallels between this process and the production of physical models can be drawn. Both can be time-consuming and difficult to change once constructed. Various research projects have attempted to address more challenging AR applications. These include the augmentation of computer generated visual information onto a video sequence or even a person's view of a proposed site or partly completed facility. The European funded Collaborative Integrated Communications for Construction (CICC) project was one such research activity. The CICC

AR work and related work areas will be addressed in the next chapter which examines the CICC project in more detail.

3.3 Telepresence

Telepresence may be defined as 'the ability to operate a device by remote control, including perceptual data and sensory feedback transmitted from the operator, such that it appears to the operator as if the operator were present at the site of the remote device and operating it directly' [Morris, 1992]. This is a rather broad definition and it is important to define more clearly the context within which the term is used in this thesis. Within a collaborative communications setting, Telepresence can be viewed as the facility which enables collaborating parties to be virtually co-located within a given (3D) environment, in which they are able to interact with one another or with virtual objects that are also present in that environment [Anumba & Duke, 1997b]. The intended aim of this being to create the illusion of 'being there' [Cochrane et al, 1993]. This is perhaps Telepresence in its purest sense. Another definition – 'Telepresence is enabling human interaction at a distance, creating a sense of being present at a remote location' [Walker & Sheppard, 1997] - implies that technologies such as the telephone (by extending human speech and hearing) or video conferencing (by also extending vision) provide Telepresence to a degree. The other end of the spectrum is embodied by technologies such as the VisionDome™[6][Traill et al, 1997]. This immersive projected display technology (shown in Figure 1.3) can be used to provide a high degree of Telepresence.

It is evident from the above definitions that Telepresence systems have significant potential for improving communications in a variety of settings. Equipment maintenance/installation, mobile news-gathering, telemedicine, and remote surveillance are just a few of the emerging applications [Cochrane et al, 1993]. There is major scope for enhancing construction project team communications through the use of Telepresence. In Section 2.1.4, a series of strategies for the adoption of concurrent engineering in project teams were identified. Each of these concurrent engineering approaches could be enhanced, to varying degrees, with the use of Telepresence [Duke et al, 1998]. The following sections describe these potential enhancements.

Figure 3.3. Demonstration of an architectural review meeting inside the VisionDome.

3.3.1 Ad hoc concurrent engineering based on small company structure and good personnel communication

This approach requires the least amount of supporting Telepresence technology and the organisations employing it are in the least likely position to be able to afford it. The lack of complexity in the organisation is reflected in the lack of complexity in the communications carried out. However, the need does still exist in construction, particularly for people who are remote from a construction site or from colleagues (e.g. site investigation teams). This can result in low visibility of both other people and the project in general - a problem which Telepresence can be used to address.

[6] VisionDome is a registered trademark of Alternate Realities Corporation.

Small organisations are heavily reliant upon the knowledge of certain key individuals. If these individuals and their knowledge are lost to the organisation, the effects can be devastating [Quinn et al, 1996]. The employment of knowledge management techniques can help overcome this problem by representing knowledge electronically. The Telepresence Environment could be an appropriate way of accessing this knowledge over networks.

3.3.2 Rigorous sub-system review meetings with representatives from engineering, production, purchasing

Today's complex buildings require complex organisations to design and build them. Review meetings will be numerous, require input from many people and will be faced with complex decisions. The deployment of Telepresence will enable people to participate in meetings without the need to travel to a physical location thus reducing inconvenience, time and cost. It will also enable more effective review meetings by allowing more of the key people to participate and perhaps for only the part which is directly relevant to them. Audio, video [Parke (1997), Russ (1997)] and virtual conferencing [Mortlock et al, 1997] are appropriate technologies in order of increasing complexity. With virtual conferencing a 3D meeting space is represented. Ideally, users would be able to do everything they can in a real meeting. They would be able to choose their own view and see and interact with representations of others in the meeting as well as the topic of the discussion.

3.3.3 Multi-Disciplinary Teams (MDT)

This approach has been employed in construction for many years, although the 'over the wall' approach has prevailed within it, resulting in many of the potential benefits being lost. A truly concurrent MDT would involve a complex communications infrastructure. The multi-perspective decisions required are taken earlier in the project life cycle and often before a team has begun to gather in a physical location. The high degree of specialisation in the industry means that there may be only a small number of recognised experts in a particular field. The ability to collaborate freely in a virtual space would be highly beneficial to this approach. Again, travel costs are reduced, decisions can be made quicker and the likelihood of chosen specialists being able to participate is increased.

3.3.4 Design verification via automated constraint management.

This approach employs knowledge based systems to replace a lot of the mechanistic design tasks. This has the effect of reducing the complexity of person-to-person interaction and thus it could be argued that the need for Telepresence is reduced. However, the Telepresence Environment could be used to direct users to areas where constraints or design changes affect them. Often constraints are not 'set in stone' and some opportunity for negotiation exists. When violations occur, users could be informed of whom the other people involved are. Establishing communication with them via appropriate channels would hopefully permit an ad hoc project team meeting to take place and allow the issues to be resolved.

3.3.5 Integrated data including design and production rules to allow consistent tool automation.

Telepresence is particularly suited to this final approach. An integrated database of project information will greatly increase the usability and effectiveness of a Telepresent Environment. Users would be able to navigate around a representation of the construction project, delving into it to gain access to underlying project information. This could then be shared with others. The environment would exist as a multi-user 3-D interface to the project data [Anumba & Duke, 1997b]. This is explored further in Chapter 4.

3.4 Collaborative Virtual Environments

The Collaborative Virtual Environment (CVE) can be seen as a particular form of Telepresence. The CVE is generally seen as a technology that allows groups of people to be Telepresent within a computer generated virtual world. Lower quality environments (e.g. those employing textual input only) have also been described as CVEs although this is certainly not the general view. The origins of CVEs can be traced to 'text chat' environments, as described in Section 3.1.2.1. These environments have employed a room metaphor for the representation of different chat sessions. As the capabilities of the home-computer have improved along with the bandwidth available over modems so have the possibilities for providing richer environments. This has the enabled the room metaphor to become embodied via 3-D graphics that illustrate these rooms and spaces and also the people within them.

These representations of people are known as 'avatars'. This term is derived from the Hindi word meaning the incarnation of a deity in a human form [Merriam-Webster, 2001]. Early examples of these 3-D chat spaces include Sony's Community Place[7] and OnLive[8]. These both allow the individual to choose or customise their own avatar.

One form of CVE which has potential for early adoption in the industrial sector is the Virtual Meeting Room. This builds upon the developments in Audio-graphic conferencing as explained in Section 3.1.2.3. In a virtual meeting room, participants should be able to interact more naturally and have more of the feeling that they are located in the same place.

3.4.1 The Virtuosi Project

The potential for CVEs to support business applications was explored in the Virtuosi project. This was a collaborative project involving partners from industry and academia and was specifically focused upon providing support for virtual organisations. The project involved two pilots. The first was with members of the fashion industry. Its focus was on providing a high quality environment that would allow parties to collaborate upon the design of garments. These garments could be worn by virtual models and altered in a variety of ways within the environment. The second pilot was concerned with a global cable manufacturing organisation. Here, a virtual factory was built that would provide links to various real factories around the world via integrated video, still pictures and data conferencing. The intention was to bring the common functions (and associated personnel) in the various factories closer together with a view to improving them through knowledge sharing.

The project produced some interesting conclusions. One of these was that animation in complex models containing items of clothing would appear to be slow even on very powerful graphics computers. Parallels can be drawn with the construction industry where 3D models are also often very complex. Another conclusion was that user navigation within environments is far from simple and in many cases interfered with the overall task being attempted. A third

[7] http://www.community-place.com/
[8] http://www.onlive.com/

result was that allowing individuals in a group to have vastly different views of the subject of collaboration, such as a garment, was not necessarily beneficial. Often it was more appropriate to give everyone an identical view and frame of reference (something that is not possible in the real world).

3.4.2 Chance Encounters

Although, there are many advantages associated with the formation of virtual teams and organisations, one disadvantage that is often associated is that it is difficult to establish and maintain a sense of community. Communications technologies can go some way in overcoming these difficulties. However, one form of collaboration that is not currently well supported by technology is that which occurs as a result of a chance encounter. Chance encounters have been recognised as vitally important to the success of organisations due to the way in which they support information flow. One existing technology that supports chance encounters is the 'buddy list' as identified in Section 3.1.2.1. However, Huxor (1998) argues that although ICQ style tools do allow users to see who is 'around', they do not support 'weak ties'. These are encounters that occur with 'people outside of one's own immediate group which can provide an alternative view on problems, and new resources to solve them' [Huxor, 1998].

Huxor goes on to state that what is needed is 'to create the type of encounter common in the typical workplace, exploiting the spatial forms employed by these workplaces, in which we meet people appropriate to the work activity being undertaken. We must also allow for management of distribution from one's known contacts, and at the same time allow for distraction from 'visitors' who may have something relevant to contribute [Huxor, 1998].

The Collaborative Virtual Environment could be used to accommodate the forms of interaction advocated by Huxor by providing a space in which remote colleagues could inhabit - effectively mirroring traditional workplaces in which people are co-located. A system attempting to address this notion is considered in the next section.

3.4.3 The Forum

Two of the concepts identified in this section on CVEs have been tackled by a BT research project called 'The Forum' [McGrath, 1998]. This project had two main work areas. The first, the Forum Meeting Space, addressed the Virtual Meeting Room concept and the second, the Forum Contact Space, addressed the issue of supporting chance encounters and the flow of knowledge.

In the Contact Space, people (or rather their avatars) cluster around zones and planes of common interest or activity. Figure 3.4 shows a screenshot from the Contact Space. The space contains a number of interest groups represented as circles. Users, represented by avatars, are placed in these interest groups by an agent sub-system, which maintains profiles of the users. This placement changes over time with the desktop activity and subject matter of the user's work. The avatar placement should be based upon the user's current focus. They will almost certainly have several interests but just one of these is deemed by the agent to be the most relevant to their current activity at a particular time.

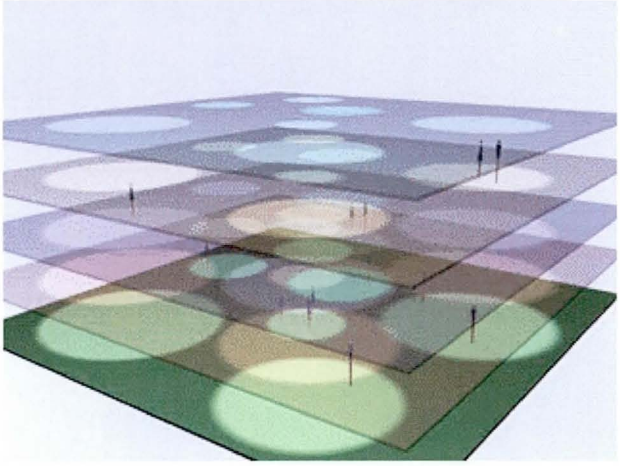


Figure 3.4. The Forum Contact Space.

The Contact Space recognises that sometimes it is good to talk to people not because they are interested in the same things but rather because they are doing similar activities - the semi-transparent 'action' layers handle this. Avatars are moved between these layers when the user is engaged in an activity where discussing with others outside the confines of a subject might be beneficial. One such example might be when the user is searching for a contract or project plan. This feature opens up the users to 'meeting' others doing similar activities but in differing subject areas. The movement between these planes is again handled by the agent. It can detect application or systems that are currently in use e.g. a financial planning system and navigate the user appropriately. These activity planes would need to be configurable to different kinds of workgroups so that appropriate activities were included.

As the system moves the avatars around it orientates the viewpoint or direction of view of the avatar towards other people in the space who have similar long term interests, this knowledge about the long term interests of the users is gathered by the agent system.

Figure 3.5. The Forum Meeting Space.

The Forum Meeting Space is an integrated audio and data conferencing environment (and is in fact an advanced version of Conference Call Presence - introduced in Section 3.1.2.3). Figure 3.5 shows the 3D graphical element and gives an illustration of the user's view of the meeting. The intention is to represent the meeting as if it was a physical one using 'symbolic acting' [McGrath, 1998]. Not only do the avatars give a representation of those present in the meeting, they are animated to act out the symbolic function of the users in the meeting. Thus, if someone uses the desktop whiteboard tool their avatar will be seen to stand by the whiteboard - conveying this information to all. Documents can be dragged from the computer desktop and placed on the desk visible between the avatars. To share a document, a user can drag the icon onto the centre of the table. Others at the meeting will see that user's avatar symbolically slide the document onto the table.

The Forum Contact Space and Meeting Space differ from most other CVEs in that they do not require the user to navigate around an environment. Instead they use a 3D environment with automatic movement and action within it to inform the user of actions and events.

3.4.4 The CAIRO project

The CAIRO (Collaborative Agent Interaction control and synchROnization) system is a distributed meeting environment that was developed at the Massachusetts Institute of Technology [Peña-Mora et al, 2001]. The CAIRO effort develops a methodology for computer-supported co-ordination of distributed design meetings using the Internet. Like the Forum Meeting Space, one of the primary goals of CAIRO was to add structure to the collaboration process in the virtual space by defining various protocols of interaction that are commonplace in physical space.

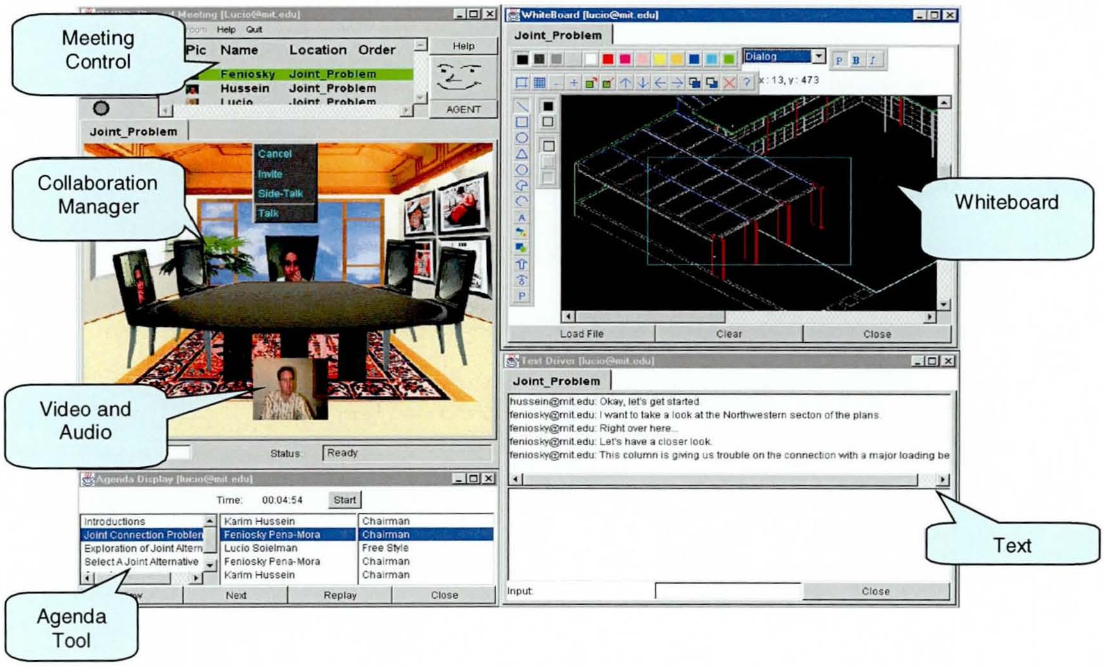


Figure 3.6. The CAIRO interface.

As can be seen in Figure 3.6, CAIRO has many features in common with the Forum Meeting Space i.e. a virtual meeting table, shared whiteboard and text chat tool. Conference participants are, however, represented differently. Video windows of the participants are applied to locations around the conference table. CAIRO uses IP technology to provide the video and audio in the meeting.

CAIRO features a number of systems that aim to improve the quality of meetings. An agent system is used to support the meeting moderator. The agent can make suggestions to the moderator such as that the time allocated to agenda items has expired or that the number of requests to speak is high and a 'freestyle' meeting format is required as opposed to a chaired one. A social agent includes a number of features that can be used to convey the mood of meeting participants. 'Emotional Icons' can be selected by participants which are then displayed on the interface. CAIRO also includes affective communication technology to automatically infer emotion. This involves using methods for capturing, interpreting, translating, and representing non-verbal behavior, namely facial expressions and body movement through camera based data collection, wearable computers and sensors.

The integration of CAIRO with a Telepresence Environment was proposed in a joint paper [Peña-Mora et al, 2001]. The rationale behind this proposal was that CAIRO supports synchronous communication well whilst the Telepresence Environment is aimed at providing support to people outside of synchronous meetings. An integration of the two systems would allow people to who meet in the Telepresence Environment to move into a CAIRO-based meeting if it was deemed that a focused communication session was appropriate.

3.5 Project Models

Although the project model is not strictly a communication technology it has wide implications for the adoption of technology in general and also for the adoption of an integrated communications infrastructure in a CLDC environment. There is a vast amount of research into project models for construction. The key characteristics, benefits, architectures and projects are discussed in a paper by Anumba et al (2000). Anumba et al summarise the definitions from the various schools of thought on an integrated construction project model by stating that 'some see it simply as an amorphous collection of all the information relating to a project, irrespective of the medium of storage (people's heads, paper drawings and specifications, CAD files, etc.) or the method of dissemination of the project information. Others see it in terms of an integrated database which holds all the information on a project and which is accessible to all members of the project team. Yet others view the project model as an integration of product models (which hold information relating to the building product) and process models (which hold information regarding the construction and business processes required to translate the product information into a physical product - the constructed facility).' The key benefit which the project model offers the construction industry is a facility for seamless multi-disciplinary working and through which the consistency of project information can be maintained as it evolves and is communicated between project team members and across stages in the life-cycle of a project. Figure 3.7 shows the communication of information across the key stages in a project's life-cycle [Anumba at al, 2000]. It should be noted that at each stage bi-directional communications take place with the project model. Thus, the flow of information across these stages is primarily through the project model, although some will informally occur through the project team members that are involved in two or more stages. It should be noted that, at each project stage, information is fed both forward and backward.

3.6 Mapping of Technologies To Communication Facets

The key communication facets that need to be addressed in concurrent life-cycle design and construction were introduced in Section 2.3. In addition, the stages in the life-cycle of a construction project require effective integration. Information needs to be conveyed effectively and unambiguously between all stages. Clearly, a communications infrastructure needs to support the key communication facets in order to facilitate integration between members of a project team and across stages in the project life-cycle. The communication technologies identified in this chapter could have a role in the development of a communications infrastructure to facilitate CE in construction. The potential of these technologies in relation to the communication facets is now examined [Anumba & Duke, 1997a].

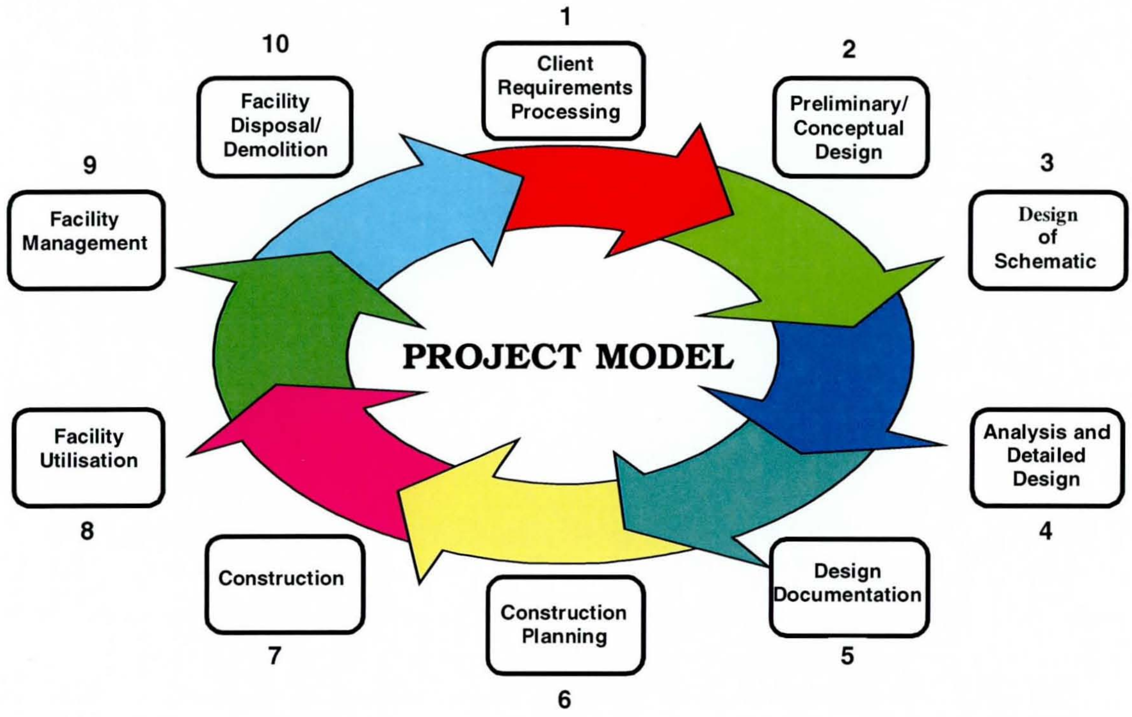


Figure 3.7. Communication Across Project Stages.

3.6.1 Intra- and Inter-disciplinary Tool to Tool Communication.

These levels of communication are more a function of the individual tools and their associated hardware platforms, and so are less readily supported by the information and communications technologies discussed above. Data exchange protocols (such as DXF, STEP [Crowley & Watson, 1996], etc.) offer the greatest potential for addressing tool to tool communication and will enable design information to be transmitted between different applications and between different disciplines. In the case of tool to tool communication, in a distributed environment, appropriate communications networks based on Internet technology will have a role [Anumba et al, 1997].

3.6.2 Designer to Tool Communication

The quality of communication between designers and their tools is highly dependent on the design of the user interfaces to the tools. Clearly, the more designer-oriented a system is, the more efficiently it can be deployed by the designer. The advent of multimedia, virtual reality and mixed reality offer much scope for increasing the communication bandwidth between designers and their tools, thereby improving the quality of user/system interaction. Many computer-aided engineering (CAE) systems already employ multimedia techniques and offer enhanced visualisation of design information. These are expected to lead to a better understanding of the operation of these systems and hence, more effectiveness, improved throughput and better quality [Anumba & Watson, 1992]. In addition to this, the advent of Web enabled design tools will facilitate a greater integration with collaboration tools allowing integrated information and communication environments to be created.

3.6.3 Project Team Communication

This level of communication is the one on which the emerging information and communications technologies are likely to have the most impact. Given the fragmentation problem in the construction industry, there is potential for significant cultural changes. All the listed technologies do have a role in this regard albeit to varying extents as discussed below:

- Collaboration technologies such as E-mail and videoconferencing, although well-established in the global context, are still used only to a limited extent by construction industry practitioners. E-mail could replace the Fax machine and postal mail as the main form of asynchronous communication used in the industry. Legal issues are often flagged as reasons for its lack of adoption but these could be overcome with the use of digital signatures or other electronic authentication methods. Synchronous communications technologies such as video and audio conferencing will enable project team members to discuss design and/or construction issues when remote from each other as opposed to (or more likely in addition to) holding face-to-face meetings.

- The Internet represents not only an invaluable source of information for construction project teams, but also a means of communication between design team members. It also offers an economical advertisement platform for clients, consultants, contractors and material suppliers, and provides the opportunity to set up Websites to 'showcase' both ongoing and past projects.

- An intranet can offer the construction project team secure communications links between all the appropriate parties on a project. Intranets belonging to parties that are linked to each other via secure Internet links or dedicated communications links are often termed 'Extranets'. These require careful management to ensure that the appropriate level of access is given to participants. Broadband network technologies may be required for facilitating the fast transmission of rich multimedia information between members of a project team across both short and vast distances.

- Both virtual and mixed reality can be used to improve communications and co-ordination between members of a construction project team. The ability to immerse the team within a VR environment will enhance visualisation of the project, facilitate interaction, and provide a better 'feel' for the working of a facility. Being able to superimpose CAD or VR models of buildings on real scenes or vice versa has obvious visualisation benefits for the project team, and the construction client in particular.

- Telepresence, like other collaboration technologies, will improve communications between distributed project team members. However, it will have a greater impact where it is used to integrate people and information in a collaborative virtual environment. This is further explained in the next chapter.

- The potential role of a shared 3-D project model in improving project team communications is well recognised, and has immense benefits in terms of model consistency and improved co-ordination. Appropriate mechanisms for access, change and version management will need to be established.

- Data exchange protocols can enhance project team communications by facilitating the direct exchange of design information between their heterogeneous Computer Aided Engineering (CAE) systems.

- Electronic document management (EDM) systems are well-suited to managing the flow of information between the disparate professionals in construction project teams. The large volume of documents generated by construction projects can be effectively and securely managed using an appropriate EDM system.

3.6.4 Discipline to Project Model Communication

Bi-directional communication between each discipline and the central project model is very important. Most of the information and communications technologies discussed have a role in this regard. E-mail, the Internet and intranets will facilitate access to the project model by each member of the project team. The format of design information, and exchange or visualisation mechanisms, will depend to a large extent on the hardware and software platforms of both the project model and the intra-disciplinary CAE tools. Discipline partial-models may be of CAD, VR or Mixed Reality (MR) format but it is important that compatibility is ensured. This may be achieved either by all members of the project team using the same platforms (which is restrictive) or using systems that support an appropriate, effective and mutually acceptable data exchange format.

3.6.5 Communication Between Stages in the Project Life-cycle

This facet of communication is one of the most important but is only marginally supported by existing CAE systems and communications protocols. Perhaps, the most important technology in supporting communication between stages in the project life cycle is the common 3-D project model. The shared model can store both graphical and non-graphical design information which can be updated as the project progresses, allowing information from the early stages of the project to be available for reuse at later stages. For maximum benefit, the non-graphical information stored in the model should include details of design intent and rationale in such a way that these are traceable to explicit and implicit client requirements. In addition, safety information (possibly, encapsulated in the Health and Safety Plan and the Health and Safety File required under the CDM regulations [HSE, 1995]) should be included in the project model. It is also essential that adequate consideration is given to archiving methods to ensure that the project model does not become obsolete within a short time-scale.

3.6.6 Project Team to Third Party Communication

All the information and communications technologies identified earlier as beneficial for communication between project team members are equally applicable to this facet of communication. The only difference lies in the fact that third parties will only need to have limited and short-term access to the project model and the project team's communications network. Once their input to the project is complete, such third parties will lose their access rights. It is important that details of these third parties are stored within a people information database so that, where necessary, some of them may be reconnected at a later date if their services are required.

3.6.7 Discussion

It is clear from the foregoing that there is considerable potential for the use of emerging information and communications technologies to support concurrent engineering within the construction industry. While some facets of communication can be supported by several of these technologies, others are less well supported. For example, there is much scope for transforming communications between members of a project team, and between a project team and third parties. This should bring project team members closer together and help to reduce the fragmentation within the construction industry. Other potential benefits of the information and communications technologies discussed include:

- easier access to appropriate project team personnel, third parties and information;
- fast and efficient access to design and other project information;
- secure communication of design and construction information within a project team;
- enhanced visualisation of design information and the project as a whole;
- more realistic communication of design intent and rationale to clients and other members of the project team;

- improved co-ordination of inter-disciplinary perspectives;
- increased consistency of project information;
- reuse of project information from other disciplines or project stages without the need for re-input; and
- improved corporate knowledge due to centralised pool of project information and improved communications protocols.

Aspects of project team communication which are not adequately supported include those which are primarily software and/or platform-dependent (i.e. facets F1, F2, F4 and F7). Intra- and inter-disciplinary tool to tool communication (facets F1 and F7) and discipline to project model communication (facet F4), as mentioned earlier, need to be based on the use of common software and hardware platforms or appropriate data exchange protocols which allow smooth information interchange between heterogeneous systems. Designer/tool communication (facet F2) can be significantly improved by better user-interface design and the use of enhanced visualisation and simulation tools such as VR, MR and multimedia.

The use of a shared 3-D project model is central to the success of concurrent engineering in construction. It should be noted that no existing system possesses the level of functionality required to adequately support the 'seamless inter-working' considered to be possible with such a model. In particular, there are limited facilities for ensuring the persistence of design intent and rationale. Also, the provisions in many systems for change propagation and management, and version control are very limited. However, there are real prospects for the emergence, in the short to medium term, of modelling systems with the required functionality. In addition to adopting these emerging information and communications technologies, there is a need to ensure that these are effectively managed to ensure maximum benefit. All project team members need to agree guidelines for the use of the communications infrastructure when set up, and clear mechanisms established for access, change and version management.

3.7 Current Usage of Information and Communications Technology In The Construction Industry

This section examines the current usage of the technologies that have been discussed in this chapter. The intention of this is to determine the degree to which Telepresence technologies are being used and the suitability of existing technologies and infrastructure to support the further application of Telepresence. In order to determine the current usage of communications technology, a number of sources were examined. These are primarily publications based upon the results of surveys into different areas of the industry, an individual company (henceforth known as XYZ plc) and the whole industry in a specific country or region [Sørensen & Andersen (1996), Futcher & Rowlinson (1998), Edum-Fotwe et al (1998), Howard et al (1998), Building Centre Trust (1999), Rivard (2000)]. There are also studies on the impact of individual technologies [Edwards et al (1996), Cooter (1995)], the role of IT management in construction [Li (1996), Breuer & Fischer (1994)] and issues of communication with respect to construction management [Pietroforte (1997), Goodman & Chinowsky (1996), Guensler (1996)]. The studies on industry sectors focus on the architectural profession [Oliver & Betts, 1996], engineering design consultancies [Gardner (1996a & b), Healy & Orr (1996)] and subcontracting organisations [Jamieson, 1996]. There is also a study on the use of IT in construction site processes [Construct IT, 1996]. All the surveys have been carried out in the last five years. Where appropriate a comparison is made between earlier and later surveys in order to infer the rate at which changes are being made.

3.7.1 General Computer Usage

At a general level, the penetration of computers in the construction industry has been mixed but is clearly increasing. A study of contracting firms in Hong Kong [Futcher & Rowlinson, 1998] found a four-fold increase in the 'staff per PC ratio' between 1992 and 1996 where it rose to a figure of 4. Later studies [Howard et al (1998), Rivard (2000)] found the same measure to be 1.25 for architectural and engineering firms. The Building Centre Trust (1999) survey found that 86% of staff had their own computer and 13% shared access to one. The vast majority of companies are utilising computer technology for some of their practices. A study of consulting engineering firms [Healy & Orr, 1996] stated that 'a large portion of the work in the consulting engineer's office, includes a range of tasks that have been successfully computerised by some firms. These tasks would, in the past, have been structured and repetitive in nature involving activities such as design calculations and draughting'. Provision of Computer Aided Drawing in the various studies indicates that this is the primary function for which computing is employed. Gardner (1996a) finds that 70% of respondents produced the vast majority of their drawings using CAD packages. Sørensen & Andersen (1996) found that 84% of Danish firms in the construction industry use CAD and, more specifically, 92% of engineering practices do so. Most drawings are produced in 2-D.

The usage of computers with general purpose business software is widespread in the construction industry. All studies covering this aspect found that word processing, spreadsheet and database packages were widely used, with Microsoft applications and operating systems being dominant - as high as 90% of the market in some areas [Howard et al (1998), Rivard (2000)].

An Information Week article entitled "Constructive Computing" [Levin, 1998] finds that construction and engineering firms are also standardising upon Microsoft's server and desktop operating systems due to the homogeneity that they provide. The article also investigated Bechtel's experience and found that it has 'created standard setups for server platforms including a desktop application suite; an engineering, procurement and construction system; document management; computer-aided design; messaging; and file and print services'.

3.7.2 Networks

The uptake of network technology has again been mixed but is also showing signs of recent improvement. The study of subcontracting organisations [Jamieson et al, 1996] found that 60% of firms had some form of communications network. This figure is mirrored in the studies on the consulting engineering practice, XYZ plc. Although connectivity within organisations is quite high, the earlier surveys found that the infrastructure required for connectivity between different organisations was not in place. Only 23% of subcontracting organisations had ISDN in place and an examination of the usage of electronic exchange mechanisms found that floppy disks were still the most popular form with 50% usage. Modem links were second with 26% usage while ISDN had only 16% usage. The more recent studies [Howard et al (1998), Rivard (2000), Building Centre Trust (1999)], however, suggest a marked improvement with around 90% of the companies surveyed being connected to the Internet. Modems are still in widespread use although there appears to be interest in exploiting new technologies such as ADSL (Asymmetric Digital Subscriber Line) and Cable Modems. The Building Centre Trust survey [Building Centre Trust, 1999] promisingly found that over two-thirds of companies had high speed (i.e. either ISDN or leased line) connectivity.

3.7.3 Collaborative Communications

Once an organisation has networks in place they can begin to utilise collaborative communications services over them. The increasing investment in networks seems to have been matched by an increase in the penetration of these technologies. The study of sub-contracting firms [Jamieson et al, 1996] found that only 17% used electronic mail systems, either within their own organisation or externally between them and other organisations. The report found that the usage of communication tools was lower in subcontracting organisations than with leading contractors and consultants. This is backed up by the study of XYZ plc where the usage of e-mail among employees was as high as 62%. In the recent Canadian survey [Rivard, 2000], e-mail was found to have 87% penetration with a further 8% of firms implementing it, while in 1996, only 15% were using it and 17% were either implementing it or considering doing so. The use of Web browsers in the industry increased from 15% to 82% in the same period.

The picture is similar when considering other communications technologies. The survey of subcontractors found no examples of the use of video-conferencing (however 31% stated that they would consider installing a system in the future). The sharing of files and databases was found to be in existence with 45% and 50% of those questioned using them respectively. A suprising statistic from the more recent surveys [Howard et al (1998), Rivard (2000), Building Centre Trust (1999)] is the number of documents that are still transferred by traditional means. The design document has the highest probability of being transferred electronically at only 28%. Rivard puts this down to 'slow internet connections, the lack of common standards for the exchange of data and the fact that this new mode of communication has still not been integrated in the business culture of the industry'.

3.7.4 Information Retrieval

Where information sharing, storage and retrieval does occur electronically, the simplest and most common mechanism employed involves passing around documents and drawings of an agreed format as e-mail attachments. The data formats used are generally determined by the market dominance of a few packages. For example, documents are generally stored in Microsoft Word format and CAD files are generally stored in DXF format, thanks to the dominance of AutoCAD.

The recent surveys [Howard et al (1998), Rivard (2000)] looked at the form in which data is held in CAD systems. The Canadian survey found that almost all drawings are stored as 2D (94%) although the majority of these are structured with layers and attributes or integrate databases or external reference files. In Scandinavia, the use of 3D objects and project models is much higher with over 30% of firms in Finland and Sweden employing them.

Two early examples of the practical usage of Electronic Management Systems are given in the Building Services Journal article 'Model Contractors' [Pearson, 1998]. At the Bluewater Retail Park development an electronic equivalent to the traditional paper-based system was employed and the plot file format became the common interchange format. A higher risk strategy was possible at the KLM Stansted development due to its smaller size. A fully-fledged 3D single-project model was employed that allowed the project team to view the data in different forms, (e.g. as VR, graphically or in a scheduled format).

An encouraging development is the number or offerings in the field of Web-based document management systems. As identified in Section 3.1.1.4 there are many advantages in delivering applications via the Web browser. Examples of offerings in this area include VieCon[9] from Bentley systems and ProjectFirst[10] from Citadon. These systems can be delivered as an end-to-end product that is installed and maintained on an organisation's own hardware or via the ASP (Application Service Provider) model where a trusted third party manages and maintains the server hardware and access to it. This latter approach is becoming increasingly popular with SMEs (small & medium sized enterprises) [Radjou, 1999] where the initial outlay required in implementing such systems is often prohibitive. Usage of these systems is by no means widespread; however, some of the more forward-looking organisations are beginning to adopt them.

3.7.5 Industry Trends

The sources suggest that the industry still relies heavily on traditional methods of information retrieval and collaborative communication. The use of IT is definitely on the increase but the level of interest in new technologies is mixed. The usage in engineering practices was generally found to be higher than in the industry as a whole. There seems to be a lack of formal planning with firms adopting a 'follower strategy' [Healy & Orr (1996), Building Centre Trust (1999)]. Limiting factors are seen as the level of finance required for the investment (particularly for smaller firms), the lack of integrated computing including standardised communication [Sørensen & Andersen, 1996] and the difficulty in quantifying the benefits of the investment. Despite this, however, a promising result from the Canadian study was the receptivity of the staff towards new technology. 82% of engineering firms reported that their staff quickly accept or are actively involved in a greater use of IT. The benefits of IT that were identified, namely the ability to respond to clients' requests and the ability to process more work, could infer that IT is seen as a public relations tool rather than a mechanism for radically changing work methods and services offered [Healy & Orr, 1996].

[9] http://www.viecon.com/
[10] http://www.citadon.com/

Gardner [Gardner (1996a & b)] suggests that the ability for larger, multi-disciplinary engineering practices to invest in advanced IT may result in a restructuring of the industry. A few, large multi-disciplinary practices will operate in the global market place while a relatively large number of smaller practices supported by modest computer equipment will serve local and specific needs. Consequently, medium sized practices may well suffer.

The changes already occurring in the industry (i.e. the trends towards flatter, virtual organisations and a federated approach to business [Breuer & Fischer (1994), Pietroforte (1997), Jamieson et al (1996), Latham (1994)]) will generate a greater emphasis on the need for collaborative communications technology. At present, it seems that the use of technologies such as Telepresence is non-existent or, at best, extremely isolated. There is, however, evidence that the infrastructure required for such technologies is being put in place. PCs with sufficient power to run CAD software and networks connecting them together are becoming much more widespread. Such progress should permit the adoption of Telepresence - enabling the many benefits that it and other such technologies have to offer the industry.

3.8 Summary

This chapter has described a series of advanced communications technologies that have been applied to the construction industry or that could be applied in the future. The findings of relevant research studies concerned with the application of the technologies were identified and discussed. In addition the expected applications for each of the technologies within the construction industry were described. These findings and potential usage scenarios will be considered in the application of Telepresence technology in a Concurrent Engineering environment.

Each of the key communication facets that require addressing in CLDC were considered with respect to the technologies and an appropriate mapping between the two provided. Those facets requiring particular attention were identified.

An assessment of the current usage of communications technologies within the construction industry was then carried out with the use of numerous surveys, reports and papers that provide a picture of both the current situation and likely trends. The results of the assessment suggested that little practical usage of the advanced communication technologies introduced in this chapter had been made by the industry. As a result, the many benefits that these technologies have to offer are not being exploited. The next chapter introduces an approach that attempted to address this issue - advocating the adoption of collaborative communications technology by the Construction industry.

Chapter 4 A Telepresence Environment for Construction

This chapter firstly examines an approach to the implementation of some of the technologies that were introduced in the previous chapter. This was carried out in a collaborative EU project entitled Collaborative Integrated Communications for Construction (CICC). The potential of a Telepresence Environment for use in construction organisations is first identified. This is followed by an explanation of the objectives of the CICC project including its aim of creating a common environment for accessing project people and information. The CICC technologies, Augmented Reality and the People and Information Finder (PIF) are introduced. A detailed explanation of the implementation of the People and Information Finder, developed by the author, is then given. The chapter goes on to present an advanced Telepresence Environment that would be applicable to Concurrent Life-Cycle Design and Construction projects. It builds upon the approach developed in the CICC project. The intent of the CICC technologies such as the People and Information Finder was to support project personnel by providing access to information over networks via a common user interface. A description of how the Telepresence Environment could achieve (and further) these goals is given. The aims of the environment are identified followed by descriptions of the proposed functionality and a conceptual architecture.

4.1 The Potential of a Telepresence Environment

Technologies such as Telepresence and Collaborative Virtual Environments (CVEs) were identified in the previous chapter. The potential of these technologies in the support of virtual organisations has also been explored. The construction industry is one that is particularly well placed to take advantage of Telepresence and CVEs. Not only does it make wide use of transient, virtual organisations, it also is concerned with the development of complex 3-D facilities via a collaborative design process. These characteristics increase the reliance upon the provision of multimedia communication and community support tools. An integrated environment that encapsulates these two areas will allow people to interact and collaborate with others as if located in the same place whilst having all the appropriate information readily available.

An approach towards the development of such an integrated environment was made in the CICC project. The aims of this project and the work carried out will be described in this chapter, with particular focus on the People and Information Finder (PIF) - an early Telepresence system developed by the author and which the advanced system described in the later part of the chapter builds upon.

4.2 The CICC Project

Collaborative Integrated Communications for Construction (CICC) was a project in the European Commission ACTS (Advanced Communications Technologies and Services) programme. The CICC consortium included members of the Telecommunications and Construction Industries as well as commercial and academic research organisations. CICC worked on the application of Telepresence, Intranet, Augmented Reality, Mobile and Multimedia technologies to construction scenarios. The aim of CICC was to allow people to access project information regardless of their location or the form of the information. Possible forms of the information were seen as:

- object-oriented CAD and relational databases;
- unstructured electronic documents;
- paper;
- facts in people's heads; and
- the project site itself.

CICC recognised that in a collaborative engineering environment, the first three forms of information would exist (possibly as duplication) in a common project model. This model, as well as giving a visualisation of the project, would provide place holders for all project related information. Such a model would exist as a reference point for discussions between project personnel. These people would not necessarily be co-located. CICC technologies were intended to allow participants in a discussion to collaborate with others, the project model, and the actual site regardless of whether they were located on the site or away from it. The integration of these technologies was to provide a consistent user interface that would promote effective collaborative working. This is illustrated in Figure 4.1, which shows CICC's Cycle of Information.

The Cycle of Information includes four distinct information sources. These were identified in the CICC final report [Leevers et al, 1998]:

- **Information in People's Heads.** When this information is emotionally neutral and trust has been established, a direct question can be asked. However, the more important the information the less likely it is to be neutral. Extracting such information from inside another person's head can then become an enormously ingenious exercise which is highly dependent on the degree of understanding and commitment between the two. The other person is no longer an information source but a collaborator.

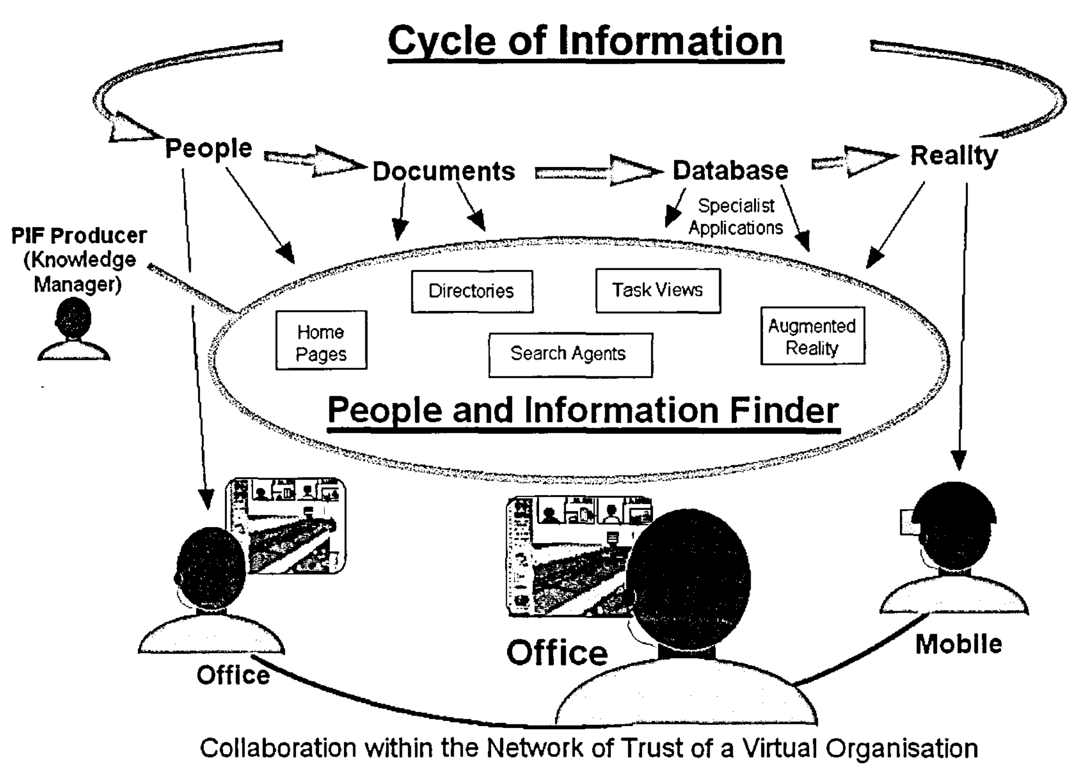


Figure 4.1. The CICC Cycle of Information.

- **Information in Documents.** Both paper and electronic documents are included. These are raw unstructured facts that have yet to be logically related to each other and added to the database.

- **Structured Database.** A database includes a vast amount of information in a structured but not necessarily convenient form. It can be difficult to link its structure to the subtleties of the real world. Object orientation has improved flexibility and made it easier to insert these links as they are discovered.

- **Physical Reality.** Much of the information inside our heads comes from the physical world. After passing through the document and database stages, this value-added information returns to the physical world as new and rearranged objects. Individuals' responses to the new physical reality starts a new iteration. This cyclic process is particularly clear at the construction site and on the factory shop floor where people are continually responding to what they see happening around them.

The Information in the stages of the Cycle of Information is reached using a wide range of tools that are integrated by a common browser known as the 'People and Information Finder' (PIF). During the project, it became clear that the integrating capabilities of the Web browser made it an ideal interface for the tools that the PIF had to offer and would enable them to be delivered over a project intranet. As well as reaching office-based personnel, the PIF was designed to be accessible by site-based or mobile users as well. The PIF implementations in CICC included the following components [Leevers et al, 1998]:

- **Home Pages**. Personal Home Pages included information about the position of individuals in the organisation and their availability. In its most direct form this included a small video window and a miniature of the person's PC screen that was updated every 30 seconds. Having some idea of what a person is doing makes it easier for others to choose the right time to interrupt them, as in an open-plan office. Pointers to organisational “nearest neighbours”, i.e. those who the individual worked closely with (although not necessarily physically), were also included on the home page.

- **Task View.** This was seen as the primary common artefact for supporting a particular collaborative activity. A top-level Task View or project chart is an important component of any group activity. If it captures the essential structure of a project it helps to bring new team members up to speed. A classic example is the London Transport Underground map, the common artefact for every member of the London commuting community. In construction a visualisation of the current state of the project could be often used.

- **Augmented Reality.** The real world is a grossly under-utilised source of information. Far more of this information could be used if it was logically linked with a project database. This is the promise of Augmented Reality. Not only is the project model registered with what can be seen on the site but the visualisation can support hyperlinks to related information that could be shown e.g. on a see-through head-mounted display.

- **Directories.** Directories are well established in both paper and electronic filing systems. Web-based directories are becoming increasingly common.

- **Search Agents.** Every time someone makes their way through the PIF to reach a particular piece of information they leave a record of their pattern of work and recent requirements. The search agent can use this information, together with many other types of analysis, to provide faster ways of getting to information and more convenient ways of displaying it.

Although seen as part of the PIF, the Augmented Reality work carried out was a major part of the project. The PIF and Augmented Reality work in CICC will now be considered in more detail.

4.2.1 Augmented reality

As identified in Section 3.2, Augmented Reality (AR) involves overlaying the user's view of the 'real world' with computer generated images. This includes using a video or still image as the 'real world' basis. Exploiting people's visual and spatial skills, AR brings information into the user's real world rather than pulling the user into the computer's virtual world. Users can interact with a mixed virtual and real world in a natural way [Klinker et al, 1998].

The potential applications for AR in construction are seen as:

- **Design and Marketing**: Creating a design and evaluating it for function and aesthetics, and showing a customer what a new structure will look like in its final setting. AR provides the unique opportunity to integrate the design into the real world context.

- **During Construction**: Visualisation of whether an actual structure is built in accordance with the design can tremendously benefit the quality and efficiency of the construction phase. Furthermore, quick updates of work plans after a design change has taken place can immediately be propagated to everybody involved once AR technology becomes as widely available as today's use of mobile telephones. The visualisation of consequences of potential design changes before they are agreed upon can benefit the negotiation process between contractors and customers.

- **Maintenance and Renovation**: Visualisation of hidden information (wires, pipes, beams in a wall) is of use when buildings are being renovated and holes are drilled into walls full of pre-existing infrastructure. Furthermore, much non-geometric information (heat and pressure in pipes, maintenance schedules and records) can be readily visualised during daily maintenance procedures in large industrial plants, such as power plants or chemical facilities.

There are various means of tracking the view so that the computer image is correctly positioned and moves, as appropriate, with the scene [Koller et al, 1997]. An approach that is consistent with construction is the use of the Global Positioning System. The construction industry is increasingly using this technology for the accurate location of facilities (e.g. piled foundations), so it may be appropriate to utilise this technology for AR tracking. Other alternatives are optical tracking, where reference points are established and located by the computer (these reference points may be existing features in a scene or deliberately added features that are easy to recognise), and magnetic tracking where sensors on the head set or cameras are used to determine position.

There are also many challenges associated with tracking for AR in construction. These include the sheer size of many sites and the vast amounts of detailed information available (this data generally requires converting into a simpler and 3-D form). In addition, construction sites are not well structured. They contain both natural and man-made objects that are in a constant state of change.

In the light of these challenges the AR work in CICC focussed upon small-scale scenarios or those where a more steady-state environment (that could be controlled) existed. The development of more sophisticated tracking techniques (involving a combination of the approaches identified above) should make the wider application of AR to construction more appropriate in the future. One such scenario was the Sunderland Bridge pilot (as shown in Figure 4.2).

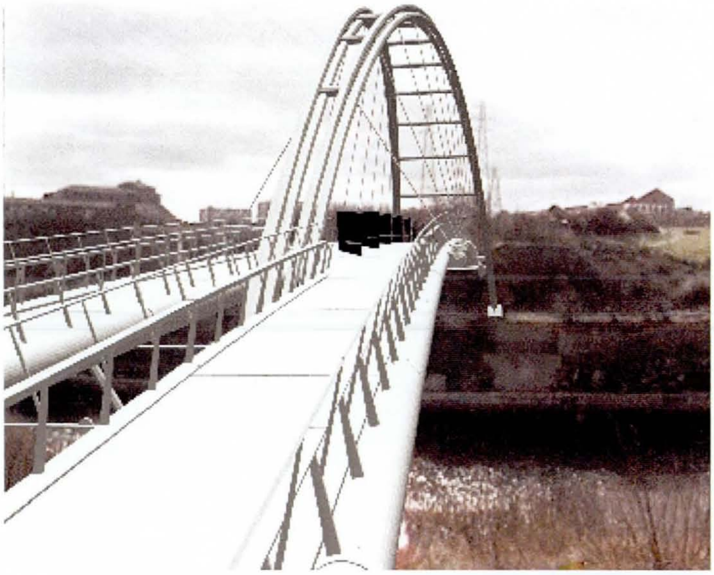


Figure 4.2. Computer Model Augmenting a Scene.

This involved overlaying a panned video sequence of the proposed site with a 3D model of the bridge. Artefacts in the scene (such as the water's edge and distant pylons) were modelled in 3D. Changes in the relationship between these artefacts for each frame in the sequence allowed the current position of the camera to be inferred and the correct placement of the model to be determined. This process could be carried out in real-time although it did make use of a powerful graphics workstation in a laboratory. Use at the site itself would require the process to be feasible upon a portable device - which is not currently the case.

4.3 People and information finder (PIF)

The PIF promotes communication between individuals and groups from all parts of the construction project. It is a Web-based technology that allows users to search for information about people and the project. This section details an implementation of the PIF that was developed at part of a CICC pilot [Duke, 1998]. It focuses upon providing information on and access to people in the project organisation. The PIF tools that were implemented were homepages, directories and a searching mechanism.

The details of project people were stored in a database. Information held includes contact information, an electronic image, details of the person's position in the organisation, whom they work with and any relevant background or project related information. This information is displayed in a Web page as the result of a search.

When wishing to collaborate upon an issue with others, individuals are able to search for the best person to help them. This person may be known to them and so only the contact details are required. However, the ability to search using various criteria provides people with a useful way of determining exactly who in the virtual organisation has the most knowledge of a particular aspect of the project.

The PIF also incorporates indications of the availability of the people being searched for. Different approaches were adopted here. The first takes images of a person's desk area using a static camera and displays them on a Web page. Similarly, a small 'screen glance' showing what is currently displayed on the computer screen is added to the Web page. Another method is to monitor the activity of a person's computer and telephone and, on this basis, display the estimated availability on the Web page. The intention of all these methods is to give an indication of a person's whereabouts and activity. Upon locating a person with whom collaboration is required, the initiation of the communication is integrated with the results returned.

4.3.1 Architecture

The People and Information Finder is an Internet based technology. By using a browser, users can access information stored on a server over a network. The protocol used is HTTP (hypertext transfer protocol) and the data is generally in the form of HTML (hypertext mark-up language). Since the PIF is all about finding information, users should have the ability to search through the data in order to find what they are looking for. The implementation of PIF discussed here allows users to search through a database of people information. Alternative search strategies employ 'search engines' to search through the text of Web pages for matching words or phrases.

Figure 4.3 shows the PIF architecture. Users browse with an HTTP client (most commonly Netscape Navigator or Microsoft Internet Explorer) over a network. The network will generally be an Intranet (closed corporate network) or an Extranet (closed virtual organisation network).

The HTTP server employed is Microsoft Internet Information Server running on Windows NT. This serves data, in the form of Web pages, to the clients. The PIF Web pages are a mixture of forms, that allow users to specify search criteria or to enter data (as shown in Figure 4.4), or dynamic pages, containing information from the database, as a result of searches (Figure 4.5).

The PIF employs WebDBC (a commercial product) to achieve connectivity between the Web server and database. This software converts the contents of Web forms into database queries and permits the contents of databases to be published on Web pages. This type of technology is becoming more important since the Web, as a means of providing heterogeneous access to distributed data, is growing in popularity.

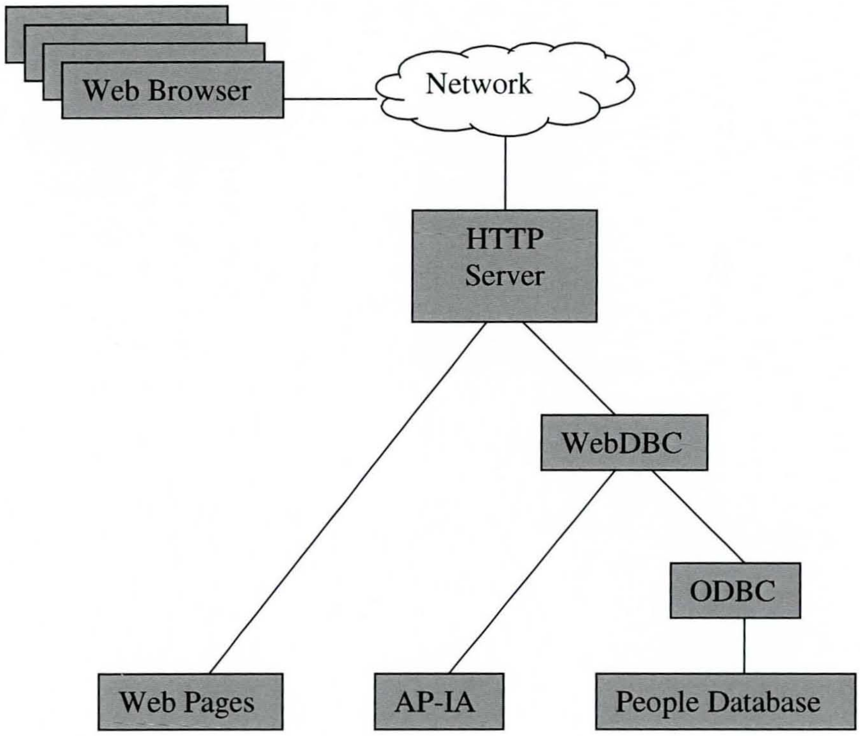


Figure 4.3. PIF Architecture.

The queries generated by WebDBC are ODBC (Open Database Connectivity Protocol) compatible. ODBC is a, Microsoft supplied, Application Programming Interface (API) that provides a standard for accessing different kinds of database. The intention is to provide a level of abstraction such that the calling application does not need to know about the workings of the underlying database and can treat all databases in the same manner.

BT has developed AP-IA, the Availability of Person - Intelligent Agent, within the CICC project. AP-IA is used in the PIF to augment the information in the database with estimates of the current availability of people. AP-IA is explained in detail below but it essentially works by monitoring the activity of equipment that people use frequently in their work (i.e. the phone and the computer). It is a low-level agent that works best when used in conjunction with other agents or information systems. Agents such as Grapevine [Crabtree et al, 1998] which uses the commonality in different people's expressed interests to promote personal contact could use AP-IA to inform users of the current availability of others with similar interests.

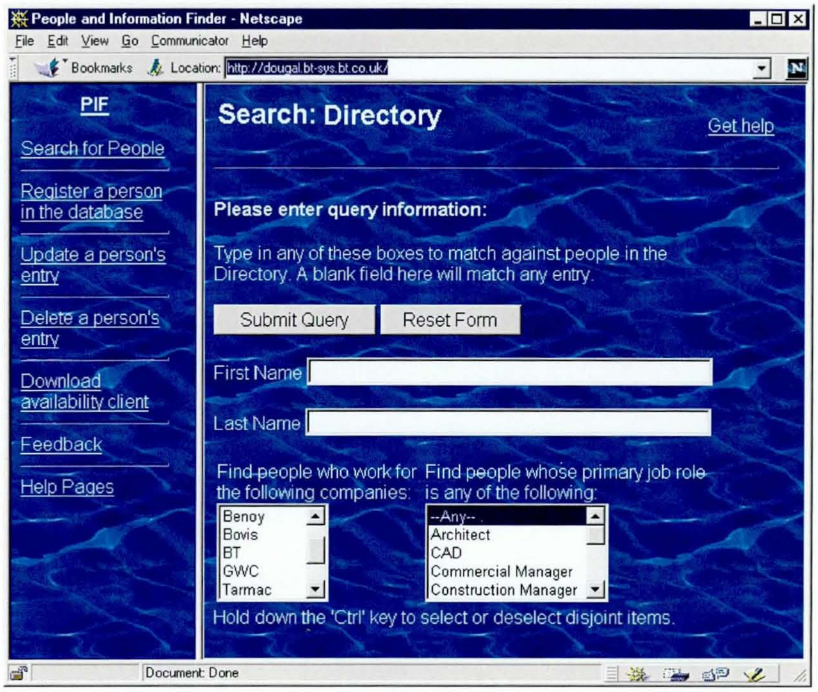


Figure 4.4. WWW Form.

4.3.2 Operational Context

The following description is an example of a user session. It explains the processes involved. A member of the design team wishes to alter the dimensions of a particular area of the building. They see that this impacts upon the available corridor space and feel they should check that no safety regulations covering the size of corridors are contravened. They wish to contact an individual in the virtual organisation who will be able to help them with the issue. Not knowing the name of such a person, they can specify 'safety' in the job role section of the search page (see Figure 4.4). Upon receiving this information, the Web server calls WebDBC to construct a database query. This is then passed to ODBC, which carries out the search on the appropriate database. For each matching record, WebDBC calls a program that interrogates AP-IA and returns the current availability of the person. The results are added to the database information and displayed on the user's browser via the Web server (Figure 4.5). Each person in the result set has a coloured dot next to their name to indicate the result of the AP-IA look-up (Green means they are probably available, red means they are unavailable and grey means that AP-IA has no record of that person). The user can then see, at a glance, which of the people is available and select them from the list. This selection (again via WebDBC etc.) returns more detailed information from the database, as shown in Figure 4.6. This figure also includes images from a 'Webcam'.

The image from a camera pointing at the desk area of the individual is periodically written to a file. This is then added to the Web page. Although giving a very good indication of availability, it is more intrusive than AP-IA and perhaps more intrusive than some people would prefer. The value of this feature is that at a glance people can see if others are available to collaborate or not.

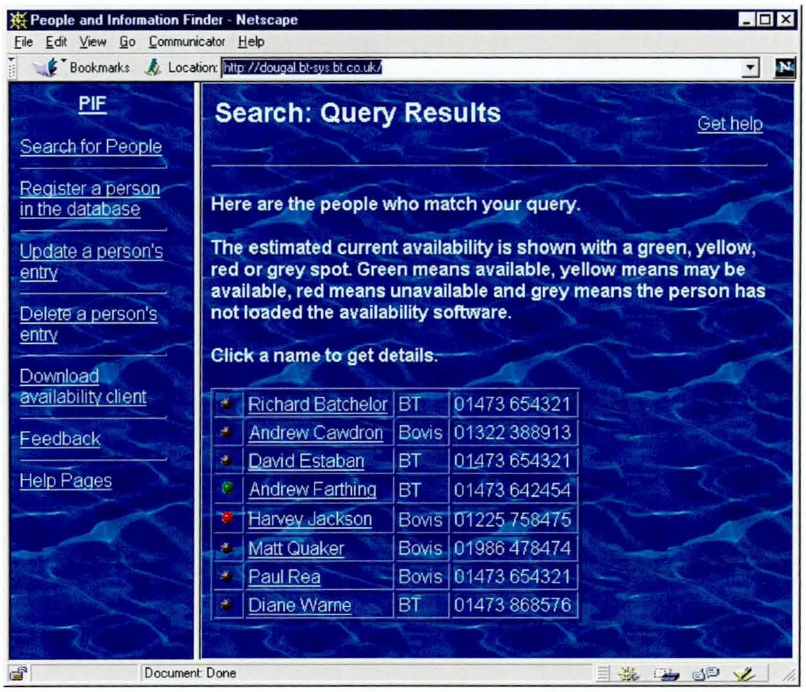


Figure 4.5. Results page.

Obviously, it is important to consider people's privacy in systems of this nature and also ensure that it cannot be abused. The user must remain in control of what can and cannot be observed by others. Hopefully most users would be comfortable with a status summary that simply tells other whether they might be available or not - this in effect similar to the 'buddy list' applications introduced in Section 3.1.2.1. It is appreciated that cameras pointing at a desk or a group of desks are not for everybody.

4.3.3 Detailed Implementation

The following example illustrates how WebDBC is used to extract information from the underlying database and display the results on a generated page. In this example, the database is queried to find all the people who work for a certain person. The result page is called when the 'people details' link is selected from the person's page. The link is URL encoded as follows:

http://webserver.bt.com/bin/webdbc.dll/JV/Guests/select/&/samples/pif/staff.htx?d_LMFirstNa me=<%r+FirstName>&d_LMLastName=<%r+LastName>">People Details

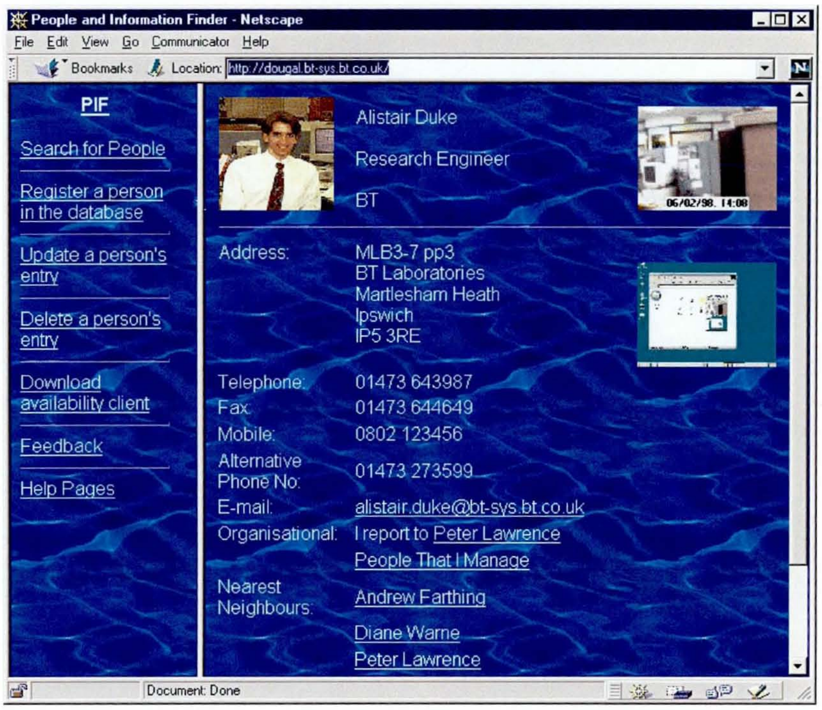


Figure 4.6. Personal details page.

The first part specifies the Web address and the path to the WebDBC control file. This is then followed by the database (JV) and table (guests) to be queried and the query operation, in this case 'select'. The second part identifies the htx file. This is the result file that displays the result of the query. Finally the query is specified. Here all people who have the current individual specified as their manager are selected and added to the result set.

The following listing (Listing 4.1) of an htx file shows how the results are displayed. WebDBC commands are specified as <%........>. The lines between the DETAIL commands are executed for each record in the result set. The variables - specified as r_variable are substituted for the relevant content of the database and displayed upon the Web page. The people are specified as hot links so that when selected the database is again queried for further information about them. Thus, a further URL is included in the DETAIL section. The page also shows the AP-IA call for each person, which allows the availability information to be determined.

```
<html>
<h2>Search Results</h2>
<hr>
<!Beginning of dynamic context>
<%DETAIL>
<!Add header on the first pass>
<%if Q_NUMROWS eq 1 >
<h4>Here are the people (with an estimate of their availability) who
match your query. Click a name to get details:</h4>
<p>
<%/if>

<!Get availability if supported for this person>
<%if r_APIAName="">
   <IMG SRC="/images/greydot.gif">
<%else>
   <%exec
cmd="c:\inetsrv\wwwroot\samples\pif\apiadummy.exe#r_APIAName#">
<%/if>

<!Show results with the name as a hot link>
<a href=
"/bin/webdbc.dll/JV/Guests/select/&/samples/pif/details.htx?d_FirstNa
me=
```

```
<%r+FirstName>&d_LastName=<%r+LastName>">
<b><%r_FirstName> <%r_LastName></b></a>
<%r_Company>
<%r_Contact>
<p>
<%/DETAIL>

<!If no records then show this message>
<%if Q_NUMROWS eq 0>
<h4>Sorry, no entries match those criteria.</h4>
<%/if>
<p>
<hr>
</html>
```

Listing 4.1. WebDBC Results Page

4.3.4 Using the PIF

It is envisaged that people might use the PIF for a number of different reasons:

- To find out how to contact a colleague, whom they already know, be it to find their phone number or their e-mail address.
- To monitor the availability of a person or a group of people to see when it is best to contact them.
- To locate a person who performs a specific role within a part of the organisation with a view to contacting that person to discuss an issue.
- People may wish just to browse around in order to increase their general visibility and understanding of the virtual organisation - fitting names to faces and so on.

Specifying search criteria on the Web form can fulfil all these requirements. Specifying a name will return information about an individual while specifying a job role or a company will return a group of people who may be appropriate to deal with an issue. In all cases, the availability information will enable people to decide whether to try to make contact with an individual or to try a colleague or alternative contact.

Once the required person has been located in the database, a desirable feature would be to enable users to initiate an appropriate communication channel with them directly from the Web page. This is easy to implement for e-mail since most browsers support this facility. It is more problematic for the telephone since some form of Computer Telephony Integration is required. The system currently employed uses a single PC with a telephony card. The 'Auto Dial' button shown in Figure 4.6 sends a request to the PC with the source and destination phone numbers. The PC then uses its telephony card to set up a two way call between these two phones. The length of time it takes to set up the call is dependent upon network traffic and the load on the telephony PC. Currently, the process is generally longer than it would take to dial the call manually; however, it is expected that this will improve.

Besides searching, the other main user operation of the PIF is to maintain the information held about themselves. The level of access given to each person is an important issue. Should users be able to change data directly or merely through an administrator who ensures integrity of the data? The type of organisation and the skill level of the users will be important factors in determining this.

4.4 Availability of Person - Intelligent Agent

4.4.1 Architecture

AP-IA is a system designed to determine the likelihood of a person being available [Duke (1996), Tracey (1996), Duke & Anumba (1997)]. The intention is to aid the initiation of communication between people at remote sites. AP-IA is a low-level system. Its use in systems such as the PIF is intended to allow ad-hoc meetings to occur between remote colleagues - the sort of meetings that people who work in the same place find very useful and often take for granted (e.g. discussions across the office or chance meetings in a corridor). AP-IA works by monitoring the equipment that people use in the working environment (e.g. telephones and computers). Transponders residing on, or associated with, these pieces of equipment generate event messages and send them to the AP-IA server. They also listen for information requests from the server, which they respond to. The AP-IA server holds this information in a database.

The server responds to requests made to it with the data stored on a particular person, giving an indication of the availability of that person. It is envisaged that requests will be generated by:

- users browsing a people database with a view to establishing communication;
- an automatically updating Web page giving an estimate of a person's availability; and
- a virtual world with representations of people, which change depending upon their estimated availability.

The data stored for each person is potentially wide-ranging depending on the amount of equipment that they use that can be reliably monitored. A person with a PC, phone and associated transponders might have the following data stored:

- **Screensaver** - on/off, active period.
- **Electronic Mailbox** - time mail was last read, number of unread messages.
- **Electronic Diary** - current appointment.
- **Phone** - time of last phone call, number of unanswered calls.

4.4.2 Modular Description of AP-IA Server

The APIA server is written in C and resides on a UNIX Workstation (current versions work on SunOS 4.1.3 and Irix 5.3). Figure 4.7 shows a schematic diagram of the AP-IA modules. These modules are independent processes. They communicate with one another using UNIX FIFOs (First In, First Out) or *named pipes* and with external processes and machines via

TCP/IP sockets. In both cases, the communication is carried out using packets of data with an agreed format.

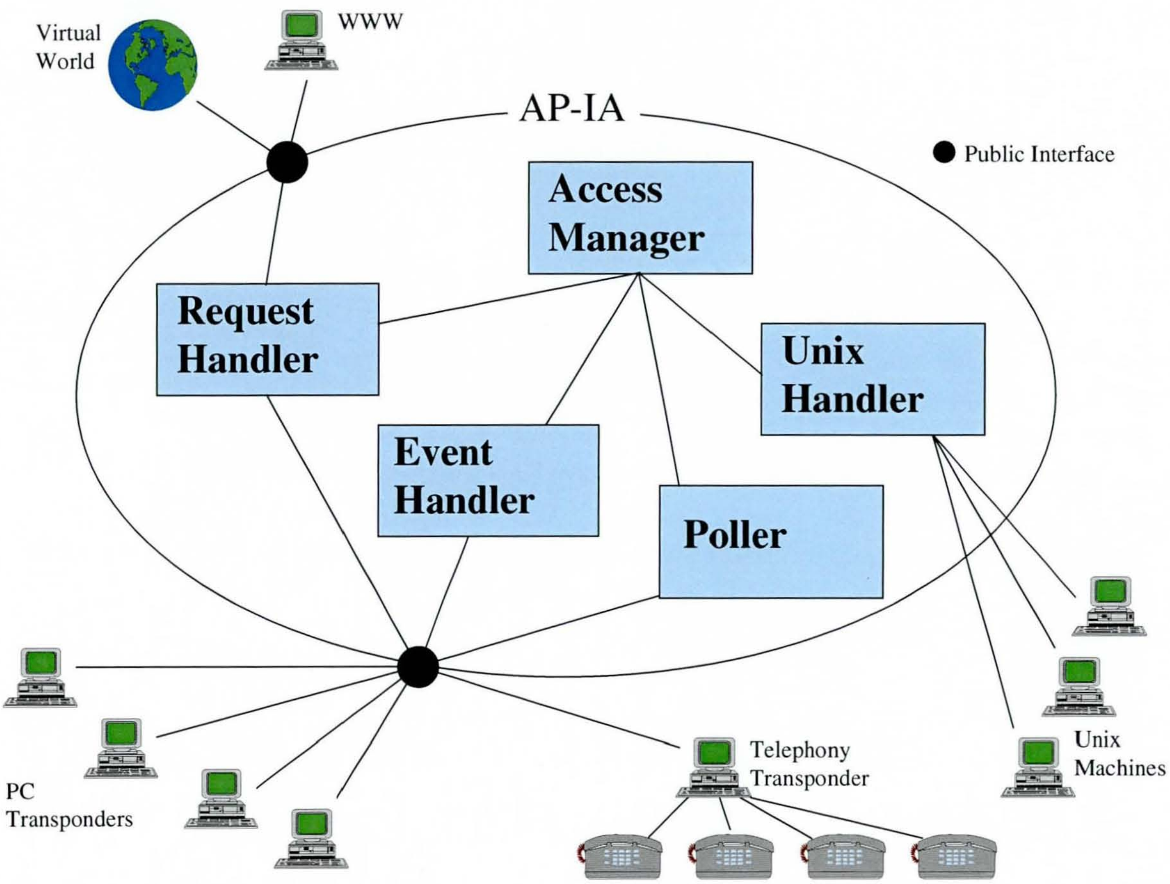


Figure 4.7. Modular description on AP-IA

A popular form of inter-process communication (IPC) is the pipe. However, these pipes can only be used when the two processes in question are related (e.g. one is a child process of the other) and can refer to the same file descriptor (the standard UNIX way of performing I/O). FIFOs were used because they allow unrelated processes to communicate with each other. These are like pipes but have a name associated with them (hence their other name – named pipes). The name is actually the path of a temporary file that the FIFO creates. Since both processes are aware of this path they can create a file descriptor for it and carry out the I/O. When there are potentially many processes writing to another process, as is the case here with many accesses to the database, it is important that these accesses are controlled. FIFOs ensure that the integrity of the database is maintained by only letting one process write to it at any one time. Figure 4.8 [Stevens, 1992] illustrates this. Where data is returned to the client process, as is the case with database read requests another FIFO is opened up to perform this function.

All modules listening for external connections have the ability to be controlled by the Internet Superserver, or 'inetd'. This allows a single process to be listening for multiple connection requests. This reduces the number of processes in the system but increases the time for a data transaction. In stand-alone mode, the main process 'forks' a child process to handle the transaction. This places fewer demands on the processor and is thus quicker.

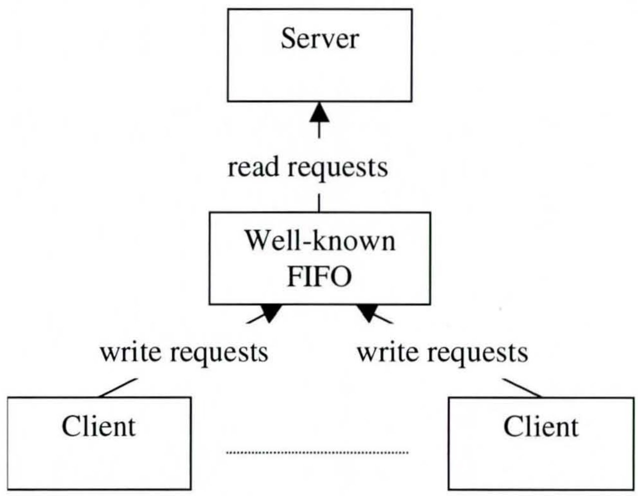


Figure 4.8. Clients sending requests to a server using a FIFO.

4.4.2.1 Access Manager

The Access Manager controls access to the database of availability information. It maintains the database by receiving updates from the Event and UNIX Handlers and the Poller. It receives requests from the Request Handler. All communications to and from the Access Manager take place using FIFO IPC. This form of IPC is particularly suitable since it allows any number of processes access to the database but restricts access by allowing just one process to be reading or writing data at any one time.

The database itself is a doubly linked list. This method, while being fast, also supports dynamic record creation, allowing the database to grow and contract, as required, while the process is executing. The dynamic memory allocation is achieved via the '`malloc`' and '`free`' commands. Thus, when a new record is required, more memory can be allocated and subsequently freed when it is no longer needed.

Figure 4.9 illustrates a doubly linked list. There are two fields additional to the information fields. These are pointers to the next and previous records. Pointers are actually variables that store the memory address of other variables. In this case, the variables are other records.

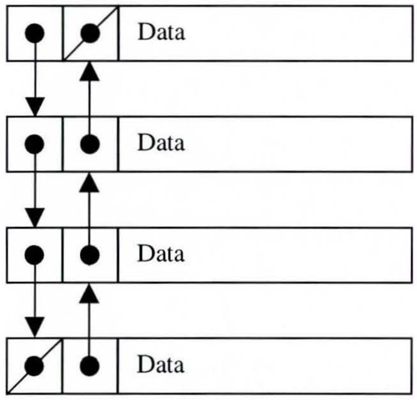


Figure 4.9. Doubly linked list with four records.

Operations on the database (e.g. find the record for a particular person) use the pointers to move up and down the database until a match occurs. Operations are fast because the data is held in memory. No time-consuming disk accesses are required, as would be the case if the data were stored in a file. When a new record is created it is added to the database by setting the pointer of the last record to the memory address returned by the `malloc` command. Records are removed by freeing up the memory and setting the pointers to null or to the new following and preceding records.

4.4.2.2 Request Handler

This module listens for external requests on a socket with a well-known port number. These requests are forwarded to the Access Manager, which accesses the database and returns data on the person's availability, if they are known. The age of this returned data is then compared to an age threshold, specified in the original request. If the threshold has not been surpassed, the data is returned to the requester. If, however, the threshold is surpassed, the Request Handler immediately initiates requests to the person's equipment transponders to get up-to-date information. Upon receiving this data, it is returned to the requester as before. It is also sent to the Access Manager, which updates the database.

The rationale behind the specification of an age threshold is an attempt to meet the differing requirements of requesters. A potential trade-off exists between the time it takes to get the availability data and the accuracy of the data. For example, a user trying to determine the availability of a particular person would generally be willing to wait for the information if they knew it was going to be accurate. Alternatively, a virtual world may be populated by a number of representations of people, which do not need to be represented so accurately. When building this world, it could be time consuming to carry out a poll, directly to the transponders, for each of the people represented. It may be more appropriate to use the data that is already stored on these people. When navigating around the world, only the representations of the people close to the user would require the most up-to-date availability data.

Data returned to the requester is accompanied by summaries of the person's availability. These summaries show the likelihood that a person is present and / or busy based on their phone and computer usage. They create an easy reference for representation of a person's availability. Also, if used on their own, they allow a reduction in the amount of raw information that a user can determine about a person's activity. This is useful if security is an issue of concern.

At present the summaries are determined from fairly simple calculations based on assumptions made about people in their working environment. This is an area for further study. It may be beneficial to monitor people's actual activity and see how that relates to the data collected upon them. Hopefully this would reveal which sources of information are the most reliable as the basis for calculations. These could then be given more weight. Allowing the calculations to be tailored to individuals would perhaps be a more reliable way of determining a summary of availability.

4.4.2.3 Poller

The Poller uses a list of transponders from which availability data can be determined. These transponders are periodically polled. Data returned from them is collated and then forwarded to the Access Manager. The Access Manager determines which person they refer to and updates that record. The period between polls is an important issue. Too low a poll period will place a burden on the server and transponders. In particular, a transponder located on a PC running MS Windows will harm usability of the PC if it is polled too frequently. If the poll period is too high, a high proportion of the availability requests would ignore the information gained from the poll and a higher number of polls on demand would result. This would generally increase the response time of the system and effectively make polling redundant. This may be an acceptable arrangement if the response time is acceptable for all requesting applications.

4.4.2.4 Event Handler

When a change of state occurs, for example a user selects 'Do not disturb', the transponder recognises this, connects to the AP-IA server via a known port and sends a message to the server. The Event Handler listens for these messages. It interprets them and forwards them to the Access Manager.

The procedure that handles the decoding of the packet from the transponder uses a recursive algorithm (an algorithm containing a function that calls itself). This is because the number of data elements sent by the transponder is unknown. These data elements are encoded with a unique tag (a number), the length of the element and the element itself. The decoder calculates the length of the whole data section by using the overall packet length. It then recursively calls a function 'read_data_item' which strips off and decodes a data element as a record then reduces the remaining length counter by the amount it has stripped off. It calls itself until the counter reaches zero. The end result is a linked list of data records, which are then converted into a single record. The following pseudo code (Listing 4.2) illustrates this:

```
begin
   counter = length of data portion
   if counter > 0
      allocate storage for record
      read_data_item(counter, pointer to record)
   end /* record is now complete */
end

record read_data_item(counter, pointer to record)
{
   read tag and determine type
   read length
   read element
   set record fields
   reduce counter by length
   if counter > 0
      allocate storage for record
      record = read_data_item(counter, pointer to record)
   end
}
```

Listing 4.2. Psuedo Code for Reading Packets.

4.4.2.5 UNIX Handler

The UNIX Handler works differently to the other data gathering modules in that it does not communicate with a transponder. Instead it executes a Perl script. The script reads a list of machines. For each of these it executes the 'rusers' command. This returns a textual report of the users currently logged in, together with their idle time. This is parsed by the script. The script returns a data file with a list of users, the machine they are logged into and the idle time on that machine. The UNIX handler reads this file, collates the data and forwards it to the Access Manager. If a user is logged onto more than one machine, the machine with the least idle time is recorded as the one in use.

4.4.3 The AP-IA Client

The AP-IA client is known as the PC Transponder. This resides upon the PC of each person that AP-IA is to monitor and collects information about the usage of that PC. The following are monitored by the transponder:

- Changes in mouse position
- Changes in caret position (keyboard cursor)
- Current Schedule+ appointment
- Number of unread mail messages (MS Mail or Exchange)
- User Message
- Do not disturb selector.

The transponder is written in Microsoft Visual Basic. This rapid application software allows lightweight clients with supporting graphical user interfaces to be developed. All the CPU usage required for this monitoring process is carried out using idle time. This means the user should not notice any degradation in performance as a result of the transponder. The transponder is designed to run as minimised on start-up. User interaction is achieved via the GUI illustrated in Figure 4.10. This allows the user to enter a message or specify whether they wish to be disturbed or not.

The mail and Schedule information is determined with the use of MAPI - Microsoft's Messaging Application Programming Interface. This allows the status of messaging applications to be interrogated by other processes on the same machine. Visual Basic programmes can use MAPI via 'Custom Controls'. By adding these to the GUI (although they are hidden when it is executing), Visual Basic is then allowed to modify their properties and call relevant functions.

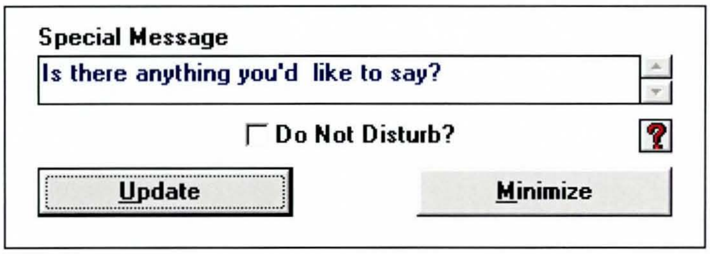


Figure 4.10. Transponder GUI

Communication with the server is achieved with the use of sockets. This functionality was implemented with the commercial software IPWorks. This is a set of 'Custom Controls' that can be added to the Visual Basic form to allow the required communication to take place. The transponder users IPport to listen for requests from the server, IPdaemon to connect to the server with updates and IPinfo to provide IP address to name mappings.

4.5 PIF Pilot Trial & Evaluation

The PIF was trialled as part of a CICC pilot on a large construction project. The project involves a large number of organisations distributed across many locations. The site itself is very large so even those located on site are distributed amongst the site offices and management team office. In such an environment, technologies such as the PIF can be beneficial.

The trial included both technical evaluation and usability studies. This was to determine how useful such systems are in the workplace and how they impact upon the working environment. It also highlighted technical issues with the system and steered the technical development process. One such example of this was the 'Personal Address Book' facility. Upon exposing the PIF to construction managers, they revealed that although the search facility is vital during the earlier stages of the project, at later stages the need for it is diminished since most communications tended to take place with a few, key individuals. A facility was required that could display information about the key people that each user contacted most often. The 'Personal Address Book' was added that allows each user to select people to add to their individual page. The page (available within one mouse-click after starting the PIF) not only shows the phone numbers of people, but also their current availability. Thus by keeping the page open, users can see at a glance, those who are available for contact.

The PIF was installed at the project management office, on-site, and at the offices of the client in London. New users were introduced to the technology and observed while performing a series of tasks using it. The intention was to evaluate the usability of the system and its interface. They were then asked a series of questions related to how they find and contact people currently and whether a system such as the PIF would be beneficial on construction projects.

Generally, the results have shown that the PIF could be a useful tool for overcoming many of the communication problems that exist in large virtual organisations. However, there is quite a large investment involved in setting up and maintaining the information. This is a potential barrier to the successful adoption of the technology. It quickly became clear from the trial that the 'bottom-up' approach of allowing people to add their own information was problematic. Users are more than willing to add data about themselves but have high expectations of the data available about other people. If that data is not yet available then the likelihood of them using the system is diminished. A 'top-down' approach, with information being set-up and maintained from a central resource, may well have been more successful.

4.6 An Advanced Telepresence Environment

The intent of the CICC technologies such as the People and Information Finder was to support project personnel by providing access to information over networks via a common user interface. The PIF was seen as a first step towards creating a Telepresence Environment in that it allowed people to maintain an awareness (akin to that possible for co-located colleagues) of other's availability and ability to carry out communication. It was also intended to improve the level of knowledge available to individuals and the organisation by providing a means of locating people in particular roles or with particular skill sets. This section presents an advanced Telepresence Environment that would be applicable to

Concurrent Life-Cycle Design and Construction projects, building upon the approach developed in the CICC project.

4.6.1 Aims of The Environment

The principal aim of the Environment is to support Concurrent Life-Cycle Design and Construction projects by providing a collaborative space for personnel that integrates access to people and information. The Environment should contain visual representations of the construction project and of project team members (i.e. the users). These representations provide the users with access to underlying project data (such as drawings, schedules, rationale, etc.) and to the other users via integrated communication channels.

The Environment aims to provide support to users in two ways:

- **Passive** - to allow people to maintain an awareness of others and of the construction project. The environment should draw the individual towards features and people that are of interest or are currently impacting upon their work area. The aim is to facilitate serendipitous contact with people and information via interest profiling.

- **Active** - to act as a ubiquitous user-interface for finding, contacting and communicating with people and for locating information about the construction project, thus providing teleconferencing with a context.

In both scenarios, the aim is allow project personnel to work as if co-located with colleagues and as if located at the construction site.

4.6.2 Proposed Functionality

4.6.2.1 Overview

This section outlines the proposed functionality of the Telepresence Environment and explains the way in which it is expected that the users will interact with it. Determining the feasibility of this interaction and general functionality formed a large part of the development process. The issues involved and potential approaches are discussed.

As with the PIF, the technological basis for the system will be IP (Internet Protocol) or, more specifically, Web technology. This will allow users to access information stored in the network using a common client or browser. Thus, it is essential that all project information should be accessible over a project extranet and that existing project systems should be Web-enabled.

It is envisaged that usage of the system will be persistent i.e. a client will be started as a user logs-on and remain running throughout the day or working session. The contextual load placed on the user will be variable and will adapt to different usage situations. The load will be varied by techniques such as changing the window size of the client or altering the style of information delivery. For example, when users are performing activities such as writing a document, the window size will be reduced giving users a 'background' awareness of the information being presented. Upon seeing something of importance, users would be able to select the client and increase the window size. The window could also be increased to full screen during periods of inactivity - rather like a screensaver.

Integral to the client will be a 3D browser. This will enable 3D environments to be downloaded and displayed and allow users to navigate around it. The environment will contain a 3D representation of the construction project. It will also be multi-user and contain avatars to represent the other users. Objects and avatars in the environment will contain hotlinks to information. In the case of avatars, this will be a link to the corresponding user's homepage. Construction objects will have links to project documents (drawings, schedules, rationale etc). As stated above, the system is dependent upon a single project repository or a Web-enabled document management system. By associating URLs with objects in the environment, access to stored information can be given. Since this information might only be available to specific people a user authentication process would be required. This could be carried out as users join the environment and then used whenever restricted documents are accessed.

4.6.2.2 Project Information Integration

As stated above, the environment relies upon existing systems that can provide data about the project and personnel. Two topologies describing the environment and this information integration process are now described. The first, shown in Figure 4.11, is an ideal situation where a central object oriented database (or single project model) is used [Anumba et al, 2000]. Here, all building elements are expressed as multi-attribute objects (including geometric data, cost, structural qualities, manufacturer, etc.) The adoption of this approach is a general aim for the industry (as alluded to by Hannus in Figure 1.2 and described in Section 3.5). The approach would allow users to generate discrete 2D & 3D drawings, documents, schedules, costs, etc. from the central object repository. Similarly, it would be possible to generate a 3D visualisation of the project from the same model with links to information objects in the model integral to it. This visualisation could then form the basis of a Telepresence Environment. The approach adopted in research projects such as OSCON (as identified in Section 3.2.1.) could soon allow such visualisations to be produced with a minimum of human intervention [Aouad et al, 1997].

It should be stated at this stage that a full 3D representation of the whole project containing all objects is not appropriate for use as a navigable 3D visualisation. The complexity and detail in such a model would be far to high for even the most powerful computers to provide a level of interaction that would be acceptable to users. Instead, it is necessary to provide a visualisation that is in effect an abstraction of the full model. Different views or layers can be used to encapsulate detailed information and conceptual representations of object groups can be used.

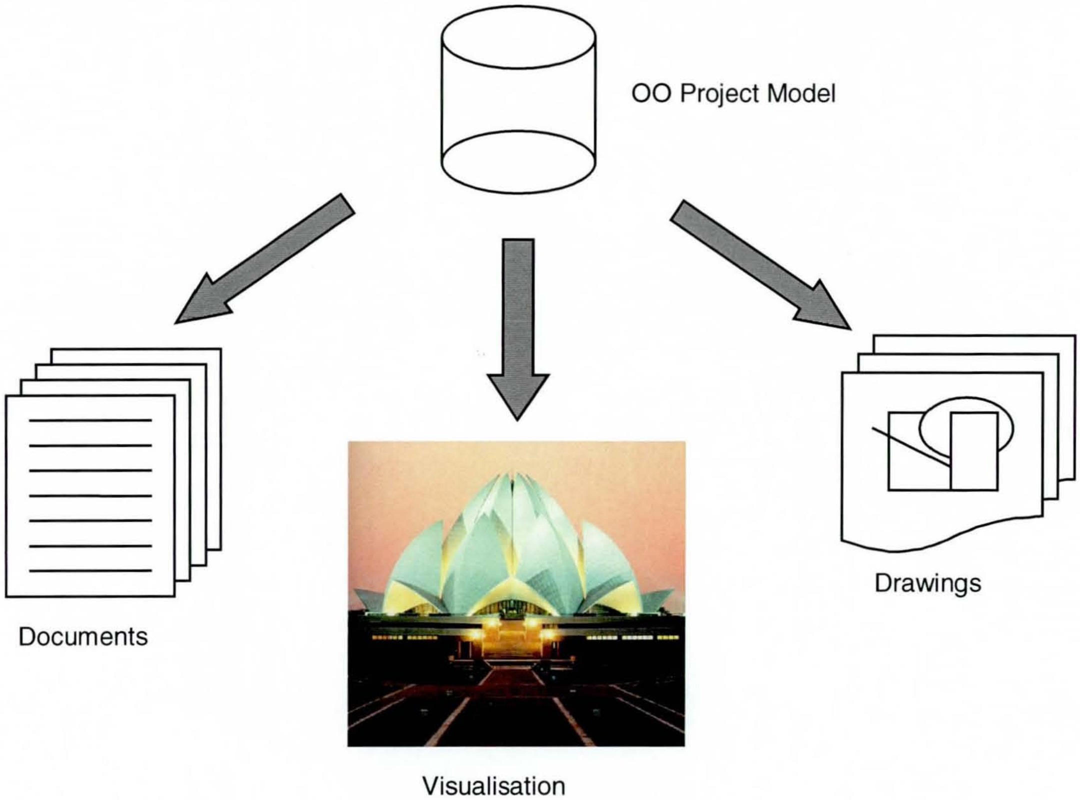


Figure 4.11. Ideal Topology.

Were such complex 3D visualisations feasible today, a logical extension of the Telepresence Environment would be to enable it as an on-line design environment. Although this approach does sound superficially appealing, it would however be fraught with difficulties such as addressing the impact of any changes upon other parts of the model, notification of appropriate personnel and the visual representation of design data pending approval and design as-is. It is also questionable whether the scenario of multiple users meeting within a virtual environment to collaborate upon a design is appropriate. A more likely scenario would involve designers collaborating by sharing a design application possibly with the use of additional conferencing facilities. Design changes would then be represented in a model once the necessary checks and approvals had been made.

The second topology, shown in Figure 4.12, describes an approach that is more feasible using today's systems. Here a document management system is used to control discrete 2D & 3D drawings, documents, schedules, costs, etc. in the form of files. Obviously it is not possible to generate a visualisation from such data and so a separate 3D modelling process is required to produce it. This has the disadvantage of also being a discrete file (albeit with links to other data) and so would not remain up-to-date with the design. In order for such a visualisation to remain useful over time, it would need to be periodically updated or be sufficiently conceptual such that it remained a good representation of the project and its principal elements. Links to the document management system would need to be manually inserted into the 3D model. These would allow user to select objects in the 3D model and receive information about them from the document management system.

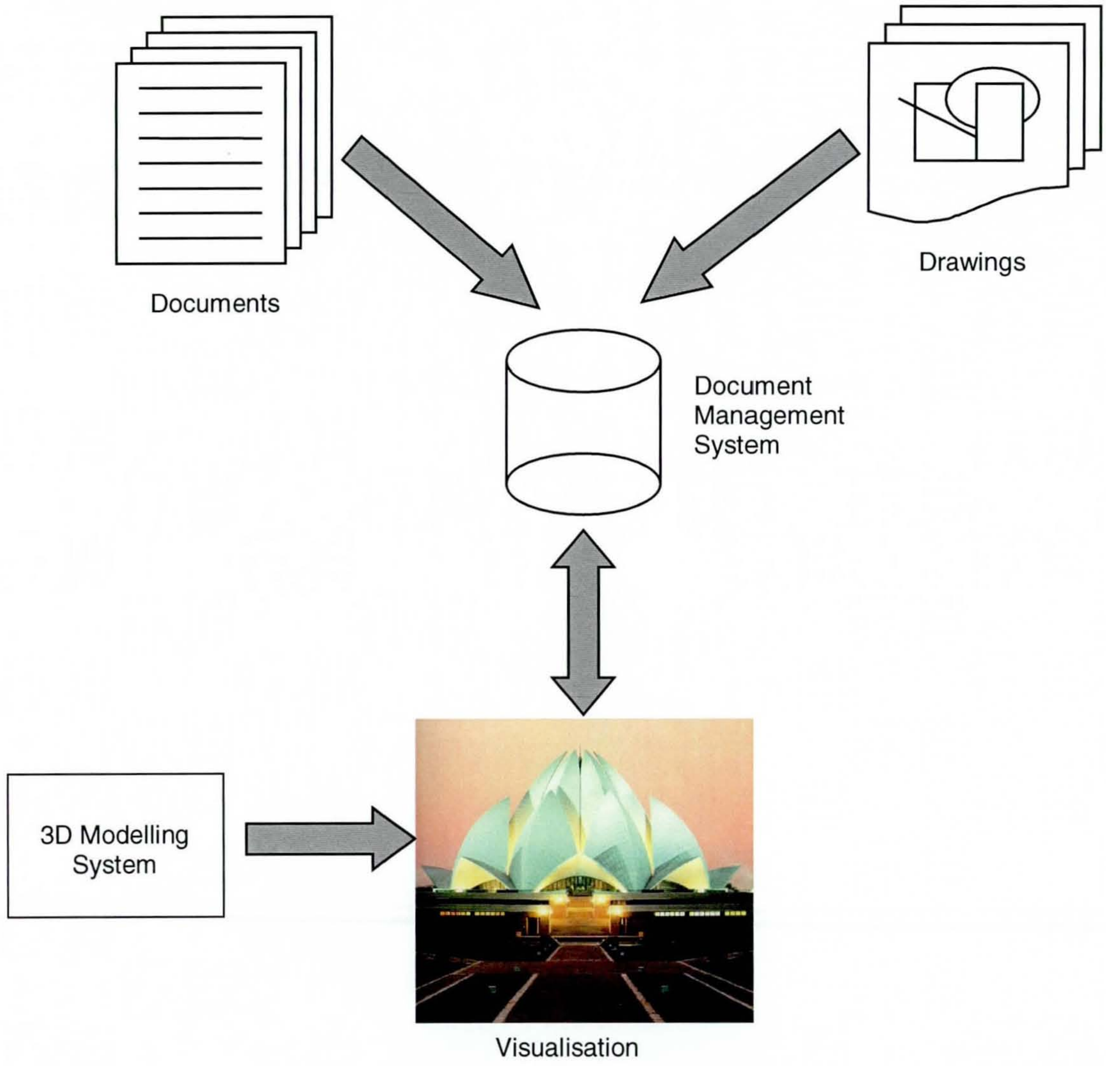


Figure 4.12. Currently feasible topology.

4.6.2.3 Communication Integration

In addition to representations of the project, there will also be those of project personnel. A user navigating around the space will be represented by their avatar thus allowing others to see their current focus. The act of approaching and/or selecting individuals in the environment could allow appropriate integrated communication channels to be opened up. These channels could be textual, audio or visual depending upon different situations and requirements. This will facilitate *ad hoc* project discussions. Individuals querying information systems about a common area of interest will be able to interact with each other whilst using the relevant part of the model as a reference for discussions.

Once communication is taking place, it may be appropriate to represent this fact to other users. This would allow them to request to join in the conversation if they so wished. Those currently communicating would be able to accept or deny these requests.

4.6.2.4 Profiling and Automatic Navigation

Descriptions of functionality have, up until now, focused upon situations where the user is navigating around the environment by themselves. A parallel paradigm is that where the user's view of the environment is controlled.

The reasoning behind this approach is that information can be conveyed to the user in a manner that promotes serendipity. Section 3.4.2 identified the importance of ad hoc meetings and 'weak ties' in collaboration [Huxor, 1998]. These are the meetings that happen when two people meet in a corridor or other shared/public space. A discussion often ensues that at least one of the parties was not prepared for and generally the information gleaned from it was certainly not directly sought. Parallels can be drawn to situations where people are located 'on-site' or at the 'workface'. Chance encounters with product related objects or events can provoke thought or remind individuals of important issues. In general, chance encounters can enable a wider perspective and help to promote a better understanding of detail. They are, or course dependent upon the entities involved being co-located and those located remotely can suffer as a result.

By drawing users towards both people and information of relevance, chance encounters can be promoted for individuals remote from each other or the site. In fact, there is no reason why this should not be equally beneficial for those working in the same office or at the site itself since co-location does not necessarily infer that awareness already exists.

The important issue is how to determine the relevance of people to each other and the relevance of information to individuals. Similarly, how much information should people be made aware of? Too much will soon lead to information overload whereas too little will cancel out the need for the delivery of information in this manner.

There are a number of techniques in existence and under development that can allow the relevance of people and information to an individual to be determined. These can be used in conjunction with each other to build up a personal profile. Some examples with associated issues are:

- Recording the role of an individual within a project or specifying a name for their job. This was the approach used in the PIF. People often are quite particular about what they call their job and two people in the same job may describe it in differing ways.

- Recording a job description of an individual using free text or a list. This might include their skills, previous experience and current activities. It could be searched against when determining relevance. Again, people describe their jobs in different ways. Additionally, this sort of information can be difficult to collect and keep up-to-date.

- Specification of skills or interests against a pre-constructed list or ontology. This has the advantage of constraining people to a set of descriptors and makes subsequent searches against the list easier. The difficulty here can be the generation of the ontology - people will often want to add to or change it. Again, keeping the profile up-to-date can be an issue.

- Searching through a body of work to determine expertise or recurring themes. The work could be a series of documents or drawings authored by the individual or, as in the case of the MIT expert finder [Vivacqua, 1999], a body of computer code. Algorithms can be constructed to search through the work and generate a profile. This has the advantage that, since it is largely an automated process, it can more easily be kept up-to-date. However, it is complex to set up.

- Current focus. Systems can be employed to monitor the focus of the user. This may involve determining the Web page currently being accessed, or monitoring the words being typed into the computer [Crabtree et al, 1998]. Again, this approach is automated and very powerful but also has inherent security and privacy issues.

- Recent focus. Similar to the above except that historical data is kept to maintain a wider view of interests and concerns.

These examples illustrate the possibilities but also identify the difficulties and research issues that are currently being addressed or need to be addressed in the future. For the purposes of this research it is necessary to select an approach or approaches that map well onto the problem domain and can effectively utilise the information systems being employed.

It is important to consider what kinds of information should be presented to users. It is envisaged that at any one time, there will be a number of entities that will be of relevance. These may be of the following nature:

- Other users with similar profiles;
- Other users looking at the same information;
- Objects relating to relevant data;
- Objects relating to recently generated events; and

- Other users who have either authored some documents of relevance or who have recently generated an event of relevance.

Events may be RFIs (requests for information), approvals, delivery notifications, etc. The relevance of each entity may change over time as might the 'need to know' about it, e.g. a drawing approval might be very relevant immediately after it occurs but become less relevant over time. Similarly the 'need to know' level of an approval will be largely reduced once it has been read or acknowledged. As deadlines for RFIs approach, their relevance and 'need to know' levels might increase. With people, colleagues who work very closely maybe highly relevant to each other but their 'need to know' about each other would probably not be high.

The result of these varying factors will mean that the information displayed to the user should change over time. Indeed, if the interface is to promote chance encounters, then changes of scene and visual stimulation through movement should be used to draw the attention of the user. Importantly though, it should also not be too repetitive and it should respond to user acknowledgement so that digested information is not repeatedly delivered (although some repetition of highly relevant scenes may be beneficial).

It seems that what is required is a constantly updating list of entities for each user. Each item on the list should have rationale as to why it is considered to be relevant and a measure of that relevance which changes over time. As each item is presented to the user, they should be given the opportunity of acting on it by initiating communication or retrieving information or merely acknowledging it. These actions will alter the relevance of the item or remove the item from the list.

4.6.2.5 Forum Contact Space Agent

The Forum Contact Space that was described in Section 3.4.3 employs an agent system that determines the placement of avatars based upon profiles of users. The Contact Space agent employs a software component called the Forum Envoy that resides upon each user's computer. The Forum Envoy is in fact a development of the AP-IA transponder that was developed as part of the CICC project and that was described in Section 4.3. The Envoy extends the AP-IA transponder by also collecting information about the Web sites and documents that the user visits and reads as well as the applications that are used. The Contact Space Agent uses this information, sent continuously from a person's Envoy to determine each person's current interests. The Agent maintains a list of the most recent words associated with each person's activities. These words are derived from the titles of applications used and from the contents of the Web pages accessed. A further component called Prosum [Davies & Weeks, 1998] is used to derive this set of words from textual input. Prosum has been widely used as a Knowledge Management tool to automatically summarise passages of text into a short abstract and a series of keywords.

Similarity calculations are performed on the lists of words for each user. If matches occur between these lists or with interest groups in the environment then the user's avatar is moved appropriately. A dynamic profile is built up over time based upon this periodic input. The Agent combines this profile with a static one that is based upon interests expressed by the user.

The Forum Contact Space Agent could be adapted for use in the Telepresence Environment. In its current form it would be able to maintain a dynamic interest profile based on textual documents that are accessed. In the Construction environment other documents besides textual ones are often used e.g. drawings, schedules and cost plans. In order to build a profile based upon the accessing of these documents, an alternative strategy is required. One approach would be to access the meta-data from a document management system that is associated with each document. When documents are added to a management system, data about them are generally recorded. Such data includes the name of the document, the author's name, the work or trade package with which the document is related and the date and time at which it was added to the system.

In order to obtain this meta-data, the Forum Envoy would need to given additional functionality. If a Web-based document management system is in use, the detection of the

URLs accessed would enable the accessed documents to be identified and the associated meta-data obtained via a database lookup. In a non-Web-based scenario it would be necessary to rely upon other approaches such as obtaining data from server access logs or from a client API that might allow document accesses to be recorded.

The agent system would also need to be aware of events that occur on the document management system such as the addition of documents, the generation of RFIs and the need for approvals to be issued on documents. Relevant users could be made aware of these events via the Environment.

The way in which the agent system is integrated into the Telepresence Environment is described in the following section which introduces a conceptual architecture for the Environment.

4.6.3 Conceptual Architecture

Figure 4.13 shows a conceptual architecture of the proposed Telepresence Environment [Duke & Anumba, 1999]. The elements identified are considered essential in providing the functionality expressed in the previous section. Of the two approaches to information integration described in the previous section, the second was chosen for inclusion in the conceptual architecture. The reasoning behind this was that it relies on systems that are currently in use in the industry and could be implemented more readily that the first approach. The function of each element in the conceptual architecture is now explained as are the links to other elements.

4.6.3.1 3D Model

As shown in Figure 4.12, the 3D model needs to be generated in a process separate from the detailed design (although it may already exist as a result of an early design process). Virtual Reality Modelling Language (VRML) is a standard commonly used for publishing 3D models over the Internet making it appropriate for use in this situation. Commercial products do exist that convert existing 3D CAD files (such as DXF) into VRML. However, as stated above, design files are generally too complex to be used as visualisations and require skilled and time-consuming work to be carried out upon them.

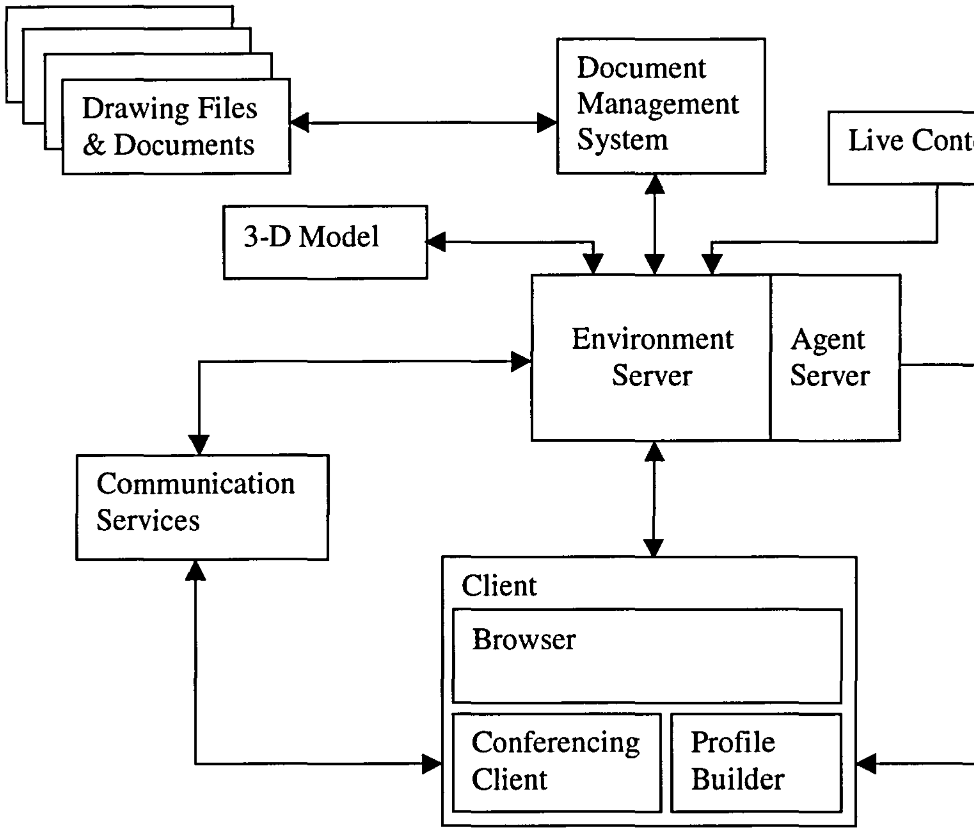


Figure 4.13. Conceptual Architecture.

An alternative is to use models built with the intention of being used for visualisation or to build one from first principles using a commercial package such as Concept CAD or 3D Studio VIZ. VRML allows URLs to be associated with objects. As well as being static, links to Web pages or models can be made dynamic. That is, the link contains descriptors for the item that can be used in a search of the document management system. For example, a beam object might be given a URL containing descriptors for its type - beam, its location - south wing and its work package - structural. When the object is selected the database can then be searched against the descriptors and a list of relevant information can be presented to the user. It is difficult to determine how effective such a process would be. It is heavily reliant upon the descriptions given to objects, upon the granularity of the objects and on relevant data being returned from a search (especially when much of the data being searched upon is graphical). In a scenario where an object-oriented modelling system is used, the process is more likely to be successful since a direct translation can be made between the visualisation object and the design object.

4.6.3.2 Environment Server

The environment server is the central element in the system. It mediates the links between the different elements and serves the environment that the user sees at their browser. Users starting the client will logon to the environment via the server which will then manage the user session. The server is linked to the document management system and mediates the serving of documents to the user with authenfication provided by the current session. In order to allow the control of the client view, the server obtains a list of relevant entities from the agent server, cycles through these and controls the client view appropriately.

4.6.3.3 Agent Server

For each user, the agent server obtains a current profile from the client. It combines this with static profile data (such as job role, etc.) and uses it to determine relevant information from the document management system and relevant people. The details of these items are then made available to the environment server which uses them to control the user's view. The Forum Contact Space Agent, described in Section 4.6.2.5, is adapted to carry out this function.

4.6.3.4 Profile Builder

The profile builder monitors the PC usage of the user in order to determine current and recent focus and the activity of the PC. This is made available to the agent server which combines it with the static profile data that it stores. It may be beneficial to give the user the opportunity to add a drawing or element to their interest profile so that when changes or events occur in relation to it they are informed of them. This will be in addition to the formal process where the notification must be assured of getting through e.g. via e-mail. The Forum Envoy, described in Section 4.6.2.5, is adapted to carry out this function.

4.6.3.5 Document Management System

This element is necessary in order to handle all the formal processes that will remain in existence such as drawing change control, access permissions and sign-off. In order to be used in this architecture, it will need to Web-enabled i.e. all interaction should be possible via the use of a Web browser. User accesses of elements in the landscape will result in queries on the management system. The user will then be presented with a list of relevant drawings or documents that they can view in their Web browser or other viewing application. Authentication is handled via the user session.

4.6.3.6 Communication Services

The environment server will control access to these services. It is aware of the relative position of users and the communications capabilities that they have (via the people database). Using these, it can set up appropriate communications links. The services will range from those with low cognitive load, such as text chat and e-mail for background conversation up to those with full cognitive load, such as audio and video conferencing for focused meetings. Interactions between individuals will be depicted within the landscape and other users will be free to join in conversations or request to join in meetings.

4.6.3.7 Client

The client is the main element on the client machine. It is the user's entry point to the system. It consists of a 3D viewer element to support interaction with the environment. In addition to this are elements capable of handling interactions with the server (such as authentication) and with data and communication tools on the client machine. It will also contain the profile builder.

4.7 Summary

This chapter outlined the potential of a Telepresence Environment for construction and examined an approach towards that goal that was achieved as part of the CICC project. The key objective of the CICC project was to provide a common environment for the access of project information and people. To some extent, the environment was to be inhabited by project personnel in an attempt to improve communication towards the levels that would be expected for co-located people in the organisation.

The chapter identified two technologies that were developed in the project. These were Augmented Reality and the People and Information Finder. A detailed account of an implementation of the latter, by the author, was given. This was seen as a first step towards creating a Telepresence Environment in that it allowed people to maintain an awareness (akin to that possible for co-located colleagues) of other's availability and ability to carry out communication. It was also intended to improve the level of knowledge available to individuals and the organisation by providing a means of locating people in particular roles or with particular skill sets.

The chapter has also described an advanced Telepresence Environment for CLDC that builds upon the integrated approach advocated in the CICC project. The aims of the environment and the proposed functionality were outlined. These have led to the development of a conceptual architecture containing a series of components that integrate to enable the proposed functionality. Each of these components has been described together with an indication of whether they currently exist or need to be built. The conceptual architecture is used as a basis for the development of a prototype version of the Telepresence Environment. The prototype, described in the next chapter, illustrates the Environment from the user's point of view. It also provides the means to more clearly define some of the implementation issues that have been identified in this chapter as a result of the development of the architecture.

Chapter 5 Development and Operation of The Environment Demonstrator

This chapter describes the concept demonstrator that was developed to illustrate the applicability of Telepresence to Concurrent Life-Cycle Design and Construction. It first presents and discusses the rationale behind the development and then goes on to introduce the architecture for the demonstrator using the Conceptual Architecture in the previous chapter as a basis. The development environment used is then identified. This is followed by a commentary on the system design process that describes the steps that were taken and the design decisions that were made. Finally a description of the functionality of the demonstrator is given.

5.1 Rationale and Methodology

The concepts that are proposed in the environment are by no means an incremental step from those that are employed in existing tools currently in use in the industry. For this reason, it is very difficult to assess whether the concepts are appropriate and that the proposed methods of implementation are correct. As a result of this the production of a concept demonstrator was identified as one appropriate course of action. The lack of available resources also meant that is was unlikely that a fully working system as described in the previous chapter could be built and evaluated on a real project with a trial group of users. A concept demonstrator would allow the realisation of at least some of the proposed facilities and would enable an evaluation to be undertaken of the value of the proposed system.

The development of a concept demonstrator or prototype is a method of evaluation that is appropriate at the early stages of a software development life-cycle. It should attempt to illustrate some or all of the proposed functionality of a system. The development of the demonstrator should aid the overall development process by allowing those performing the development to find out what is appropriate or not at a very early stage. This can save much time since inappropriate courses of action can be rejected or conversely, the developers, having something more tangible to work with are more likely to introduce new ideas at this stage too. Eason (1988) concurs by stating that 'early assessment of the degree to which a system meets the needs of users and the organisation provides an opportunity to change the design and improve the probability of the final system being successful'.

Somerville (1992) identifies the benefits of developing a prototype as:

- Misunderstandings between software developers and users may be identified as the system functions are demonstrated.
- Missing user services may be detected.
- Difficult-to-use or confusing user services may be identified and refined.
- Software development staff may find incomplete and/or inconsistent requirements as the prototype is developed.
- A working, albeit limited, system is available quickly to demonstrate the feasibility and usefulness of the application to management.
- The prototype serves as a basis for writing the specification for a production quality system.

Although as explained here, the concept demonstrator is a form of evaluation in it's own right, it is generally used as a tool to allow further evaluation techniques to take place with a group of potential users. This was certainly the intention in this project. The evaluation process that was carried out once the demonstrator was developed is discussed in the next chapter

5.2 Architecture and Development Environment

Figure 5.1 shows the conceptual architecture introduced in Section 4.6.3. In this version the various elements are colour coded depending upon their level of inclusion in the demonstrator. The concept demonstrator simulates those elements illustrated in blue. The simulation of the environment server is the main function of the demonstrator. It illustrates the log on process, the representation of other users, the presentation of agent-provided information and the mediation of access to other people and information. The demonstrator also simulates the agent system. It would be difficult to otherwise illustrate their function within a stand-alone demonstrator. The agent software relies upon profiles built over a period of time as well as interaction with other users' profiles. The absence of other users in the demonstrator also means that there is no one to communicate with and demonstrate the communication services in a 'live' manner. For this reason the communication technologies and others to communicate with are simulated by the environment. Finally a Web-based document management system is simulated in order to illustrate how it would be integrated into the environment. The items in white i.e. the browser, VRML model, and documents and drawings are principally included 'as-is' in the demonstrator. The item in grey (i.e. Live Content) has not been included in the demonstrator due to the lack of time.

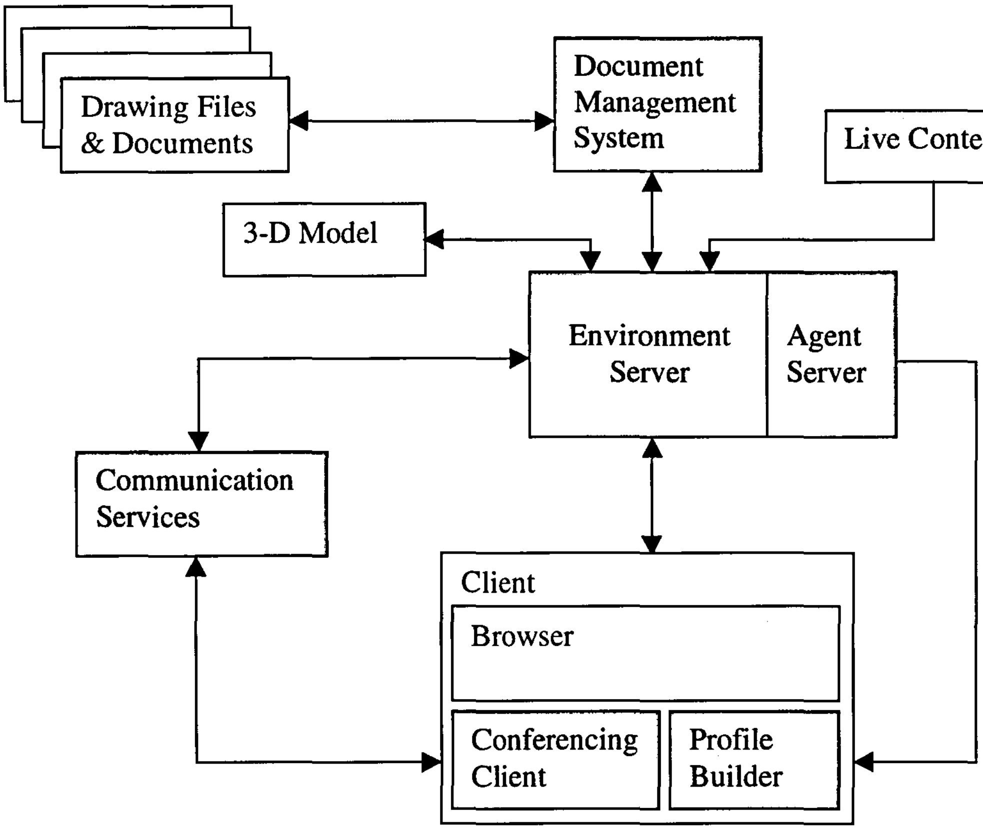


Figure 5.1. Architecture of Demonstrator

Figure 5.2 shows the technologies that were employed to produce the demonstrator. These are described it turn.

Access Database

Microsoft Access is the database component of the Microsoft Office suite of software. It allows the creation of multi-table relational databases. This means that complex sets of data and the relationships between them can be modelled and stored. It is more than adequate to satisfy the performance requirements of the prototype, is readily available and was chosen for these reasons.

ODBC

The Open Database Connectivity (ODBC) technology was introduced in Section 4.3.1 in relation to its use in the People and Information Finder. It is also used here, again to provide a link between a proprietary database and the generic Structured Query Language although in this case a further technology is required to enable that interface - JDBC (explained in the next section).

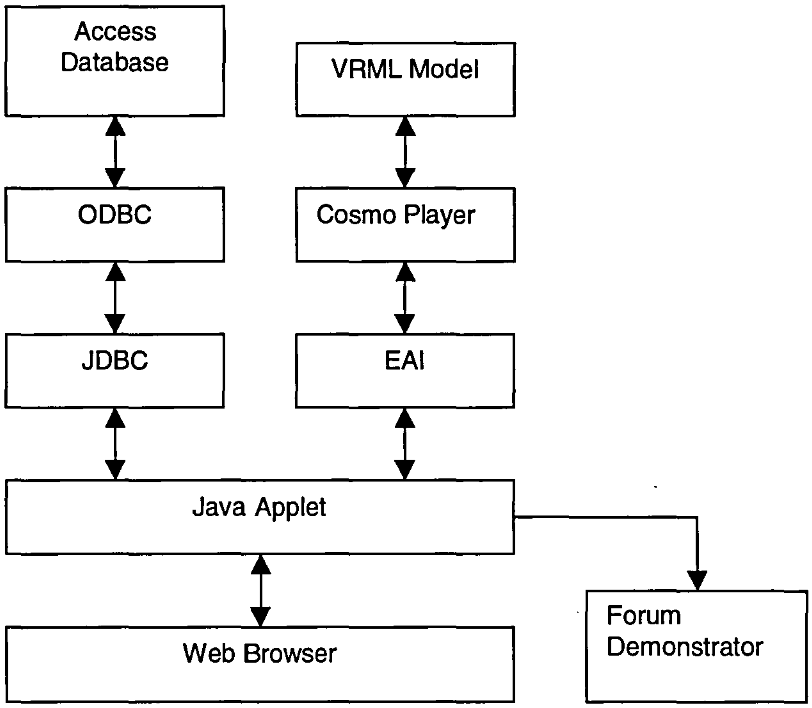


Figure 5.2. Technologies Architecture

JDBC

Java Database Connectivity (JDBC) is the technology that provides this extra link. This set of libraries is required as an addition to the Java language which has no in-built SQL or database support.

Java Applet

The Java Applet is the core of the demonstrator. It provides the interface between the user, the database and the VRML model. It was decided to implement the demonstrator using Java for a number of reasons. Firstly, Java has a well documented interface with VRML - vital for manipulation of the model itself and the user's view of it. Secondly, since Java is interpreted rather than compiled code, it can in theory be written once to run on any platform. Thus any device with a Java Virtual Machine can interpret the Java byte code and run the application. Finally, a Java applet is downloaded and run within the context of a Web browser. This has the advantages of users not having to install an application or to re-install an application when changes or bug-fixes are made. The disadvantages of using a Java applet are that they run more slowly than a compiled application and that they require downloading before they can be used.

VRML Model

Virtual Reality Modelling Language (VRML) is the 3D modelling language for the Web. This has been described in Section 3.2.

Cosmo Player

Cosmo player is one of a small number of VRML 'plug-ins'. Basically it provides the Web browser with the capability to display VRML models. It also provides its own user interface that allows manipulation of and navigation around a 3-D environment.

Extended Authoring Interface (EAI)

EAI is the link between Java and VRML. It allows a VRML model to be controlled from within a Java program and also allows events generated by VRML to be passed back into a Java applet or application.

Web Browser

The Web browser is the environment in which the demonstrator is run. Most Web browsers contain a Java Virtual Machine which allows them to interpret and run Java byte-code. It also provides the so called 'sand box' in which the applet runs separated from the local file system thus providing a level of protection for it from the downloaded code.

Forum Demonstrator

The Forum Demonstrator is the stand-alone demonstration of an Audiographic Conferencing system. It is employed here as an illustration of how communications facilities can be integrated into the environment. The demonstrator is an installed application and does not run in the Web browser.

Development Environment

Microsoft J++ was chosen as the development environment for the Java portion of the demonstrator. J++ is not the choice of the purist since it allows the developer to include code that is specific to Microsoft platforms. This goes against the Java principle that the same code should be able to run on any platform that has a Java VM. However, it is also possible to produce code that fully conforms to this principle. J++ uses an Integrated Development Environment (IDE) that is similar to the ones employed by Visual Basic and Visual C++ (also Microsoft products) and is also free. These were the reasons for its use.

An additional development environment was employed to test database code. This is not well supported by J++. The environment used was JDBCTest from INTERSOLV[11]. This free piece of software, written in Java allows the developer to write and test small pieces of SQL database code and to view the results.

[11] http://www.intersolv.com/

5.3 System Development

5.3.1 Storyboard

The first phase of the system development involved determining what exactly the demonstrator should do. This was achieved by 'storyboarding' a typical user session. It was recognised that this storyboard would also form the basis for the demonstration of a typical user session once the prototype was complete. As well as this, it also formed the basis of the development plan with each feature illustrated by the storyboard being developed and tested in turn. The hand-drawn images from the storyboard have been reproduced here with the use of a scanner and can be seen in Figures 5.3 to 5.9. These figures show a user's desktop with various windows open on them. In addition to the main environment window, they also show a 'control box' window. This was added to allow the demonstration to be run. The buttons are designed to be pressed to kick-off certain aspects of the demonstration.

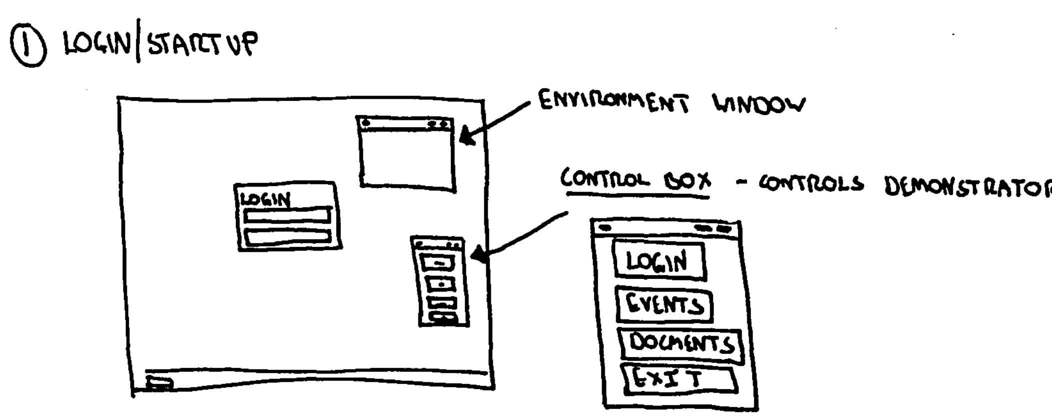


Figure 5.3. Storyboard Scene 1

The first stage of the storyboard in Figure 5.3 shows the environment being started as the user session on the machine starts and the user being asked to log on to the environment. This is started in the demonstration by clicking the 'Login' button in the control box. After the username and password have been entered, the user database is checked and if correct, the user is then logged into the environment.

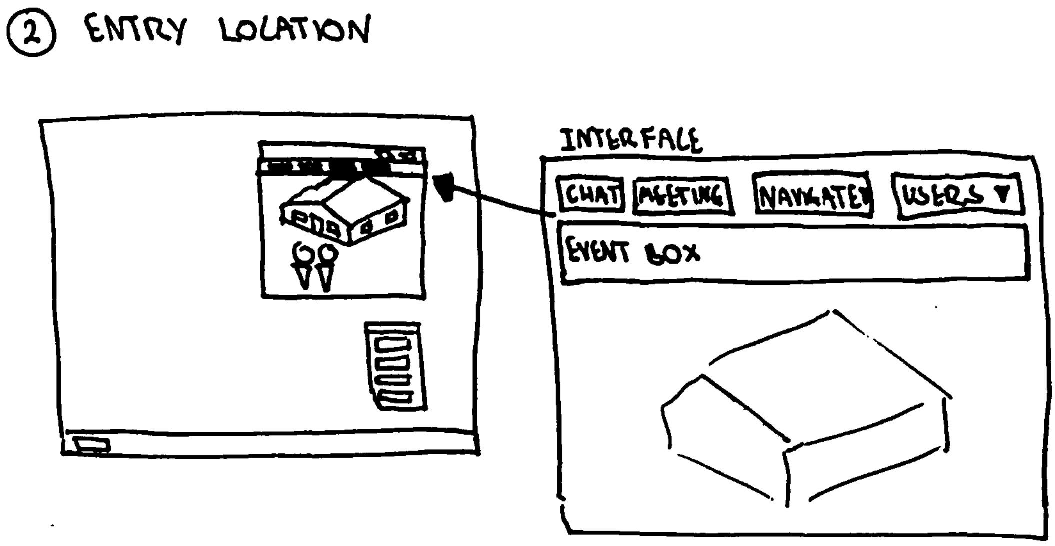


Figure 5.4. Storyboard Scene 2

Following a successful login, the user is navigated to a location in the environment called the 'entry location', as shown in Figure 5.4. All users entering the environment would be navigated to this location. The intention is to allow users to interact with each other on a general level as they start work - something that is common amongst co-located colleagues.

Figure 5.5 shows one of a series of navigation actions to particular locations based on the output of the agent. In the demonstration, this is started by pressing the event button in the control box. Each navigation is accompanied by text detailing the event and giving the user the option to get more information. Upon selecting this, a window appears showing the full text of the event and a set of buttons allowing the user to open a document (if the event was document related), or navigate to the user (if the event was related to another user) if they were in the environment. There is also the option to open the homepage of the document author or user to get their contact details or to find out more about them.

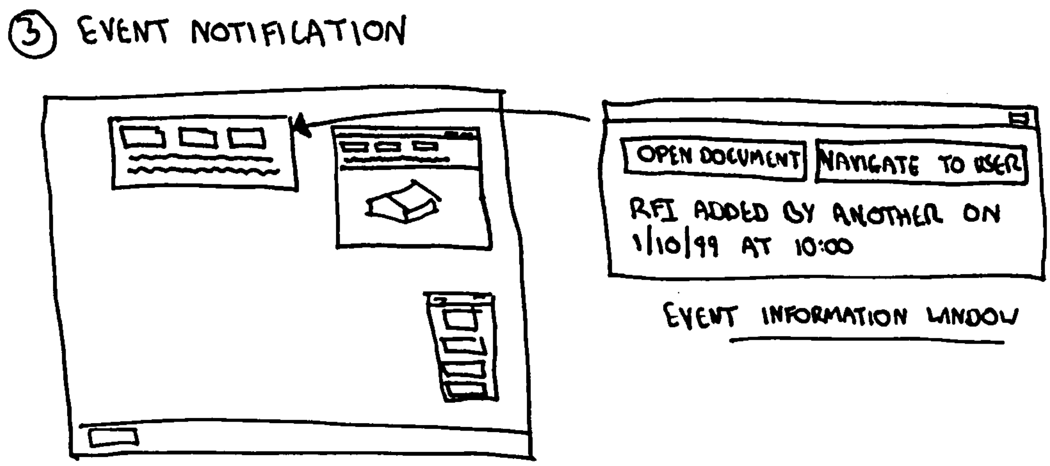


Figure 5.5. Storyboard Scene 3

The fourth stage of the storyboard in Figure 5.6 shows what happens when a user opens a document related to an event. The URL of the document is determined from the database and it is opened in a separate browser window. This simulates the access to a Web-based document management system. This could also occur when the user clicks on an element of the 3-D model. In this case a search on the database for all associated documents would occur and the user would be able to open any of the returned documents.

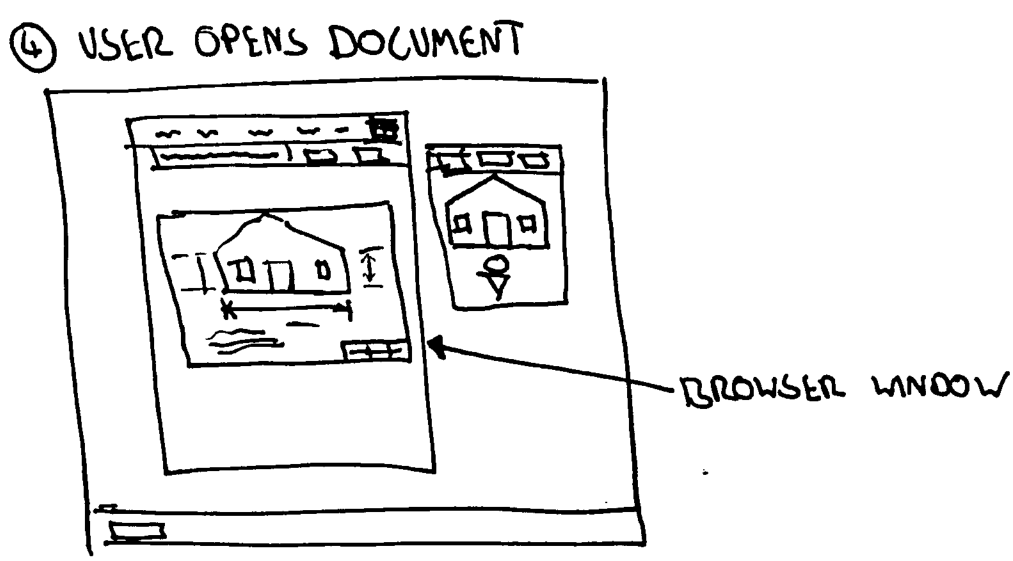


Figure 5.6. Storyboard Scene 4

The next stage shows the user acting on an event related to another user. The homepage of the user is accessed and opens in another browser window. A text chat session is started to allow informal communication to take place. This is shown in Figure 5.7.

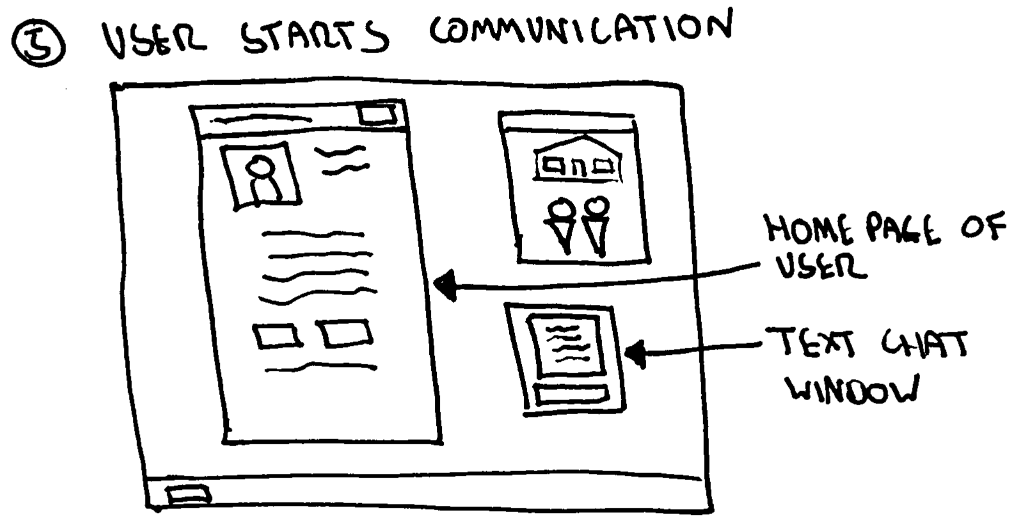


Figure 5.7. Storyboard Scene 5

Following this, the storyboard shows the users upgrading their communication session by commencing a Forum Meeting Space session. This is illustrated in Figure 5.8

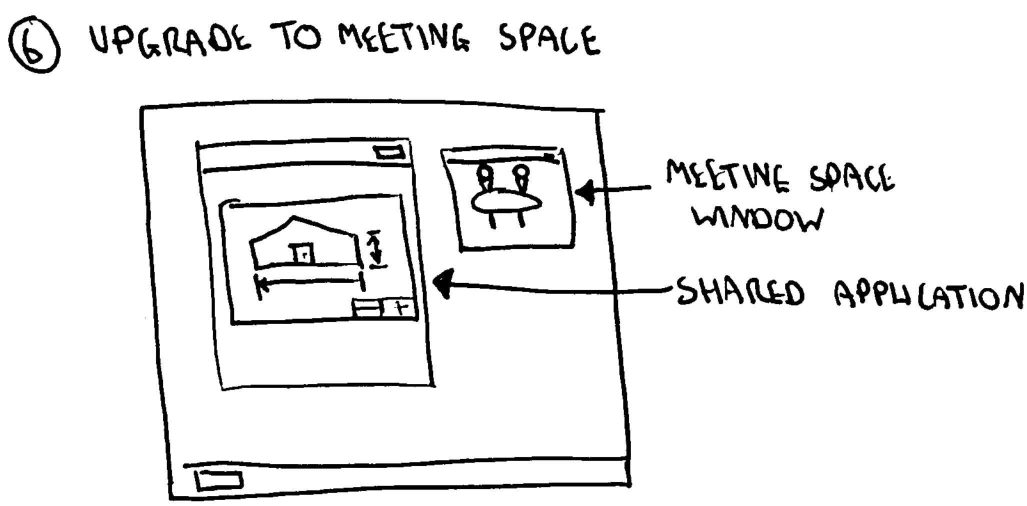


Figure 5.8. Storyboard Scene 6

The final stage in Figure 5.9 illustrates how agent events can be generated as a result of the user carrying out their normal work. The user has a document management system window open and is accessing documents. Upon opening a document, the user is navigated to the location in the environment that is associated with the workpackage of the document.

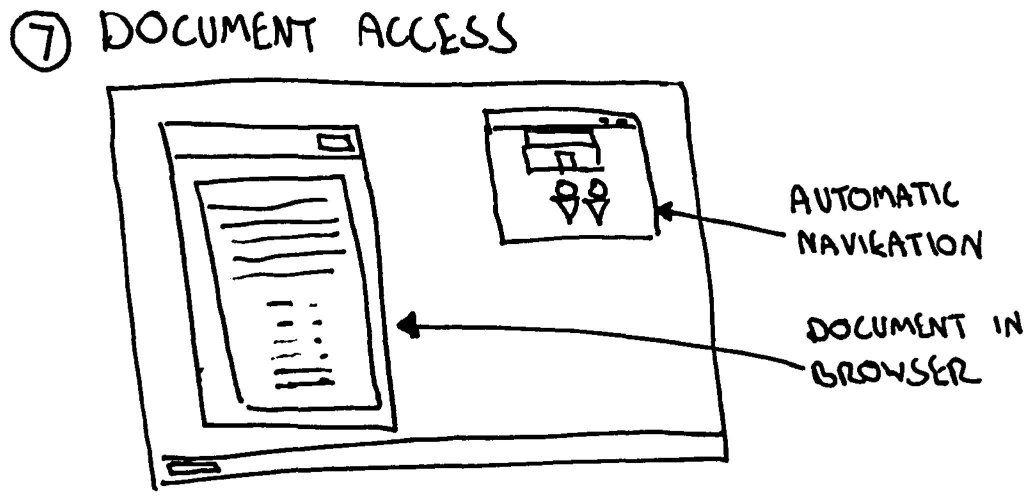


Figure 5.9. Storyboard Scene 7

5.3.2 Early development

As stated above, the plan for the development of the prototype used the storyboard as a basis. However, before development began on this, a series of small programs were written in order that familiarisation with the various technologies and their interfaces could be carried out. The majority of time was spent developing and testing Java applets with help of a Java textbook [Lemay & Perkins, 1996]. In addition to this, time was spent developing programs to read and write from simple databases and programs to access VRML using the EAI. With the later features such as touch sensors, the movement of objects and changes of location and viewpoint were explored with the use of a very simple VRML file. These small programs were then adapted as routines and used as building blocks at later stages of the prototype development.

5.3.3 Database Design

The storyboard enabled a clearer picture of the requirements for the data portion of the demonstrator to be determined. Figure 5.10 shows the various tables in the database and the relationships between them. Although in the prototype all of these tables exist in the same database this would not be the case in the real system as different sub-systems would create and maintain their own databases. It will be vital that these databases are able to interact with each other. This section will describe each of the tables, the function that they perform and the relationships between them.

The 'people' table contains the details of all the personnel working on the project. The details held include a unique id, full name, address, contact details (e-mail, phone, etc.), company, role or job title and a URL to a Web page. It is envisaged that this table would exist as a separate project personnel database. The unique id given to each person is very important since it is used throughout the other tables and would be used in all the databases in the real system to identify that person.

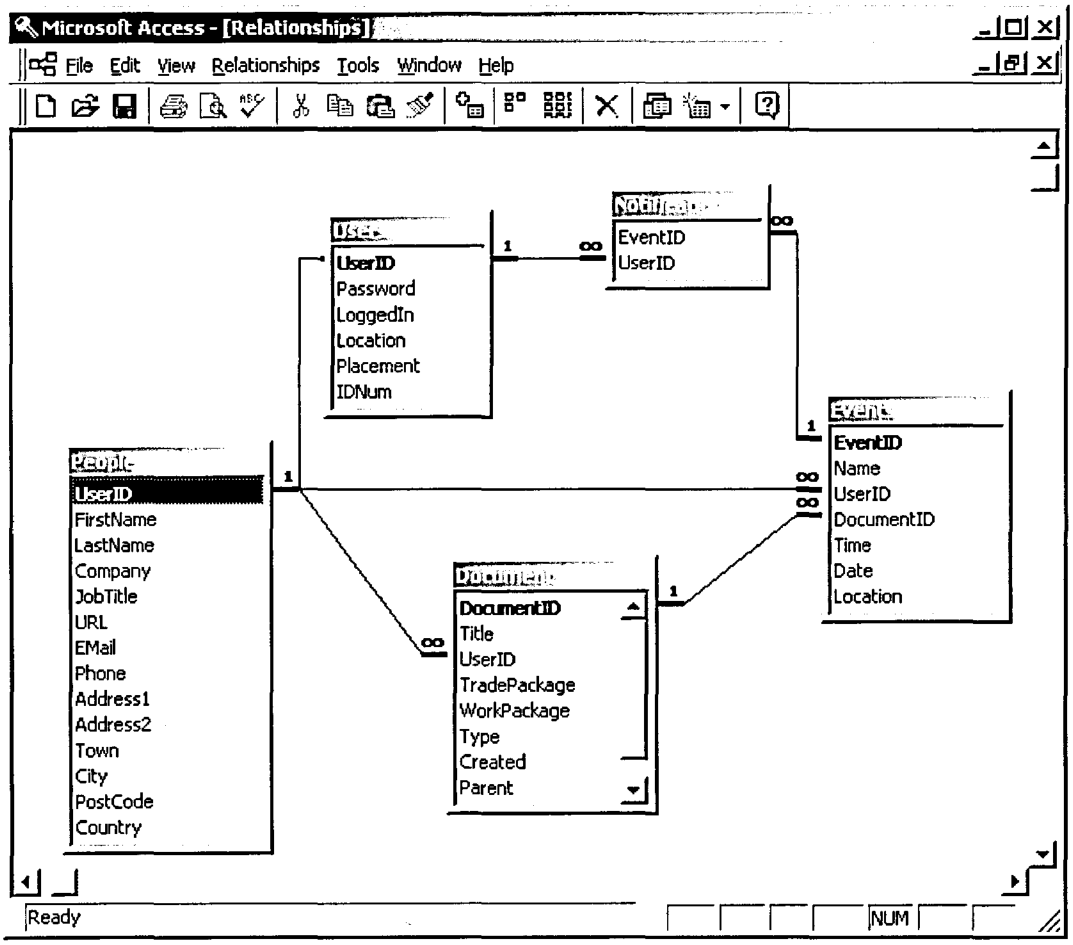


Figure 5.10. Database Design

The 'users' table is the database that stores the state of each user with respect to the environment itself. For each registered user, the unique id and password is stored. Along with this, flags determine whether the user is logged in and what their location and placement is in the environment.

The 'documents' table represents the project document management system. Each document in the table is given a unique id. The author of the document is identified via their unique id from the people database. Other data stored include the title of the document, the workpackage (e.g. foundations) and tradepackage (e.g. structural) that it refers to, its type (e.g. drawing, request for information (RFI), bill of quantities, etc.), the date and time it was created, its parent document if it has one (e.g. in the case of an RFI) and lastly its URL. The URL is important since it allows a document to be linked from the environment. In practice, the URL could be automatically constructed from the unique id of the document by the document management system.

The 'events' and 'notifications' tables are intended to represent the output of the agent. As discussed earlier, the function of the agent is to identify items of data that it deems are of relevance to particular users. Although, this function is not actually carried out in the prototype, it is simulated by these tables. Starting with the 'events' table, this maintains a record of events that have occurred be they user actions or changes to the people database. They could also be generated as a result of a change in a user's dynamic profile (i.e. a document or user becomes relevant to someone as a result of them accessing a certain Web page or document). Each event is given a unique ID. The name field is used to store a description of the event that has occurred. The userID and documentID fields hold the unique id of the person or document that the event refers to. The time and date fields record when the event was created. This is important since the relevance of events can change over time. The final field holds the location that is assigned to the event and to where the associated users are navigated. The 'notifications' table simply provides the mapping between events and users. Since each event could be relevant to more than one user, this table is necessary to maintain the many-to-one relationship of users to events. It does this by maintaining a set of records with just two fields containing the unique ids of the user and the event.

5.3.4 Applet Development

In this section the applet development process is described. This will explain how the principal items of functionality have been implemented. Algorithms and fragments of code are included as appropriate to illustrate this. Design decisions made during the process are also explained.

5.3.4.1 The Webpage

The first steps of the applet development process involved creating the Webpage to contain the applet and model, creating the applet itself, and establishing a link with the database. The following listing is a fragment of the HTML page that launches the model and applet. Only the body portion is shown but there is very little else to the file. It simply includes an applet detailing the filename of the main class file, the applet name and its size. It also defines the background and foreground colours that the applet should use. Following this the VRML model is embedded into the page using the EMBED command. The .wrl extension of the source file is recognised by the browser and the Cosmo Player plugin is launched. It displays at the size specified in the EMBED command and loads the specified source file. The size values are either stated as a percentage in which case they scale against the size of the browser window or as an absolute size which is the number of pixels. The MAYSCRIPT statement is included to allow the applet to access script objects within the Webpage.

```
<BODY>
   <applet
      code=MyBuilder.class
      name=MyBuilder
      width="100%"
      height="80"  MAYSCRIPT>
      <param name=background value="008080">
      <param name=foreground value="FFFFFF">
   </applet>
<EMBED SRC="model.wrl"  WIDTH="100%" HEIGHT="100%">
</BODY>
```

Listing 5.1. Environment page.

The Webpage is actually launched from another HTML file. This is done so that the appearance of the browser window can be changed (e.g. size, interface, etc). The following listing shows the launching page. It uses JavaScript to define the appearance.

```
<SCRIPT LANGUAGE="JavaScript">
<!–
      self.open("model.htm","MyBuilder","menubar=no, toolbar=no,
            location=no, directories=no, scrollbars=no, status=yes,
            resizable=yes, width=500, height=430")
      window.close();
//-->
</SCRIPT>
```

Listing 5.2. Launching page.

Only two lines of script are required. The first opens a new browser window as a child of the current window. This has a number of parameters. The first two are the URL of the page and the title of the window. The next five parameters turn off various parts of the browser user interface such as the URL location box and the menus. The status bar at the bottom of the browser is used by the demonstrator so this is kept turned on as is the ability for the user to resize the window. The initial width and height of the window are also specified. The second line of the script closes the current window, as it is no longer required once the environment window is open.

5.3.4.2 The `init()` method

Java applets include a number of methods that are called by the browser. These are `init()`, `start()`, `stop()` and `destroy()`. The `init()` function is called when the applet has finished loading. As a result it can be used to initialise the applet. In the demonstrator applet, `init()` contains the code to set up the JDBC driver and connect to the database using the `getConnection` command. The result of `getConnection` is stored for use throughout the applet whenever database access is required. Also in `init()` is the `getBrowser` command. This sets up a link back to the browser that contains the applet and allows access to other items on the page which in this case is the VRML model. The final principal activity carried out within `init()` is the setup of the interface. The various buttons, text fields and listboxes are defined and added to the applet and event handlers are defined by them. An instance of the control box class is also created and displayed.

5.3.4.3 Environment Logon

The first thing the user would be presented with when the environment starts up would be a logon window. 'Logon' is the first button in the control box and this starts the demonstration by opening the same window. The window prompts the user to enter their user id and password. Upon doing so and clicking on 'OK' the applet uses its database connection to carry out a search on the 'users' table, querying for a record with the user id and password specified. If one is found, the 'logged in' flag is set to true against the user's record in the table and they then enter the environment. If no record is found an error dialogue box is shown.

5.3.4.4 The 3D Model

The VRML model used was supplied by W.S. Atkins. The model was produced using 3D Studio Max and output into VRML using Max's VRML97 Exporter. The building modelled is a planned school extension. It can be seen in Figure 5.11.

It was explained earlier that the environment relies on the various workpackages of a project to cluster people and information within it. The following workpackages were identified:

- Foundations
- North Wing
- South Wing
- Roof
- Doors & Windows

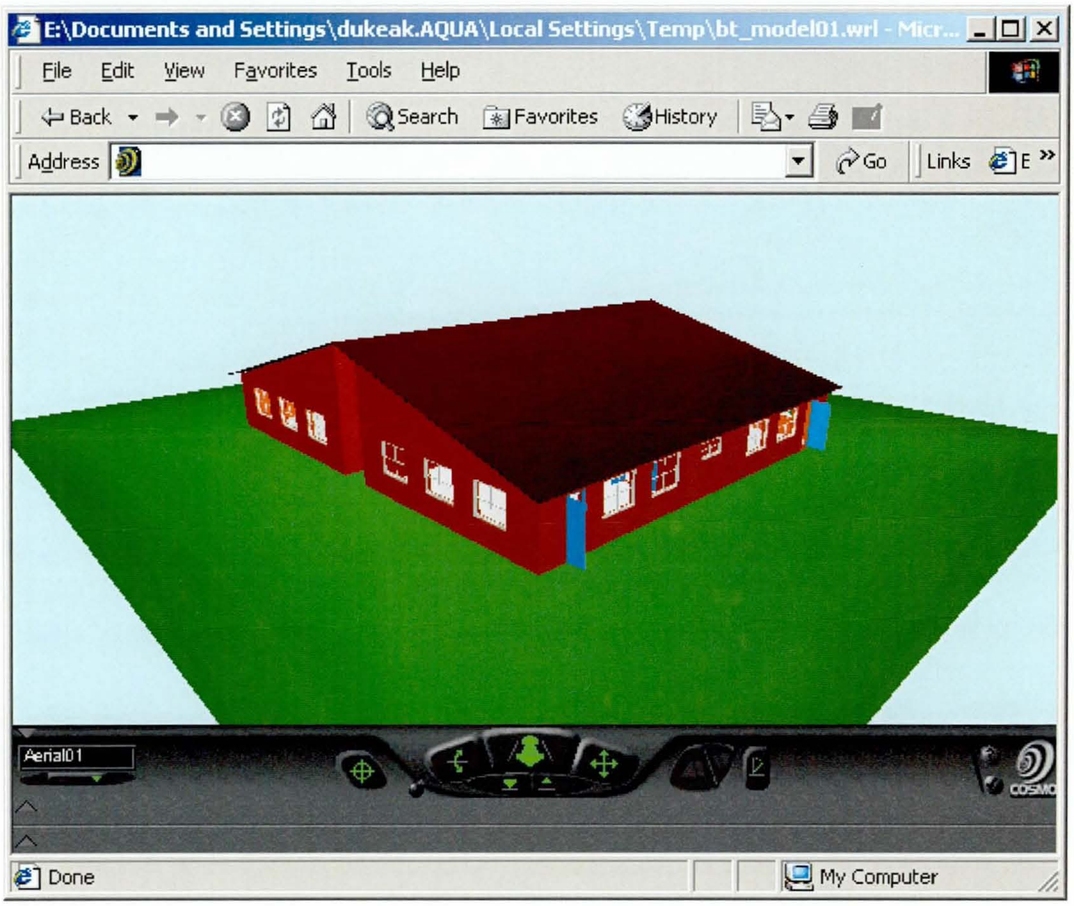


Figure 5.11. Building Model

For each of the workpackages, a location and orientation within the model were defined. These were situated near and facing the features that the workpackages are related to. As such, they became known as feature locations. Obviously, the feature location for the doors & windows workpackage could have been situated in a number of locations since there are several doors and windows. There may be many more such workpackages in a real project. An arbitrary decision was made as to where this feature location should be situated. As long as the placement of such locations is consistent, this is not considered to be a problem since users should quickly become used to what is situated where. The feature locations are defined in VRML as a Viewpoint. The viewpoint definition for the North Wing feature location is shown in Listing 5.3 below:

```
DEF NORTHWING Viewpoint {
   position 9500 1000 -33000
   description "North Wing"
```

```
    orientation  0 1 0 3.14

    fieldOfView 1.0

}
```

Listing 5.3. VRML Viewpoint Sample

The DEF statement defines the following identifier and allows it to be accessed by external script or by a Java program via the EAI. The actual viewpoint is defined by the position, orientation and fieldOfView statements. The position statement is followed by 3 numbers (floats) that specify a position in space from an origin based upon x, y and z co-ordinates. The orientation statement is followed by four figures. The first 3 are a vector in 3D space while the fourth is a rotation in radians around that vector. Thus, the orientation 0 1 0 3.14 is a 180° rotation around the y (or vertical) axis.

In addition to the feature locations, touch sensors were added to the features themselves. This is simply done by inserting a statement such as the following for the door objects:

```
DEF DOORTOUCH TouchSensor { }
```

into the definition of the object. Again the DEF statement and the subsequent identifier allow the sensor to be accessed externally.

5.3.4.5 Avatars and the User's View

For the purposes of the demonstrator very simple avatars are used. They are just a sphere and cone combination of varying colours. However it is debatable whether the avatars in a fully working version would need to be significantly more complex. Alternative styles of avatar are discussed in the evaluation results section (Section 6.5.2.1). Figure 5.12 shows an avatar in the environment. The user has their mouse pointer over the avatar (although this is not shown in the screenshot), which results in the name of the person whose avatar is being displayed in the status area of the environment. A touch sensor was also included with each avatar. When activated, the homepage of the user in question is displayed. This was carried out by querying the 'people' database for the user id of the clicked avatar to return the URL of their homepage.

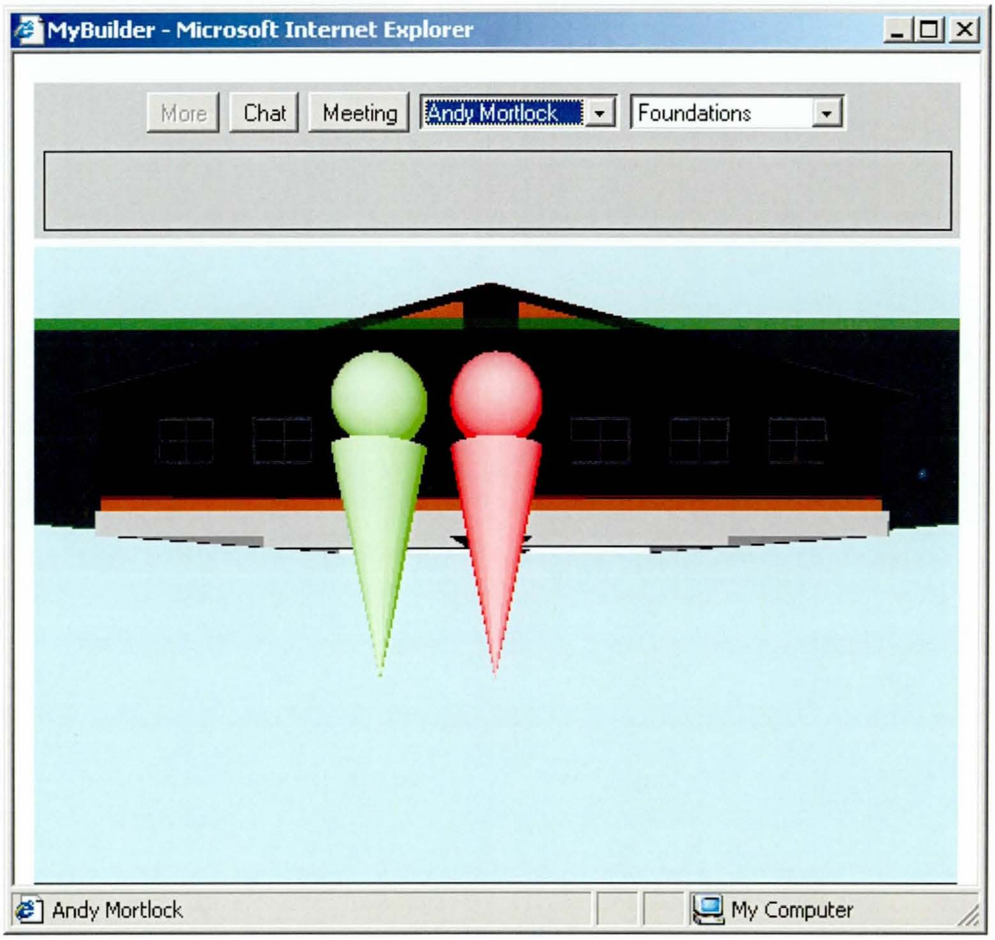


Figure 5.12. Mouse Over An Avatar

There are two common viewpoints onto virtual environments. These are a 'first person' view and a 'third person' view, the difference being that the 'first person' view is the view as you would see through your own eyes while the 'third person' view is the view from behind you or over your shoulder. With the 'third person' view, you see your own representation in the world. The view in the Forum Contact Space is first person. This is backed up with a self view that also allows you to see what your avatar currently looks like or is doing. This works well in this situation because generally the focus of attention is another avatar which may or may not be facing towards yours. This differs from the situation in this environment since the focus of attention is on a feature within the model as well as other users. A very wide field of view would be required for all users to see all the avatars at the location as well as the feature. For this reason, a third person view was chosen. This allows all avatars at a feature location to be facing the feature but also allows the user to see all the avatars that are at the location from a viewpoint located behind them.

There is an alternative solution using a first person view that relies on the placement of avatars not being consistent for all users. If there were three avatars at a location, each user would see the other two avatars. If these were represented as facing the user in front of the feature, then all could be seen in a normal field of view. This is best illustrated in Figure 5.13, which shows the view of the feature and the other two users' avatars for each user in turn. The effect of users facing the feature they are interested in is lost but this may not be a problem if the location itself is a strong enough metaphor for interest in the feature it represents.

This configuration was not used as it is much more complicated to implement and does not add much to a single user demonstrator. It is however a strong candidate for use in a fully working system.

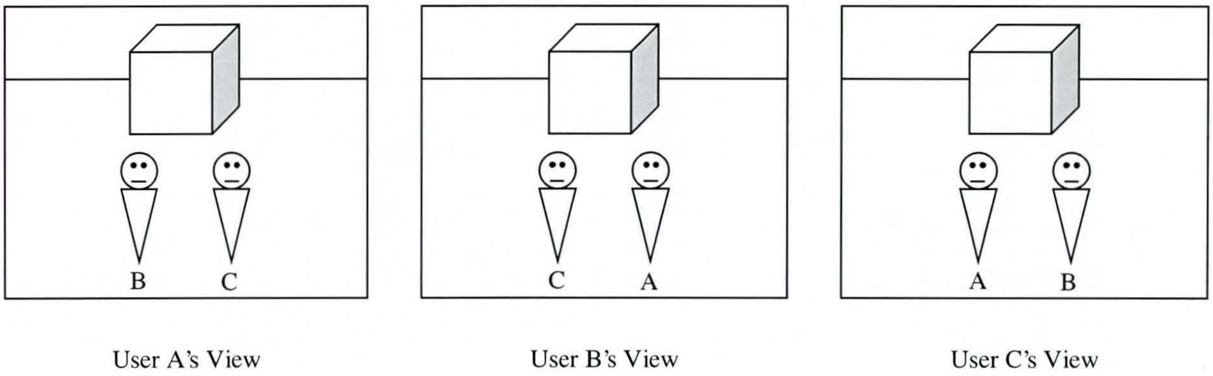


Figure 5.13. A First Person View

5.3.4.6 Moving Around The Virtual World

Once a successful login has taken place, the next action that occurs is that the user's view and their avatar move to the 'Entry' feature location from the distant location that is shown when the environment is loaded. Every time a move between feature locations occurs there are three actions that must occur. Firstly, the user's avatar must move to the new location; secondly, the viewpoint position must also move (for the user's view is from a position directly behind their avatar with respect to the building model) and finally the viewpoint rotation must also change to ensure that the view of the user is in the correct direction. These changes could be carried out instantaneously, however, the user would just perceive this as a jump to a different location in the world. This would not support their spatial awareness and would look strange to other users as they would just see avatars appearing and disappearing as if from nowhere. It is far better to animate the movement of the avatar and viewpoint between the two locations. Fortunately VRML provides a mechanism to allow this to happen called an interpolator. An interpolator is given start and end values and can be set up to interpolate any value in between those two values. VRML allows an interpolator to be linked to a timer that provides input and to other values such as a position setting to which they provide an output. The following VRML code fragment shows how an interpolator is used to animate a positional change.

```
DEF VIEW Viewpoint {
   position 0 0 0
   orientation 0 1 0 3.14
}
DEF TIMER TimeSensor {cycleInterval 1.5}

DEF POSMOVER PositionInterpolator {
   key [0, 1]
   keyValue [0 0 0, 10 10 10]
}
ROUTE TOUCH.touchTime TO TIMER.startTime
ROUTE TIMER.fraction_changed TO POSMOVER.set_fraction
ROUTE POSMOVER.value_changed TO VIEW.position
```

Listing 5.4. VRML Position Interpolators

The fragment includes the Viewpoint construct that is being set, a timer with a period of 1.5 seconds and the interpolator itself. The interpolator shown has only two values (the start and finish) but it is possible to define interim values if a more complex animation is required. The links between the timer, interpolator and position that were mentioned above are set up in this example by the final two ROUTE statements. The first ROUTE statement is just a link to a touch sensor. When this touch sensor is activated it triggers the time sensor. The timer then provides a value, that is the fraction of its duration that has passed, to the interpolator which calculates a position between the start and finish values based upon that fraction. That value is then passed to the position field of the viewpoint. This process is repeated until the timer period expires. The resultant action is that the viewpoint is gradually changed from 0 0 0 to 10 10 10 over a period of 1.5 seconds. How gradual that change is (i.e. how many positions are interpolated) will chiefly depend on the processing power available and the complexity of the model being manipulated.

In the demonstrator the key values of the interpolator and the start time of the timer are set programmatically. The following fragment of Java code illustrates how this is done. Again for simplicity only the action of changing the position of the viewpoint is shown. The positional change shown is from the current location to the South Wing feature location.

```
//This is the new location as would have been passed to this fragment
//by a user selection but is included here for completeness
float[] posSouthWing = {9500f, 1000f, 11000f};

//Prepare viewpoint change
//Setup timer
EventInSFTime startTime;
Node timer = browser.getNode("TIMER");
startTime = (EventInSFTime) timer.getEventIn("startTime");

//Get current position
EventOutSFVec3f currentPosition;
Node viewpoint = browser.getNode("VIEW");
currentPosition = (EventOutSFVec3f)
viewpoint.getEventOut("position");

//Setup links to interpolators
```

```
Node posMover = browser.getNode("POSMOVER");
EventInMFVec3f posMovePath =
(EventInMFVec3f)posMover.getEventIn("keyValue");

//Enter position values to interpolators
//First declare an array to hold the values - a matrix of two 3 float
//values
float posValue[][] = new float[2][3];
posValue[0] = currentPosition.getValue();
posValue[1] = posSouthWing;

//Now set the interpolators and start the timer
posMovePath.setValue(posValue);
//Set the start time to be shortly in the future
startTime.setValue((double)(System.currentTimeMillis()/1000 + 0.5));

//Change the database to reflect the new position of the user
Statement stmt;
stmt = con.createStatement();
int update = stmt.executeUpdate("UPDATE Users SET Location=" +
featureIndex + " WHERE UserID='" + userID +"'");
stmt.close();
```

Listing 5.5. Java control of VRML Animations

The fragment makes wide use of the getNode method called on the browser object. This obtains a pointer to part of the VRML code and is enabled by the DEF statements identified earlier. Pointers to the time, interpolator and viewpoint are obtained. Pointers to statements within those nodes are then obtained calling getEventOut or getEventIn on the node objects. getEventOut allows values to be read from the VRML while getEventIn allows them to be written. These are cast to types representing the nature of the values to be read or written. For example, EventOutSFVec3f refers to a single value vector of 3 float values. Once these pointers have been set up getValue and setValue can be called upon to modify the VRML. The timer is then fired to start the animation.

Upon completion of this the database is then updated to reflect the change in the position of the user. This shows the construction of a simple SQL statement. 'UPDATE users' refers to an update operation upon the 'users' table. 'SET Location=......' changes the Location field of the table to a value representing the location moved to. 'WHERE UserID=.......' selects the record(s) to be changed by matching the userIDs in the table against the ID of the current user.

There are two ways in which a user's position in the environment is changed. The first is where the user is moved by the agent as a result of an event. The second is by user intervention i.e. where the user elects to move to a different location or elects to move to the same location as another user. This is achieved by the user selecting a zone or other user from one of the pull down lists. This is shown in Figure 5.14. The user list is kept up-to-date with all of the other users who are currently logged on. When another user is selected, the 'users' table of the database is interrogated to find out at which location they currently are. The user is then moved to join the selected user.

5.3.4.7 Presenting Events

One of the major features of the environment is the subtle presentation of information to the user via a movement to a feature and a short statement of rationale. This information is generated by the agent. In the demonstrator the action of the agent is simulated. As identified in the database design description (Section 5.3.3) the 'events' and 'notification' tables represent the output of the agent. These are filled with dummy events with links to information and users. These are then used in the demonstration to illustrate how such events would be presented to the user.

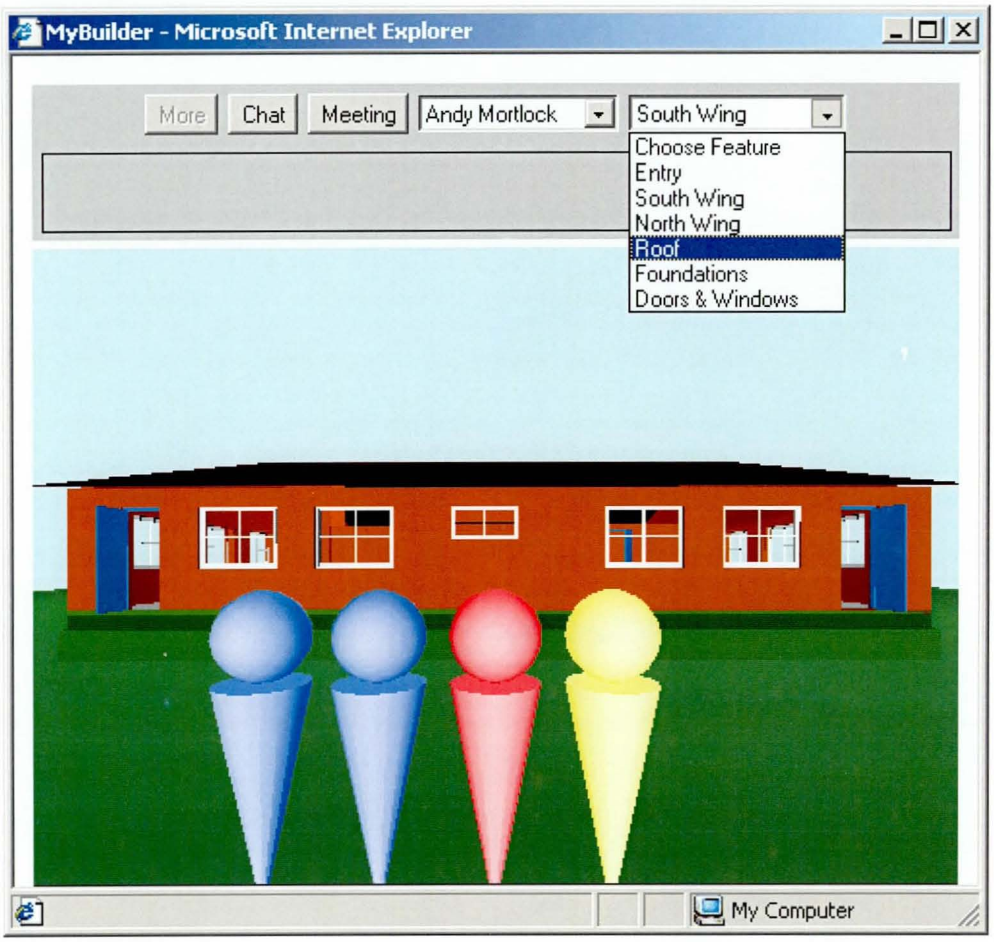


Figure 5.14. User Selecting New Location

One of the dummy records used is shown below:

Field	Value
EventID	4
Name	Document Added
UserID	mortloan
DocumentID	244
Time	10:10:00
Date	18/05/00
Location	Roof

The EventID is just a unique identifier. The name field gives details of what kind of event it is that occurred and this will be shown to the user. Events may be related to documents, other users or both. The next two fields give the unique ids of the related document and/or user. These correspond to entries in the 'document' and 'people' tables respectively. The date and time fields record when the event was added to the table. It is likely that events will become less relevant as they get older and for this reason a time stamp is required to distinguish them from more recent events. This feature is not represented in the demonstrator however. The final field is the feature location that this event is related to and to which the user will be moved when the event is presented.

Each event may be relevant to more than one user and as a result an additional method of matching events to users is required. This is carried out by the 'notification' table which basically maintains a mapping between events and users.

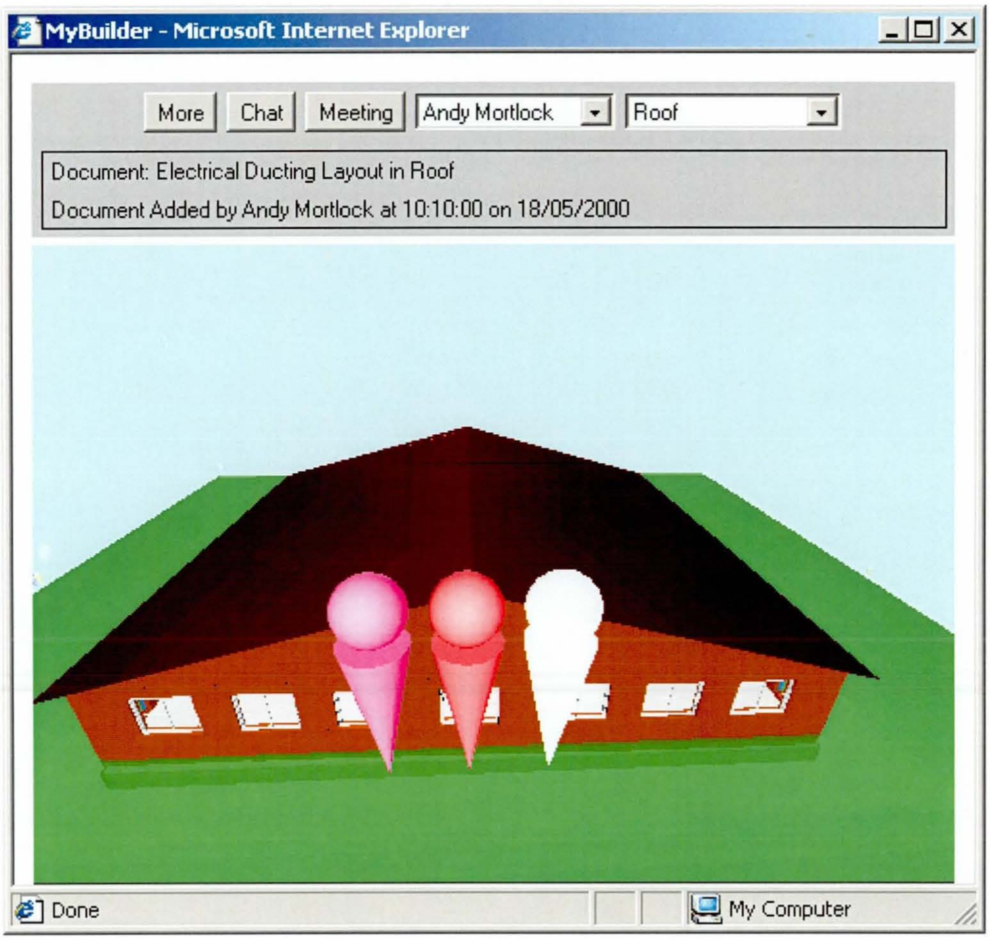


Figure 5.15. Event Presentation

Figure 5.15 shows how the event in the table would be presented. The text window of the interface shows the name of the document. The document ID is used to get its details including its name from the 'documents' table. The event name (i.e. Document added) is shown along with the person that has added it. Again the user ID is used to obtain the person's full name from the 'people' table. When an event is presented in this manner the 'More' button on the interface becomes enabled. Thus if the user decides that the event is of interest they can press this button to get more information about the event. A separate window is opened if this button is pressed. This is shown in Figure 5.16.

The window allows further information and options that the confines of the environment window do not allow to be presented to the user. Further information about the event could be presented here, such as why the agent believes that it is relevant to the user. Additional choices are available via the buttons in the notification window. These are 'Open Document', 'Open Author's Homepage', 'Navigate to Author', 'Delete This Note' and 'Close'. The first two options will open up a separate browser window containing the document or the homepage. Figure 5.22 shows a document in a separate browser window. The URL's of these pages are obtained from the relevant database tables. The 'Navigate to Author' button is only enabled if the author is currently logged in to the environment. This is included should the user wish to contact the author via the environment. Once the user has read and dealt with the event, they can delete it. This removes the link to the event from the 'notification' table mapping the event to the user. Following this, the event will not be presented to the user again in future.

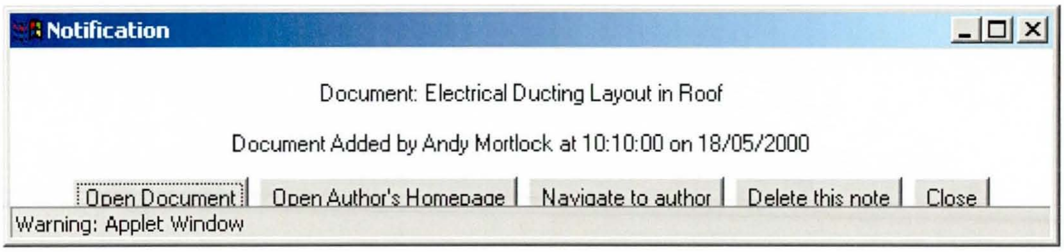


Figure 5.16. Notification Window

The demonstration of event delivery in the demonstrator is started by selecting the 'Events' button in the control box. This has the effect of extracting a list of the events for the current user from the 'notification' table. These are read into a data structure called a vector. This is a

Java data structure similar to an array in that it is accessible via an integer index. It is also dynamic (i.e. it can expand and contract at run-time as opposed to being set at design-time). The following line of code shows how the notifiers vector is declared and initialised:

```
Vector notifiers = new Vector(10, 5);
```

The new method initially creates the vector with enough space to hold 10 objects. The second argument signifies the additional space that is reserved once the vector becomes full (i.e. if an eleventh object is added to the vector it will grow in size from 10 to 15). Once each of the eventIDs has been read into the vector, the first of these is then presented to the user. In the demonstrator the events are presented to the user in a series. Each event is presented for a set period of time before the next one is moved onto. This timing process is handled by a separate thread. A thread is basically a sub-process that is allocated its own CPU time. This makes them ideal for handling timing code since they can block until a defined time has elapsed without blocking the main thread of the process. The way in which this works in the demonstrator is illustrated by the following code fragment:

```
//First set the current note to the first one in the vector
currentNote = (Notification)notifiers.firstElement();

//This presentNote method extracts all the event data, shows the
//relevent text and navigates the user to the correct location
presentNote(currentNote);

//Call the thread initialision method
startEventCycleThread();

//Create the thread to handle the event cycle and start it
void startEventCycleThread()
{
   m_eventCycleThread = new Thread(this);
```

```
    m_eventCycleThread.start();
}


//Event cycle thread
public void run()
{
    while (true)
    {
        Thread.sleep(1000 * noteChangeWait);
        //Handle cases where we don't want to move on
        if (noteBox.isShowing() || (System.currentTimeMillis() -
                (noteChangeTime + (noteChangeWait * 1000)) < 0))
            continue;
        }
        nextEvent(false); //Move to next note without deleting
    }
}
```

Listing 5.6. Events Cycle

The start method of the thread causes the run method to begin execution. This enters a 'while loop' and then blocks using the sleep method for the defined time (which was 30 seconds in the demonstration). There are two cases where it might be inappropriate to move on to the next event. These are if the user has asked for more information on an event and currently has this window open and the other is if the user has deleted or closed the current event. In this latter situation the next event might have just been displayed and a further delay is required before moving onto the next. Once the time has elapsed and these checks have been made the nextEvent method is called. This has a parameter to indicate whether the current node should be deleted. In this case no 'delete' should be carried out since there is, of course, no guarantee that the user has seen the event.

The nextEvent method does as its name suggests - it moves onto the next event in the list and repeats the process or event delivery. However, since this method can be called both by the timing thread and the main thread via user intervention (in the case of the current event being deleted or closed), it requires a special declaration as shown:

```
public synchronized void nextEvent(boolean delete)
```

The synchronized keyword ensures that this method is thread-safe (i.e. that it can only be called by one thread at a time). Once one thread has called it, subsequent calls will block until the first execution of the method is completed. Were this method not thread-safe and both threads accessed it at the same time, the results would be indeterminate.

A full implementation of the system might differ in the way it presents events to the user. It is likely that the events would be ranked in order of relevance to the user. Those events at the top of the ranking might well be displayed for a longer period of time in order to increase the likelihood that the user is made aware of them.

5.3.4.8 Simulating Other Users

Of equal importance to the presentation of events, is the interaction that is enabled by the fact that the environment is a multi-user one. This is simulated in the demonstrator with the use of dummy users or 'bots' as they have been called in the code. These bots move around the environment between feature locations in the same way as the user's avatar. Each bot has an identity that is defined at start-up by giving it an id that corresponds to an entry in the 'users' table. The table is queried to determine which users have a LoggedIn field set to true. For each of these an avatar is added to the environment at the feature location specified in the database. Their name is also added to the users list on the user interface and a record with their details is added to a users vector. The process of adding an avatar to the VRML is carried out from within the Java program. Obviously, since the avatars are only created at run-time depending upon who is logged in they cannot be in the static VRML file. Java makes use of the createVRMLFromString method which it calls on the browser with the VRML code to be added as a string parameter. This returns a node that can then be added to any part of the VRML scene.

Each avatar has two features that users can make use of. By moving their mouse pointer over the avatar a user can find out whom the avatar is representing. Their full name is displayed on the status area of the interface. By clicking on the avatar the Web page of the user is opened in a separate browser window. These features are achieved with the use of a callback structure from the VRML.

The callback works by getting a pointer to a node in the VRML and requesting to be informed when a change to that value occurs. The callback function itself is called when a change to any number of these values occurs but an object is passed to it so that the particular value can be identified. The following code fragment shows how a callback is set up to handle mouse over and click events on an avatar:

```
EventOutSFBool isOverBot = null;
EventOutSFBool isActiveBot = null;

//Fist add the touch sensor to the scene
EventInMFNode addChilren =
      (EventInMFNode)rec.node[0].getEventIn("addChildren");
Node[] touch = browser.createVrmlFromString("TouchSensor{}\n");
addChildren.setValue(touch);

// Get its EventOut
isOverBot = (EventOutSFBool) touch[0].getEventOut("isOver");
isActiveBot = (EventOutSFBool) touch[0].getEventOut("isActive");

// Set up the callbacks
SensorRecord botOverRec = new SensorRecord(rec, isOverBot, 0);
SensorRecord botActiveRec = new SensorRecord(rec, isActiveBot, 1);
```

```
isOverBot.advise(this, botOverRec);
isActiveBot.advise(this, botActiveRec);
```

Listing 5.7. Java callbacks from VRML

Firstly the touch sensor is added to the scenegraph of the avatar. This is done in the Java program rather than the VRML since the avatar has been dynamically added to the scene. When the avatar was created a record was stored containing the name and id of the user being represented and also a node object that is effectively a pointer to the avatar in the VRML scenegraph. The sensor is added as a child to this node. A VRML touch sensor has an 'isOver' field and an 'isActive' field. These are set to true when a mouse over or mouse click event occurs but they are reset to false when the mouse moves out or when the mouse button is released. Pointers to these fields are created and added to a SensorRecord object. This is the object that is then passed to the callback and contains the details of whether an avatar has received a mouse over or click event, whether the setting is true or false and also which user and avatar the event is concerned with. This pass to the callback method is handled by the 'advise method' called on the sensor node. The first argument (i.e. this) is used to indicate which thread will handle the callback since each thread in Java can have a 'callback method'. The second argument is the object just discussed.

The callback method itself looks as follows:

```
public void callback(EventOut who, double when, Object which)
```

The third parameter contains the object that was passed into the 'advise method'. This can be cast to a SensorRecord to enable the source to be found and the appropriate name or URL displayed.

The user's view onto the world and the placement of avatars was discussed earlier in Section 5.3.4.5. The method chosen for the avatar placement was that they should line up facing the feature associated with the location. In the demonstrator the user is always shown in the centre of the feature location with any other users lined up on either side of them. This could also be the method employed in the fully working system since the avatar placement does not necessarily need to be consistent between different users' views. The effect of this is that every user would see themselves represented at the centre of the feature location.

Obviously the simulated users need to adhere to the chosen method of presentation. In order to ensure that they did this, their required behaviour was set out. A suitable space between the avatars was determined. This was deemed to be sufficient to allow multiple avatars to be shown in the scene without making it look crowded. When an avatar moves to a feature location it should occupy a space as close as possible to the centre taking into account the minimum distance between the avatars and the avatars that are already in the location. The minimum separation was deemed to be 250 VRML distance units. This led to the possible positions within the location receiving numbers. These numbers are shown below and indicate the order in which positions are taken up.

The actual movement of the simulated users is generated randomly by the demonstrator. A separate thread is used. This blocks for a period (configurable on the control box) and then picks both an avatar and feature location at random. These picks are then passed back to the main thread which executes the move.

The animation of the dummy avatars occurs in a similar way to that of the user's avatar in that the start and end positions are determined and then fed into an interpolator. The difference is that the final position needs to be calculated at run-time since it is dependent upon the other avatars that are present at the feature location. The 'users' table stores for each user both the current feature location and the placement within it in the location and placement fields respectively. The placement field stores an integer corresponding to the placement as in Figure 5.17 Thus this table is queried for all avatars at the target feature location. Based upon the results of the query the closest available placement can be determined. The target placement integer is then converted to a multiplier that is used to calculate the final position.

In the demonstrator the multipliers were +/-4 with negative numbers indicating a placement to the right of centre and positive to the left.

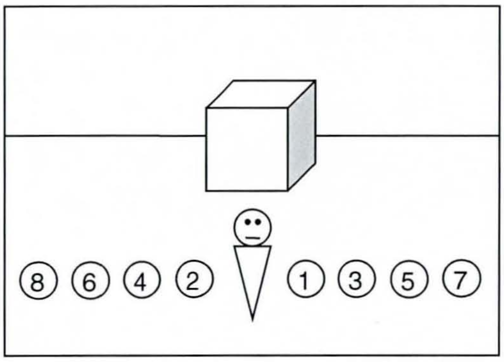


Figure 5.17. Placement Positions.

For each feature location in the environment there were two sets of pre-determined values. These were the centre position of the location and the vector along which avatars were to line up. For example, for the Doors and Windows location, the centre position is stated as:

```
float[] avatarDoorWind = {-10292.9f, 500f, 10292.9f};
```

and the vector is stored as:

```
int[] doorWindVec = {-1, 0, -1};
```

These two values along with the multiplier and minimum distance value are all that are needed to calculate the final position. This is carried out in the method shown below.

```
public float[] finalPosCalculator(int posIndex, int[] vector, float[]
datum)
{
   float[] finalPos = new float[3];

   //calculate delta values based on vector & POSSCALER(hypotenuse)
   float root = Math.abs(vector[0]) + Math.abs(vector[1])
```

```
        + Math.abs(vector[2]);

    float ratioSum = (float)Math.pow(Math.abs(vector[0]), root)

        + (float)Math.pow(Math.abs(vector[1]), root)

        + (float)Math.pow(Math.abs(vector[2]), root);

    float temp = (float)Math.pow(POSSCALER, root) / ratioSum;

    float delta = (float)Math.pow(temp, 1f / root);


    //Now calculate final position for each axis

    finalPos[0] = datum[0] + delta * vector[0] * posIndex;

    finalPos[1] = datum[1] + delta * vector[1] * posIndex;

    finalPos[2] = datum[2] + delta * vector[2] * posIndex;


    return finalPos;
}
```

Listing 5.8. Avatar Placement Method.

Along with the vector, the multiplier is passed as the posIndex parameter and the centre position as the datum parameter. The distance value (i.e. 250) needs to be the resultant value when the three components of change in position (one for each axis) are applied. It is these components that need to be calculated. First the root value is determined from the number of non-zero values in the vector (which is 2 in this case). Then the ratios of the vectors are taken into account by adding their squares - also giving 2. These two values are applied to the distance constant which is effectively the hypotenuse. This results in a scalar delta value that can then be applied to each axis. The posIndex is then applied to the scaled delta value and the result of this added to the datum to give the final position for each axis. This finalPos value is the return value of the method.

The equation that this method is based upon is shown below. Figure 5.18 illustrates the problem on a 3D graph. In both, y is the hypotenuse or known minimum distance between the avatars and z is the number of axes that a movement is taking place upon. a, b and c are the components of the vector for each axis and x is the scalar value that is to be determined. The equation satisfies the general case where a movement along all three axes is required. It does simplify down when fewer axes are required and when the vector components are always 1, 0 or -1 as is the case in the demonstrator.

$$(ax)^z + (bx)^z + (cx)^z = y^z$$

$$\therefore (a^z + b^z + c^z)x^z = y^z$$

$$\therefore x = \sqrt[z]{\frac{y^z}{(a^z + b^z + c^z)}}$$

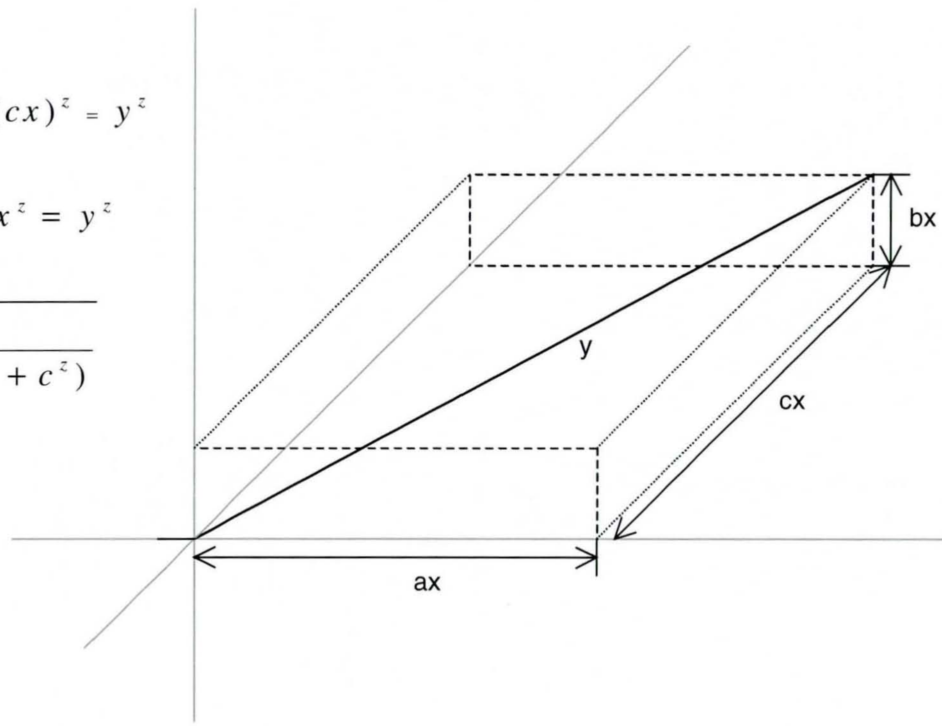


Figure 5.18. Calculation of Avatar Positions

5.3.4.9 Integrated Communication

The third major feature of the environment is the facility for users to initiate instantaneous communication with each other via the environment. In the demonstrator this is illustrated with two forms of communication. The first is text chat. This is intended to support informal ad hoc communication. The second is the Forum Meeting Space. This is intended to support more formal and / or richer forms of communication. The user interface includes buttons that allow both methods of communication to be initiated. These are enabled whenever there is another person in the same feature location as the user. Pressing one of the buttons brings up a selector box with a list of people in the current location. The user can then select which of these people they with to invite to a meeting. Following this an invite is sent out to those selected, which they can choose to accept or reject. In the demonstrator the dummy users automatically accept the requests. In the case of the text chat a chat box is then opened up which the users can add text to. With the Meeting Space, the stand-alone demonstrator is started. This is a separate application that illustrates the facilities in that system (such as symbolic acting, application sharing, audio conferencing, etc.).

In order to illustrate further the potential of the integrated communication, the demonstrator has a sample interaction session included with it. This is started by a button on the control box. The sequence of events that follow are now detailed:

1. One of the dummy users navigates to the user's current feature location;
2. They request a text chat with the user;
3. A request box appears on the screen with the name of the dummy user requesting the chat and two buttons allowing the user to accept or reject the request. See Figure 5.19;

Figure 5.19. Text Chat Request.

4. Following an accept the text chat box appears in which the dummy user asks a question
5. A short exchange may reveal the need to upgrade the communication. See Figure 5.20.

Figure 5.20. A Text Chat Session In Progress.

6. The user invites the dummy user into a Forum meeting which is then started. See Figure 5.21

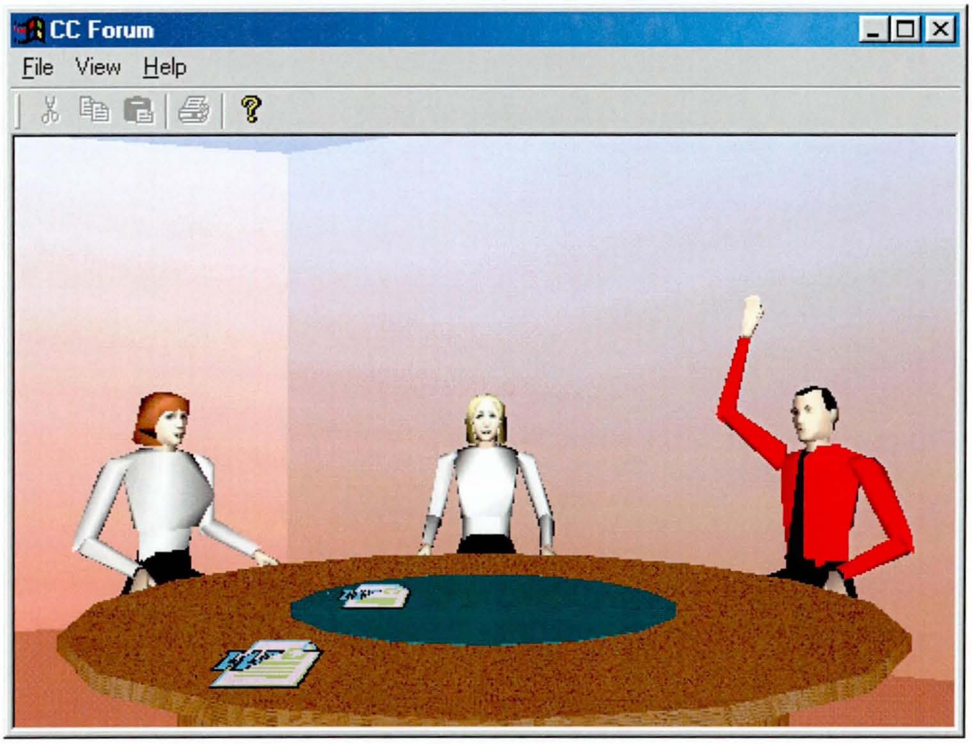


Figure 5.21. Forum Meeting

5.3.4.10 The Document Management System

A simple document management system was added to the demonstrator. This illustrates two features of the environment. The first is having the documents integrated into the environment. When the user clicks on a feature in the VRML building model a database query is fired off. The 'documents' table is queried for all of the documents associated with the work package that the feature represents. Details of these documents are listed in a window representing the document management system. The user can select one of the documents in the list and open it. This launches a separate browser window with the URL of the document as shown in Figure 5.22.

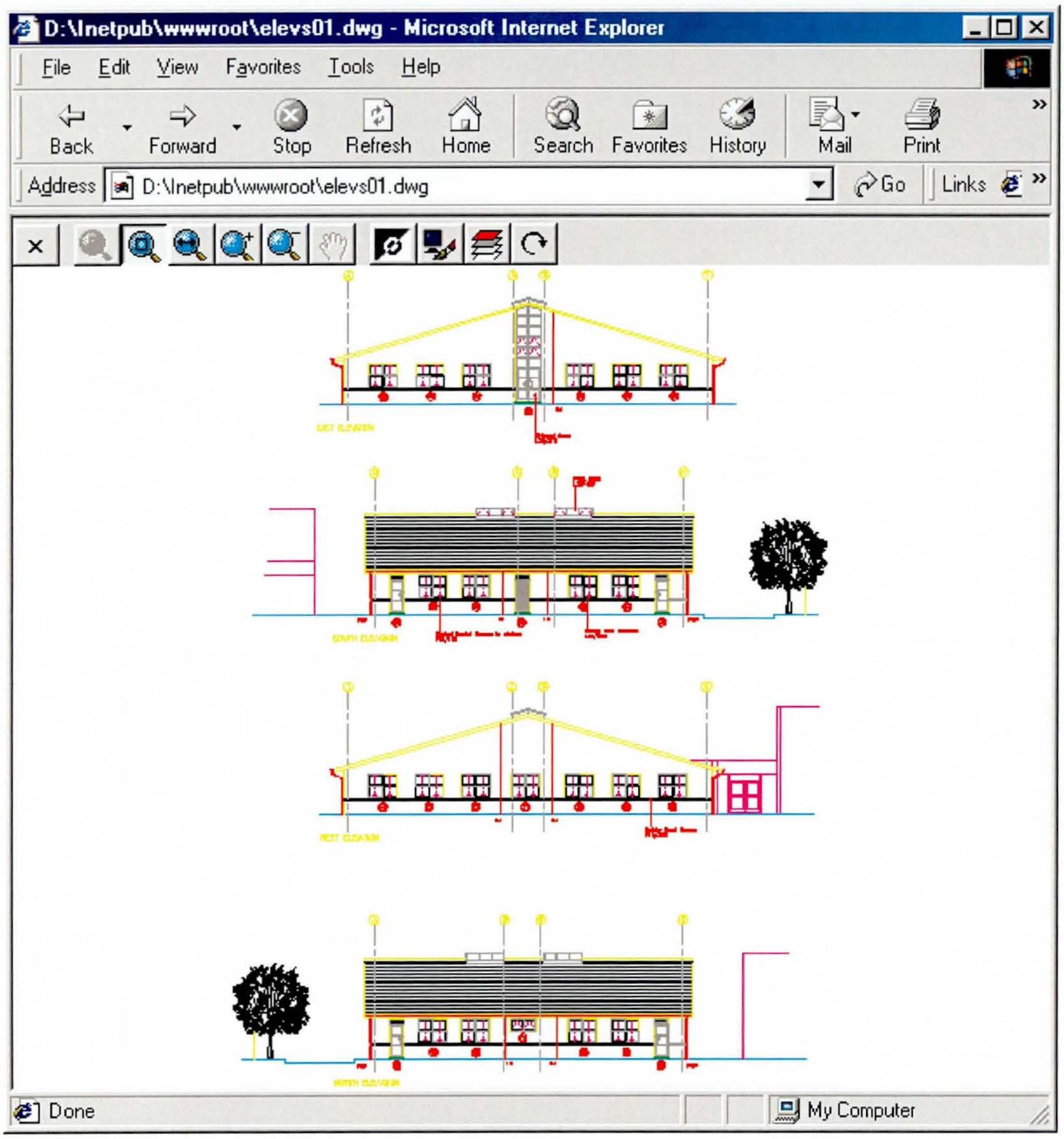


Figure 5.22. Project Document in Separate Browser Window.

A number of drawings related to the school building were supplied by W.S. Atkins and these were added to the 'documents' database along with Microsoft Word and Excel files representing other types of document. When one of these documents is opened, an appropriate browser component object handles its display in the browser. This was a .dxf viewer in the case of drawings or the appropriate Word or Excel control.

The second feature illustrated is an example of how the agent might recognise general user activity and navigate their avatar appropriately in the environment. For this the document management system window is opened via the 'Documents' button on the control box. This simulates normal use of the system. When the user carries out a search on a particular workpackage or opens a document related to a particular workpackage this is recognised and the user's avatar is navigated to the feature associated with that workpackage. This could be extended to navigate to a user when a search is made by name. This is a very simple demonstration but is intended to promote the awareness of the link between user activity and the environment. The search page of the Document Management System is shown in Figure 5.23.

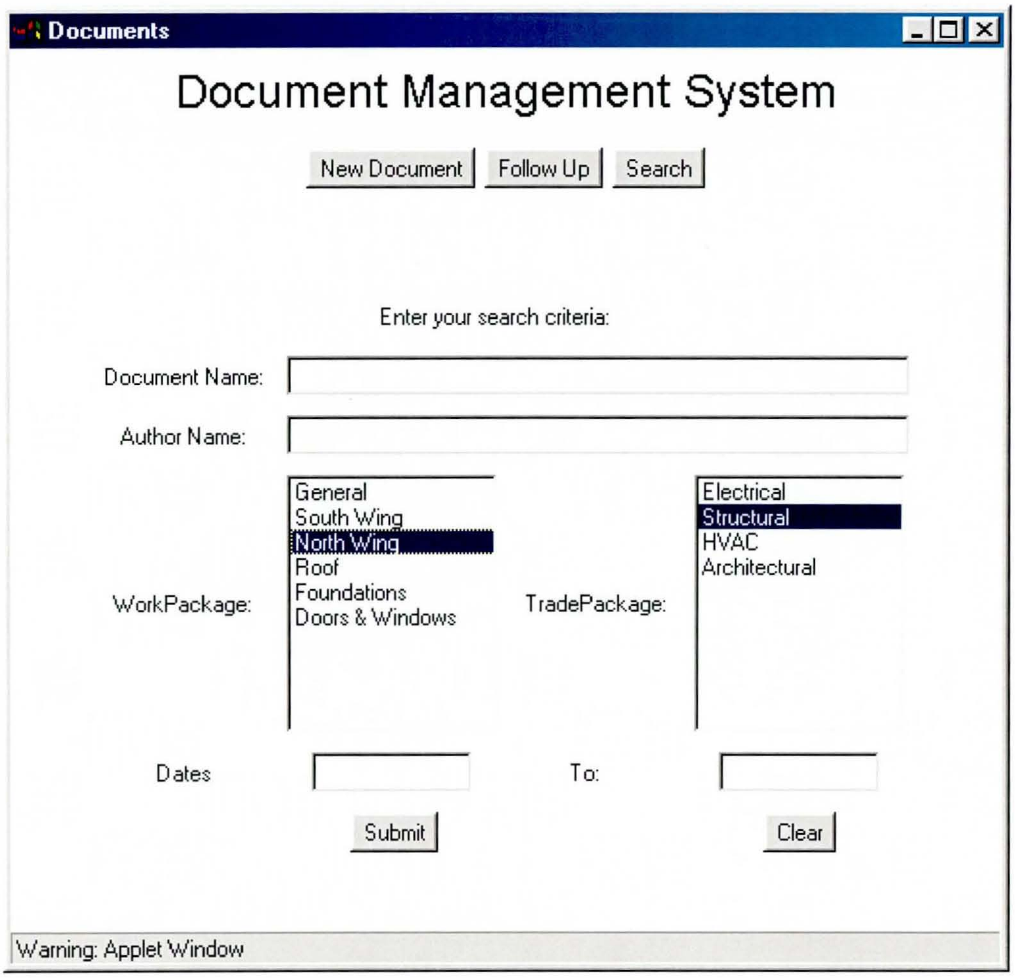


Figure 5.23. Document Management System Search Page

5.4 Summary of System Functionality

Much of the functionality of the prototype system has already been covered in the description of the development process that was carried out. This was necessary to give the background and rationale for the design decisions that were made in this process. In this section the functionality of the demonstrator will be summarised.

The demonstrator has two ways in which it can be operated. The first is by directly interacting with the interface itself (as the user would) and the second is via the control box which starts various actions that are used to show additional features of the demonstrator.

Firstly the direct interaction allows the following functionality. The user can:

- put their mouse pointer over a feature in the model to get a textual description of it;
- click on a feature to bring up a Document Management System search on items related to that feature;
- put their mouse pointer over an avatar and find out the name of the person that it represents;
- click on an avatar to open the Web page of the person that it represents;
- select to navigate to a number of feature locations available on a drop-down list;
- select to navigate to the same feature location as a user of their choice available on a drop-down list;
- initiate a text chat with any of the other users at their current feature location;
- initiate a Forum Meeting with any of the other users at their current feature location;
- respond to an event by requesting more information about it;

- respond to the further information by opening the relevant document;
- respond to the further information by opening the Web page of the author or relevant person;
- respond to the further information by navigating to the relevant user with a view to initiating communication; and
- delete an event once they have digested the information.

The control box allows person carrying out the demonstration to:

- present a login dialogue to the user asking for their login name and password (and only allow them access to the environment once they have done so);
- present events to the user simulating relevant project events or information and navigate the user to an appropriate feature location;
- change the period between the moves which dummy avatars make around the environment;
- open a Document Management System window that enables a demonstration of how the agent would monitor activity and navigate the user appropriately; and
- exit the demonstration.

5.5 Benefits In Facilitating Concurrent Life-Cycle Design and Construction

In Section 2.3 a number of key communications issues that need to be addressed within a Concurrent Life-Cycle Design and Construction environment were identified. Having proposed a Telepresence Environment in Chapter 4 and described the development of a concept demonstrator in this chapter, it is pertinent to now discuss the benefits of the Environment in addressing these issues and facilitating communication in a CLDC environment.

One major issue is that the greater the level of concurrency in a process, the greater the level of co-ordination required. The increased level of communication between project team members is enabled by the Telepresence Environment. It promotes chance encounters between team members and provides opportunities for them to communicate in an informal way. It also promotes an awareness of project events and information. The global nature and complexity of construction projects that leads to widely distributed teams increases the reliance on telecommunication since face-to-face meetings or co-location of the team are rarely cost-effective. Again, the Telepresence Environment enables teams of this nature to operate effectively.

Other communications issues were concerned with greater discipline in the management of project information and the effective communication of both graphical and non-graphical information. These issues together with the inadequacy of paper-based communication to meet the demands of a collaborative working environment highlight the need for the electronic document management systems introduced in Section 3.1.1.3. Such systems could, of course, be introduced in isolation of a Telepresence Environment. However, the Environment contains a Web-based document management system as an integral component and seeks to amplify the benefits that the management system offers i.e. increased accessibility of project information and better awareness of data related events.

The final issue was that the industry should take advantage of new information and communications technologies. One such technology is Telepresence and the environment certainly provides benefits in delivering this to construction projects. However, it also promotes the use of other new technologies such as audiographic conferencing, instant messaging (and potentially many other communication technolgies) and Web-based document management.

5.6 Summary

This chapter has described the rationale behind the development of the concept demonstrator, identified the architecture that was employed and described the development process that took place to realise it. Details of the functionality of the prototype system were included as appropriate in describing the development process. The benefits of the demonstrator have been that it has allowed a better understanding of many of the issues involved in the production of a fully-working Telepresence system such as the various data sources required, the interfaces between them and the environment, and the requirements for some of the multi-user aspects of the environment. It has also resulted in a body of code that can at least be used for further development of the system. In some cases, parts of the code could be re-used - such as that for the placement of avatars, the VRML interfaces and many of the database queries. The final benefit is that it has resulted in a valuable tool that forms the basis for the evaluation process that was carried out and is described in the next chapter. This process enabled the claimed benefits of the Environment, identified at the end of this chapter, to be evaluated.

Chapter 6 Evaluation of the Telepresence Environment Demonstrator

This chapter presents the evaluation of the Telepresence Environment demonstrator that was carried out with industry practitioners. The objectives of the evaluation are introduced followed by an explanation of the methodology used. The way in which the actual process of the evaluation was carried out is described. This is followed by a presentation of the results and a discussion focused around these.

6.1 Objectives of Evaluation

The objectives of the Telepresence Environment demonstrator are to illustrate the concept introduced in Chapter 4 and allow it to be evaluated by industry practitioners. This concept is, in short, the application of a Collaborative Virtual Environment to support distributed teams in Concurrent Life-Cycle Design and Construction projects. The objective of the evaluation itself was to determine how appropriate the adoption of this concept is to the industry and also how well the demonstrator meets the objectives that the environment is attempting to fulfil.

Specifically, the objectives for the evaluation were:

- To assess how well the environment and the features within it, support the notion of co-location within a virtual space i.e. Telepresence.
- To determine how well the environment encapsulates and represents the project itself.
- To assess whether the various elements of functionality associated with the delivery of information about people and project data are both appropriate and suitably well implemented.
- To assess whether the communication tools in the environment are sufficient and suitably integrated.

- To determine how well the environment allows users to improve their awareness of activities on the project and whether this improves the ability of the user to fulfil their role.

- To assess whether the adoption of the environment could improve the prospects of a project achieving the goals of Concurrent Engineering.

- To determine whether industry practitioners would make use of the environment and more specifically whether any groups or professions would be more or less likely to do so.

6.2 Methodology

6.2.1 Evaluation Techniques

Many methods exist for evaluating information and communication technologies. In general, these are complementary processes that are appropriate at different stages of a development life-cycle. A number of different approaches to evaluation with respect to Knowledge Based Systems (KBS) are described in the papers by Anumba & Scott (2001) and Miles et al (2000). Although KBSs are in a markedly different domain from the technology under evaluation in this thesis, there are similarities that make the evaluation techniques employed appropriate to both. Neither of the technologies is widely used in the industry and both rely on underlying algorithms to make decisions on behalf of the user. In KBS these decisions are based upon previous cases while in the Telepresence Environment they are based upon interest profiles of the users.

Anumba & Scott (2001) list a number of commonly employed qualitative techniques for the evaluation of KBSs. Those that could be appropriate to Telepresence Environment evaluation are:

- **Sensitivity Analysis.** This involves changing a system's input variables over a range of interest to observe the effect upon system performance.

- **Black Box Testing.** Information is added to a piece of code and sections of, or the whole system. Results are predicted and are compared with the actual results of the system.

- **White Box Testing.** This test consists of supplying a set of inputs to a piece of code, and studying the paths followed through the code and the combination of sub-paths, In this case, the focus is on how the system reasons.

- **Unit Testing.** Tests are conducted on a single procedure.

- **Module Testing.** Tests are conducted on a module of code, made up of many procedures.

- **Usability.** This involves assessing the expert's opinion of the system's user-interface.

Miles et al (2000) describe two methods employed for carrying out user evaluation of KBSs. The first involved supplying users with a working version of the system under evaluation and leaving them to make use of it over a prolonged time period (e.g. a number of weeks). A diary was used to provide a record of usage by the evaluator and was to include information on any difficulties that occurred and any features that were felt to be lacking. Following this period of use a discussion was then held based upon the experience as recorded in the diary. The system was then revised accordingly and the process repeated. The advantage of this approach is that the usage of the system by the evaluator is likely to be close to what would be expected in a normal working scenario. They have time to adapt to the system and fall into a pattern of usage. The disadvantage is that should they experience problems early on they may well reject the system for the remainder of the evaluation period.

A second approach was applied where a higher number of evaluators were available for a short period of time. An evaluation session was held in a single location with all the evaluators participating simultaneously. The session consisted of a hands-on usage portion, where the evaluators were guided through a usage scenario with the use of appropriate notes. This was followed by the distribution and completion of a questionnaire by each evaluator.

In a comparison of the two techniques, Miles et al (2000) find that the 'diary study obtained a lot of comments about the user interface and most usefully suggestions for improvements, while the questionnaires mostly elicited comments about the user's opinions of the system'. A mixture of both techniques is suggested in future work.

A further method of evaluation that is appropriate at early stages of the development life-cycle is the concept demonstrator or prototype. The importance of this technique was identified in the previous chapter. The concept demonstrator is also a useful tool that enables further evaluation to take place. The nature of the concept demonstrator will affect what further evaluation processes can be carried out using it as a basis so ideally the required process should be determined before the demonstrator is developed. One such process involves presenting the demonstrator to an audience by demonstrating its functionality, perhaps using an appropriate scenario to clarify its intended purpose. The opinions of the audience (which could be as few as one person) can then be canvassed using techniques such as the questionnaire or the interview. In each case the responses should be recorded, analysed and used as an input to future development processes. A different process is where the demonstrator is in a form where it can be operated by a potential user. They could either be asked to perform specific tasks or left to persevere on their own. Again, an appropriate scenario could be employed. Eason (1988) discusses the merits of these two approaches and clearly prefers the latter. 'The power of the prototype to help users appreciate the consequences of the technical change is very great but unfortunately this potential is often lost in demonstrations with the designers operating the system and then asking users for comments. The concrete reality of the system is usually sufficient to generate many valuable comments however, this kind of trial does not help users experience potential usability problems'.

Somerville (1992) identifies the following techniques that can be used in the evaluation of user interfaces. These are also applicable in the evaluation of any system where the user is involved:

- Questionnaires which collect information about what users thought of the interface.

- Video recording and analysis of typical system use.

- The inclusion in the software of code which collects information about the most heavily used facilities and the most common errors.

- The provision of a 'gripe' button which allows the user to feedback comments about the system to its designers.

In addition to video recording system use, it could be just as appropriate to observe the user and note significant events.

An important factor for these techniques is the sample employed, both in terms of how many potential users are exposed to the demonstrator and also what criteria is used to select people. Obviously, the ideal situation would be to carry out the evaluation with a statistically significant number of people with a variety of levels of experience and backgrounds. However, this can be very time consuming and expensive - factors that can nullify the benefits of carrying out the prototype evaluation in the first place.

At later stages in the development life-cycle, different methods of evaluation are appropriate. The trial is a popular technique that can be used once the system is developed to a stage where it can be deployed, at least in controlled manner. The trial is usually carried out with a closed user group over a defined period of time. Early trials may be carried out with a group of 'friendly' users who could be familiar with the system and tolerant of potential problems. Later trials may use groups that are considered to be more realistic i.e. having had no previous exposure. These groups are less likely to be tolerant of problems.

6.2.2 Rationale for Adopted Approach

The objective of the evaluation in this project was, as stated above, to demonstrate a concept and gain user feedback on how appropriate the application of it to concurrent engineering projects in the industry would be. The proof of a concept is certainly suitable at an early stage in the development cycle of a system. For this reason, it was deemed appropriate to develop a prototype in order to illustrate the concept to an evaluation group. The most important thing was to gain feedback on the concept at an early stage. An alternative approach would be to instead concentrate on the design and build of a fully working system that could then be trialled. However, omitting the prototype stage in favour of getting straight down to development would be very risky indeed. The area of work is quite new to the industry and its implementation would be by no means an incremental step. For this reason, the lower risk strategy of first gaining the views of industry practitioners was adopted.

Of the two prototype evaluation methods described above, a demonstration-type evaluation process was chosen in favour of a 'hands-on' one. As stated earlier, Eason (1988) prefers the latter approach as it allows usability to be assessed. However, at this stage of development, determining the usability of the interface was deemed to be of less importance than determining whether the concepts were appropriate and applicable. Thus, it was decided that there was little to gain at the current stage from having the users try out the system. One of the proposed benefits of the system is that it will supply relevant information to people at the right time. The effectiveness of this would be almost impossible to determine from a short user session with a pre-determined set of data. Another goal of the system was that it should fit in well along side existing working practices and not always command the full attention of the user. Again this is very difficult to assess outside of the normal working environment. The effectiveness of the system in meeting these goals would need to be addressed in later evaluation processes - perhaps at the trial stage. A demonstration would provide the necessary exposure of the concepts to those involved. The time factor was deemed to be of equal importance. The chosen method meant that the evaluation could be carried out with several people at one time - more people than could have been included had individual evaluation sessions been carried out.

Additional evaluation techniques were also employed. These were part of a continual evaluation process during the development of the concept demonstrator. The techniques were a combination of unit, module and white-box testing and involved testing self-contained sections of the system. Visual J++, the Integrated Development Environment employed provides facilities that make the tests easy to set-up. These include the setting of breakpoints in a program, stepping though procedures and the checking and setting of variable values. As a result, tests such as seeing how the software responded to user input or setting the parameters of a procedure and observing the return value could be carried out.

6.2.3 Choice of Evaluators

A sample group of twelve people were selected to evaluate the prototype. Although, in no way statistically significant, it was hoped that this number of people would provide a reasonable cross section of backgrounds and experience to produce a useful collection of responses to the questions posed. Eason (1988) states that "for a scientific study it would be necessary to obtain numbers for the sample to be representative of all levels and types of users. An evaluation for practical rather than scientific purposes may not need to be rigorous about numbers but it should include the full range of users". The people approached all had some level of experience in the industry and with IT and also, importantly, were likely to be available to participate. It could be argued that the sample group should have included people with varying levels of exposure to IT (including some with none at all). However, the purpose of the evaluation was not to assess the specific usability of the prototype but to assess whether the concepts involved were appropriate and applicable to the industry. Thus it is questionable whether the results from IT novices would have added any value as they would have been unfamiliar with the capabilities of the technologies involved in their own right let alone integrated in the way demonstrated.

6.2.4 Evaluation Feedback Mechanism

The views of the industry practitioners were gained with the use of a questionnaire and a short discussion session. This fitted in well with the demonstration approach since they are both appropriate for use with a group of people. Although fuller responses may have been gained from individual interviews or smaller discussion groups these would have been more time consuming. For this reason the method chosen was deemed to be perfectly adequate at this stage of development. The questionnaire consisted of a mixture of open questions that required a qualitative response and a series of statements that required a quantitative response indicating the level to which the respondent agreed or disagreed with the statement. This mixed approach is endorsed by Eason (1998) who states that 'Structured questions have the virtue of easy analysis and direct comparability. Their weakness is that they pre-define the answers it is possible to give and may not therefore permit the user to report the most important issues. We have always found it useful to use a structured approach to reveal issues and, once an issue is located, to use an unstructured method to explore the nature of the issue'.

6.3 Evaluation Process

Following the decision to produce a demonstrator for the Telepresence Environment it was necessary to evaluate it in line with the objectives outlined above. This was carried out by presenting the demonstrator to a number of industry practitioners and obtaining their feedback via a questionnaire. All those who were invited to participate had practical experience within the industry as well as experience with the use of Information Technology. In all, the opinions of twelve people were obtained.

In order to ensure that the respondents were familiar with the concepts involved, they were first shown a presentation. This explained the concepts of Telepresence and Concurrent Engineering. It also introduced the Telepresence Environment and identified the broad objectives of it. The slides from this presentation are shown in Appendix A.

The demonstration immediately followed the slide presentation. This was carried out with the use of a laptop computer connected to a projection system in front of all the participants. The participants were invited to interject at any point during the demonstration to ask questions of clarification. The demonstration itself took the form of a sample usage session. This covered the main points of user interaction in an attempt to illustrate its features. The actions and features covered in the demonstration are listed below:

- User logs on to the environment when the computer starts up

- User joins the environment at the entry point. The main features of the environment i.e. avatars and building model are explained.

- The ability to find out whom an avatar represents by 'mousing over' and opening the person's Web page by clicking on the avatar is introduced.

- The text chat facility for informal communication is introduced.

- The ability to move around the environment by selecting a feature location or another user is introduced.

- The user is informed of events related to people or information that is provided to them by the agent. The user's location is changed accordingly. The ability to get more information about the event is introduced followed by the facility to open the relevant document or commence communication with the appropriate person.

- A sample interaction is carried out where another avatar approaches the user and requests a text chat. A short chat reveals the need to enter a more focused meeting with other users. This is then launched and its features (such as application sharing, audio conferencing, etc.) are introduced.

- Links to the document management system are shown by clicking on a feature in the building model. This automatically carries out a search for relevant documents or drawings. These are shown to the user who can then select to open them up for viewing.

After the demonstration there was a further opportunity for questions of clarification. Following this, the participants were requested to complete the questionnaire.

6.4 Questionnaire Design

The questionnaire was the principal means by which the Telepresence Environment was evaluated. It is divided into six sections that roughly correspond to the objectives of the environment and the features and functions that it performs. Prior to completing these sections, the respondents are asked to provide information about themselves in terms of the number of years of practical experience in the construction industry, the role(s) they have held and the area of experience. Each section has a number of questions that allow respondents to express their views in both a quantitative and qualitative manner. Quantitative questions consist of a statement to which the respondents are invited to express their level of agreement with by circling a number on a five point scale. 1 signifies strong disagreement, 5 signifies strong agreement, while 3 signifies neutral or neither agree nor disagree. The 5 point scale was chosen as it was deemed to provide a sufficient range of responses without being overly complex. It also allows respondents to select the 'middle ground' if they have no specific opinion on a particular question. Qualitative questions consist of a question followed by a space in which respondents are invited to express their views in written form. The full questionnaire can be seen in Appendix B.

6.5 Results & Discussion

6.5.1 Evaluators' Background

As mentioned in the previous section, the evaluation respondents were first asked to provide some information about themselves. Firstly they were asked to state how many years of practical experience they had in the Construction Industry. Responses ranged from 0 to 23 years with an average of 7.75 years. 75% of the respondents had had 4 or more years of experience. The descriptions of roles carried out or positions held produced a wide variety of answers including Lead Civil Engineer, Project Manger, Designer, Consultant, Site Supervisor, Client Engineer, Quantity Surveyor and Safety Consultant. The areas of experience given were in the main, Building, Structural or Civil Engineering with a few respondents providing more specific classifications such as River Bank Engineering, Water Supply and Drainage and High Rise Building.

The level of experience, the nature of the positions held and the areas of experience were considered to be adequate and sufficiently varied to provide a fair assessment of the system.

6.5.2 Responses to Questions

For each section of the questionnaire, the results of the quantitative questions will be presented in a table showing the number of responses for each ranking and the mean ranking. A response of 1 indicated 'strongly disagree' while a response of 5 indicated 'strongly agree'. This is followed by a selection of the most pertinent of the responses to the qualitative questions. The results will then be discussed and the achievement against objectives assessed.

6.5.2.1 Virtual Environment

Questions	1	2	3	4	5	Mean Ranking
1. Virtual Environment						
1.1 The environment supports the feeling of Telepresence.	0	0	1	9	2	4.08
1.2 The building model itself supports Telepresence.	0	0	3	8	1	3.83
1.3 The user avatars support Telepresence.	0	1	3	8	1	3.92
1.4 The feature locations (e.g. Roof, South Wing) represent the project and its workpackages well.	0	3	2	6	1	3.42
1.5 The feature locations are sufficient in number	0	1	6	3	2	3.5
	Section Mean					3.75

In general, the respondents agreed with the statements that the environment, the building model and the avatars support the feeling of Telepresence with mean rankings of 4.08, 3.83 and 3.92 respectively. The range of responses was fairly low for these questions, however one respondent disagreed (i.e. marked with a 2) that the avatars support Telepresence and stated that they would prefer avatars that were fully controllable. This point was raised in the response to question 1.6 and is discussed below.

The two statements concerning the feature locations received, on average, lower marks and there was a fairly high variation in responses. Three respondents disagreed that they represented the project and its workpackages well resulting in a relatively low mean rank of 3.42 while seven disagreed or responded neutrally that they were sufficient in number resulting in a mean rank of 3.5. Certainly, the number of workpackages would probably be increased on a real project and these could be represented as further feature locations. The comments given by those feeling that the feature locations did not represent the project indicated that more and different kinds of feature locations were needed. These are discussed together with the responses to question 1.7 below.

1.6 How could the environment be improved?

The responses given to this question were:

- *The avatars on the model could be improved, perhaps by using photographs of participants.*
- *Be able to move around as if you were walking. See who is around and where.*
- *The standard / up-to-dateness of features could be improved to get real time feedback and discussion from correct virtual cues / prompts*
- *The level of detail could be improved, depending on specific project*
- *Could add more feature locations*

The first two responses are not unlike the most common questions that occur when environments of this nature are presented in that they refer to the quality of the avatars and the way in which one navigates around. As mentioned in Section 3.4.1, many early VR systems relied on the ability of the user to navigate effectively and thus placed a high cognitive load on the user. Although this 'freedom to roam' might appear and initially actually be appealing, it soon becomes tedious and detracts from the intended use of the system. The user's representation is another emotive issue. The use of photographs in conjunction with avatars could provide an effective means of identification of those in close proximity. As with 2-D Web pages, the images would need to be of consistent size and quality if the aesthetics of the interface were not to suffer. The time taken to initially download the environment and its state would increase with their use and the general performance of the system would decrease somewhat. Customisable avatars or the addition of name tags above the avatars are other potential solutions.

The remaining comments are concerned with the level of detail and quality of the model and improvements in the information that could be provided by it. Although it would be desirable to have a much more detailed model with more individual features, there is of course a performance trade-off, not to mention the issue surrounding how projects are currently designed (i.e. using 2D files rather than object modelling). Where a detailed 3D object model was available, it would be logical to use it as the basis for the visualisation in the environment. It could also be dynamic. However, the performance of the environment would depend on the complexity of the model, as is also the case today where it is necessary to deploy a static visualisation.

1.7 What other features could be added to the environment?

The following responses were given:

- *Current on site progress & the ability of video cameras to be utilised on site to transfer info to design office. - Include standards / external publications.*
- *Areas where an individual may be found of working e.g. site manager in site office.*
- *The standard of the 3-D model is critical to gain the acceptance of new users. This will require a big change in working.*
- *Probably showing with different colours, which part of the environment has been more recently updated*

The first two responses suggest interesting feature locations that could be added that are not related to a particular workpackage. The use of remote video in the environment was considered at design stage but was not implemented in the demonstrator due to time pressure. However a 'video wall' in the environment could provide a useful focal point somewhat akin to looking out of a site office window - something site workers are prone to do and something that often results in useful interaction taking place. Users could also be navigated to the 'video wall' by the agent if they were viewing 2D Web-cams pages on a project intranet. Additional areas, such as a site office, might also prove to be useful. These could be default areas where those users that are logged on but not engaged in work that the agent deems worthy of a placement near a feature could be placed. This is really an extension of the concept of the entry feature.

The final two points are again related to the quality of the model and the information it provides. This was discussed above, however the idea of changing the colour of features is interesting. This was also considered at the design phase. It could prove to be effective where the granularity of the features in the model is high enough to give an adequately specific piece of feedback.

The results for this section suggest that the respondents felt in general that the environment and its principal features did support the feeling of Telepresence. An overall mean ranking for this section was 3.75 out of 5. Some stated that they thought that the quality of the avatars and the environment in general could be improved. Many seemed to think that the feature locations should have been more numerous and did not represent the project and its workpackages all that well. It is likely that a real project would have more workpackages that could be represented. In addition, further feature locations could be added that do not necessarily correspond to a workpackage (such as the video wall).

6.5.2.2 Delivery of Project & People Information

Questions	**1**	**2**	**3**	**4**	**5**	**Mean Ranking**
2. Delivery of Project & People Information						
2.1 The project information is adequately encapsulated in the environment.	0	0	3	8	1	3.83
2.2 It is useful to be able to click on project features and go directly to the relevant part of a Document Management System.	0	0	0	3	9	4.75
2.3 The people information is adequately linked to the environment	0	0	3	7	2	3.92
2.4 It is useful to be co-located in the environment with those who have similar interests or focus	0	0	0	5	7	4.58
2.5 It is useful to be able to communicate with these people in an ad-hoc manner.	0	0	2	4	7	4.42
2.6 It is useful for users to be informed about events that are of relevance via the environment (e.g. A N Other has joined the environment, A N Other has added an RFI on document XYZ).	0	0	0	3	9	4.75
2.7 The way in which events are presented to the user in the environment i.e. via navigation to feature with accompanying text is very good.	0	1	2	8	1	3.75
	Section Mean					4.29

The responses to the statements regarding the delivery of project and people information are generally very positive. The range of responses indicate only a moderate to low variation for all of the statements bar 2.7. The respondents agreed that the links to information and events were good, with mean ranks of 4.75 for both, and that co-location and communication via the environment were useful facilities (supplying scores of 4.58 and 4.42). In this section, only one individual responded negatively to the statement concerning the way in which events are presented (2.7) and expressed concerns that the user should always retain control of meetings and the delivery of information. A mean rank of 3.75 resulted for this statement.

2.8 Please suggest how this aspect of the system could be improved.

The respondents supplied the following answers:

- *The user should be able to have some control of info / meetings being arranged.*
- *Strong control / management of agent needed, so as not to be inundated with information.*

The respondents were very satisfied that the delivery of information was both useful and carried out in a suitable manner and an overall mean rank of 4.29 was achieved (marginally the highest rank of all the sections). Some very valid concerns were expressed about users suffering from information overload. It was pointed out that users should have some control over both the amount of information and the way in which it is delivered, and also the access that other users have to an individual. These points are touched upon in Chapter 4 and would need careful consideration in a practical system to ensure that the user felt that they remained in control.

6.5.2.3 Communication Tools

Questions	1	2	3	4	5	Mean Ranking
3. Communication tools (Text chat, Audiographic conferencing, other tools available via homepage)						
3.1 The communication tools integrated into the environment are adequate.	0	1	1	5	5	4.17
3.2 These tools are well integrated into the environment.	0	0	0	9	3	4.25
	Section Mean					4.21

High mean rankings of 4.17 and 4.25 resulted for the two statements about the communication tools. These results are very positive with very little variation in the responses apart from one negative and one neutral response given to statement 3.1. These were backed up with the additional comments that 3D walkthroughs and virtual environments should be available and the concern over whether users could draw graphics. Certainly, the former could be addressed by linking to 3D material in the document management system although the available network bandwidth would be an issue for complex models. The latter concern may refer to users being able to collaborate on the modification of drawings or the use of redlining packages. Both of these would be possible via application sharing in an online meeting.

3.3 What other communication tools might be useful?

The evaluators suggested the following as potential additional communication tools:

- *Video cameras for site*
- *Telephone Systems, etc.*
- *Video Conferencing*
- *3D walkthrough, virtual environments to aid discussion on particilar details e.g. co-ordination issues*
- *Could users draw graphics?*

The communication tools were deemed to be both adequate and well integrated into the environment. Other tools such as video conferencing and telephony were suggested. These could be readily integrated in a similar way to the audiographic conferencing i.e. a 'click to call' system via a conferencing server. The remaining suggestions seemed to focus upon sharing data whilst in a conference. This type of interaction is feasible, however, as stated above, the sharing of complex models or walkthroughs is heavily dependent upon the availability of bandwidth.

6.5.2.4 Supporting the User

Questions	1	2	3	4	5	Mean Ranking
4. Supporting the User						
The environment allows the user to maintain an awareness of the following:						
4.1 People on the project.	0	0	1	7	4	4.25
4.2 The status of project documents.	0	0	0	9	3	4.25
4.3 The project in general.	0	0	3	5	4	4.08
4.4 The environment improves the ability of the user to fulfil their role on a virtual construction project team.	0	0	1	6	5	4.33
	Section Mean					4.23

This section dealt with the ability of the environment to support individuals on projects. Again, the responses to each of the quantitative questions were positive (all mean ranks being over 4) with limited variation. This indicated that the proposed benefits to the user were clear from the environment demonstrator.

4.5 Please suggest how this aspect of the system could be improved.

The subsequent improvements were suggested:

- *The environment is useful for long distance discussions e.g. design office / site - It would be useful if financial & planning data are also available for use.*
- *Improved representation of users. Can see who's with whom at which location*

The suggested improvements could be accommodated. Financial and planning data would be part of the document management system and would be readily available. The user list could quite easily be ordered according to the current location of each user. The results suggest that the respondents felt that the environment would support the user in maintaining an awareness of the project and fulfilling their role upon it. This is reflected in the high overall mean rank of 4.23.

6.5.2.5 Supporting the Project

Questions	1	2	3	4	5	Mean Ranking
5. Supporting the Project						
5.1 The environment would improve communication in a Concurrent Engineering project setting.	0	0	1	7	4	4.25

5.2 The environment would support a Concurrent Engineering project in achieving the following goals:						
5.2.1 Faster decision-making.	0	0	2	5	5	4.25
5.2.2 Quicker access to participants.	0	0	2	6	4	4.17
5.2.3 Earlier consideration of downstream issues.	0	0	4	6	2	3.83
5.2.4 A reduction in mistakes made	0	3	4	4	1	3.25
5.2.5 A better understanding of requirements.	0	1	4	6	1	3.58
5.2.6 Better project co-ordination.	0	1	1	7	3	4
5.2.7 Faster delivery of project information.	0	0	0	8	4	4.38
	Section Mean					3.96

This section is concerned with assessing the value of the environment in supporting the project. The first statement received a high response of 4.25 indicating that the proposed benefits to project communication are clear. One of the goals of the environment is to provide easily accessible communications tools, which should allow participants to remain in closer contact. This facility is reasonably easy to demonstrate and perhaps accounts for the high marks (all 4 or above) given for 5.1, 5.2.2 and 5.2.6 which all deal with people communication and co-ordination issues. Similarly, another goal that is quite easily demonstrated is the delivery of project information to appropriate users. The statements related to this - 5.2.1 and 5.2.7 - also received high marks (of 4.25 and 4.38). The remaining statements - 5.2.3, 5.2.4 and 5.2.5 are perhaps benefits that would result from the stated goals of the environment being achieved. Certainly, the consideration of downstream issues, a reduction in mistakes and a better understanding of requirements are all areas that should be improved with better user access to people and information. The relatively lower scores (3.83, 3.25, and 3.58) and wider variation of responses could perhaps be attributed to the fact that these goals are less tangible to a viewer of the demonstrator and would require further evaluation in practical situations.

5.3 Please suggest how this aspect of the system could be improved.

These were the suggestions supplied:

- *Needs may vary from project to project. Could be targeted to capture specific processes involved in a specific project*

- *I would be concerned about the use of the system, will it prevent work being carried out. Users would need to be fairly rigid in their use. This may prevent the flexibility of open discussion at any time.*

The comments made about the need for such an environment varying are certainly valid. Again, further evaluation would be required in order to determine the circumstances under which the environment would be of the most use. The second comment has been included although the motivation for it is unclear. It does however represent a view (albeit a minority one) that the environment could interfere with established working practices.

In general, the respondents felt that the environment would improve communication and provide support to a project by promoting the goals of Concurrent Engineering, giving an overall mean rank of 3.96. In particular it was envisaged that the environment would provide quicker access to project people and information and facilitate faster decision making and better project communication. Lower results were achieved when the respondents were asked whether a better understanding of requirements, an earlier consideration of downstream issues and a reduction in mistakes could be achieved. These are certainly much more difficult to assess and this could have contributed to the lower score. Further evaluation would be required in order to gain a better understanding of these and indeed many other capabilities. The responses to the questions in this section indicate that the benefits to the project are perhaps less tangible than those to the user as indicated by the results in the previous section. This highlights the need for further evaluation work in order to assess whether the proposed benefits would be achieved.

6.5.2.6 General

Question	1	2	3	4	5	Mean Ranking
6. General						
6.1 Industry practitioners would make use of such an environment?	0	0	1	8	2	4.09

The response for this statement indicates that the environment would indeed be used by industry practitioners.

6.2 What might discourage people from using it?

The respondents felt reasons that people might be discouraged were:

- *Loss of personal control of time.*
- *Cultural attitude to work. The environment could be deployed for tighter time-keeping.*
- *May appear complicated. May appear to remove engineer from site. Construction project may not appear 'real' and hence lead to poorer quality*
- *Control of information - e-mails etc - too much information being received already*
- *Not all staff working on site / in the industry have adequate IT knowledge*
- *The Cost*
- *There has to be clear demonstrated benefits in terms of reduction of mistakes, improvement in co-ordination, etc. Lack of these benefits will discourage people from using it*

There was a wide spectrum of response to this question with the respondents giving a number of issues and potential barriers that might discourage people from using the environment. By far the most popular expressed was the lack of exposure to IT that currently exists in the industry. This is indeed a serious problem although it is one that will improve over time. The environment, although appearing complex, is intended to be easy to use so it would need careful introduction to the workplace in order not to 'frighten off' novice users. Another common theme was that of cultural issues such as a loss of control on one's time and the possibility for the miss-use of the system as a surveillance tool. Again its introduction would be very important if cultural problems were to be avoided. As stated earlier, enough flexibility for the user would need to be built in to allow them to remain in control and to prevent miss-use of the system. The potential cost is of course an important potential barrier to adoption and the benefits to the project must be demonstrated to justify this. Similarly, the benefits to the user must be clear in order to encourage its use. Further evaluation work in the form of a trial on an actual construction project may be the best approach in order to determine both the costs involved and the potential benefits to both the users and the project in general.

6.3 State any groups or professions that would be **more** likely to use such a system and explain why.

The following responses were given:

- *Architects & Designers - this has the greatest interface during the design phase and the environment could improve communication and negotiation for design changes.*
- *People in the design aspects of the construction industry because they are linked to IT facilities more than builder trades, such as site manager*
- *Project Managers, Designers, Subcontractors. Interaction to help with planning of activities*
- *Consultant, Designer in fast track*
- *People who know how to use and can benefit from new technology*
- *Project Managers, Construction Managers, Designers*
- *Professionals - Engineers, Surveyors, Architects and site managers with IT training.*

Almost all of the respondents were in agreement that members of the design and management teams would be more likely to use the system. These are the industry roles that traditionally have a higher exposure to IT and a greater level of IT infrastructure available to them.

6.4 State any groups or professions that would be **less** likely to use such a system and explain why.

Those less likely to use the system were considered to be:

- *People involved with the on site activities because they have less experience with computer & IT resources*
- *Site workers as they do not always have access to computers and nature of job requires them to be on site rather than at a desk.*
- *Site Engineer (no time, a feeling of being supervised all the time)*

- *Traditional people who are reluctant to change. People who have for a long time been using traditional methods of communication in construction*
- *Stand alone consultants working in an environment with minimum interaction with others*

Similarly, there was agreement that site workers would be less likely to make use of the environment. This is the area with the lowest level of IT exposure and the role with lends itself least to the use of IT in its current form. However improvements to and the subsequent greater use of portable or wearable devices may still make the use of collaborative environments appropriate.

6.5.3 Further Questions

The following questions were asked by the respondents during or after the demonstration. An abridged version of the response given at the time is included.

- *Is the model updated as the project progresses?*

  It was explained that any updates made would be a manual process. As such, in order to reduce overheads, it would be important to ensure that the model was conceptual enough that it remained appropriate throughout the project life-cycle. Alternatively, if a 3-D CAD model was produced and maintained as part of an existing project process, it would be possible to use a version of this in the environment to ensure that it was up to date.

- *When in a meeting, how do you share files and applications? Who is able to control the view of applications and who is able to modify the contents?*

  The process of application sharing and collaboration was explained in more detail. It was explained that, as with Microsoft NetMeeting, a shared application could be controlled by all participants (but only one at a time and at the behest of the owner) and all would share the same view.

- *Is it possible to use mobile or normal telephones in conjunction with the Environment?*

The setting up of a phone call was not shown in the demonstration (in favour of a more sophisticated on-line meeting) but it was explained that this would be possible. It was explained that both mobile and normal phone users could be invited into on-line meetings as audio-only participants. They would also be able to upgrade to data conferencing if they were near a terminal.

- *How are CAD packages and drawings and other applications integrated into the environment?*

  It was explained that only the links to files were integrated. When selecting one of these links, the default application for that file type would open. This would be configurable by the user.

- *What happens if people don't want to join chat sessions or on-line meetings?*

  Users would be free to ignore requests to join meetings just as they may currently choose to ignore other forms of communication such as phone calls or e-mail messages.

- *As this is just a prototype, how should it be developed and validated in a real situation?*

  This is a very important question that resulted in a discussion. Possible approaches to this issue are outlined in Section 7.2.

6.6 Evaluation Analysis

As outlined earlier the evaluation process consisted of the development of a prototype and the subsequent assessment of it through demonstration and questionnaire. The reasoning behind the selection of this process is discussed in Section 6.2. This section will assess how successful this evaluation process has been in the light of the results achieved.

The evaluation process has resulted in a body of quantitative and qualitative results. The quantitative results are in general positive and give a good indication that the prototype is considered to be appropriate to the industry and that the application of the concepts it illustrates would be beneficial. This is shown by the overall mean ranking of 4.09. The qualitative questions prompted the respondents to highlight areas that could be improved and to suggest what those improvements might be. This naturally leads to a more negative set of responses. In sections where lower marks were given for the quantitative questions there were fuller responses to the qualitative questions. Respondents seemed to be keen to justify lower markings with their reasons for giving them. This resulted in a good set of potential issues and concerns being given by the respondents. In addition a wide variety of suggestions for improvements were also provided.

The assessment process has been successful in that it has provided an indication of how appropriate the prototype is as well as important issues that need addressing and areas in which it could be improved. However, from the results themselves it is clear that the assessment process alone is insufficient to determine the full suitability of the prototype and the concepts it illustrates.

6.7 Potential Benefits and Limitations of the Prototype Environment

This section distils the questionnaire responses and presents the potential benefits and limitations of the prototype environment based upon the evaluation.
The benefits are:

- The environment and the features within it, support Telepresence.

- The methods used to deliver information about people and project data are both appropriate and suitably well implemented.

- The environment provides communication tools that are useful and well integrated.

- The user is supported in fulfilling their project role and has an improved awareness of project activities.

- The adoption of the environment would improve the prospects of a project achieving some of the goals of Concurrent Engineering.

- The environment would be widely used by design and management teams.

The limitations are:

- The environment does not contain realistic avatars.

- The project could be represented better by adding further features to the environment.

- The environment could increase the problem of information overload rather than reducing it.

- The prototype does not provide tangible evidence that the adoption of the environment would improve the prospects of a project achieving all of the goals of Concurrent Engineering.

- The low use of IT and the lack of skills (particularly in site roles) are potential barriers to adoption.

6.8 Discussion

The potential benefits of the environment as given by the respondents provide a positive assessment for each of the objectives laid out in Section 6.1. There were also some very valid limitations expressed which are now discussed.

The first of these were that the avatars and features in the environment could be improved and extended. These are concerned with technical aspects and the suggested improvements could be readily integrated into future implementations should they prove to be beneficial.

However, as stated above, improved avatars would not necessarily improve the quality of the environment as a whole.

Information overload and the lack of IT skills are both industry issues that could affect the success of the environment. The environment is attempting to reduce the problem of information overload as discussed in Section 4.6.2.4. Great care should be taken to ensure that is not increased and this should be monitored in any future evaluation processes involving users. However, the nature of the Environment is that users should be able to make as much or as little use of it as they see fit. The latter issues of low IT skills and usage, as discussed in Section 6.5.2.6, are well recognised and represent a major problem for the adoption of technology in general. However, the results discussed in Section 3.7 do indicate that the necessary improvement in infrastructure is beginning to take place. This is also reported to be the case with the usage of some key technologies and importantly the attitudes and acceptance levels of members of the industry.

The vital way to improve the prospects of the adoption of a technology is of course to prove its benefits in relation to cost (and time). As a result, the limitation of the Environment in failing to provide evidence of an improved project is one that definitely needs to be addressed. One way that this could be addressed is to trial the Environment in a real project situation. This would give project personnel the opportunity to use the Environment over an extended period of time, get used to its functionality and form an opinion on whether the stated benefits are actually achieved. This is certainly not an easy task as there are many difficulties involved with carrying out a trial in a working environment. The difficulties are magnified when, as with the Telepresence Environment, the trial system must integrate with existing systems. The remaining limitation that was expressed was that the Environment could add to the problem of information overload. Again, only a trial situation would allow the users to determine whether the problem was improved or worsened by the Environment, however the issue should be considered at the forefront of further development activities.

6.9 Summary

This chapter has presented the evaluation process carried out on the environment demonstrator and the results obtained from that process. It also discusses the results and identifies the important points that can aid the further development and evaluation of the system. In general, the results are very positive and indicate that the objectives of the environment demonstrator have been achieved. The majority of respondents felt that the environment would be used by practitioners, would support the user in carrying out their role and would aid the project in general. They expressed that the environment supports Telepresence, provides project and people information in an appropriate manner and has useful integrated communication tools.

Some respondents expressed concerns about the introduction of the system. These were primarily of a cultural nature e.g. the lack if IT skills in the industry and the user's loss of control of time and access to information. Some also made the valid point that further evaluation work in a real construction project setting would be needed to determine the costs and benefits associated with the environment. As stated earlier, this form of evaluation would ideally have been carried out but was not possible due to time constraints.

Chapter 7 Conclusions and Further Development

In this final chapter the research is first summarised in terms of its objectives and the work that was carried out in order to achieve them. A series of conclusions are then made based upon the findings of the work. These are concerned with the prototype Telepresence Environment that was developed, the adoption of Telepresence technology within the industry and the establishment of a communications infrastructure for Concurrent Life-Cycle Design and Construction. Following this, a number of areas for further development are suggested. These include both extensions to the prototype and general work in the field of Telepresence.

7.1 Summary

The research reported in this thesis is concerned with the adoption of Telepresence technology in the construction industry specifically within the context of Concurrent Life-Cycle Design and Construction. In order to address this aim, a number of research objectives were identified. The first of these was to review the collaborative communications requirements of the construction industry within a CE context. The nature of the construction industry was described as being fragmented and beset with a number of problems. Many of these problems can be attributed to the reliance of the industry upon a sequential and compartmentalised approach to design and construction (or the 'over the wall approach').

The work of advocates for change within the industry was described with a two-pronged approach emerging as the way forward. Improvements in the culture and processes of the industry should be followed by the application of technology as a tool to support them. The adaptation and application of Concurrent Engineering as practised in the manufacturing industry was described as one approach that could be used to tackle the many issues that the construction industry faces.

One important aspect of CE is its reliance on (and promotion of) an increased level of communication. As a result of this, the key communications issues that need to be addressed were identified. These issues recognised that where there is concurrency in a process there is a greater need for co-ordination and communication between project team members and between stages in the process. In addition, the increased complexity and globalisation of projects, coupled with the inability of paper-based communication to support them increase the need for telecommunication technologies. A model that identifies the distinct groups of people, tools and project phases across which communication has to take place was then introduced. This identifies seven main facets of communication that need to be addressed in a Concurrent Life-Cycle Design and Construction setting. These facets are:

- Intra-disciplinary Tool-to-Tool Communication
- Designer-to-Tool Communication
- Project Team Communications
- Discipline-to-Project Model Communication
- Communication Between Stages in the Project Life-cycle
- Project Team-to-Third Party Communication
- Inter-disciplinary Tool-to-Tool Communication

A series of emerging communication technologies were described. These technologies, which included collaboration technologies, Virtual and Augmented Reality, Telepresence and Collaborative Virtual Environments, were chosen because it was felt they could be applicable to a CE in construction setting. The technologies were mapped to the communication facets with the facet - Project Team Communications being recognised as the one on which the identified technologies are likely to have the most impact. Telepresence was recognised as one technology which could have great impact in integrating project teams and project information.

This process allowed the second research objective, which was to investigate the applicability of Telepresence to collaborative communications in construction, to be addressed. It was established that Telepresence could be employed as an integration tool - providing a collaborative environment that would enable users to access a communications infrastructure, employing many of the collaborative communications technologies already discussed.

The applicability of Telepresence in terms of the industry's current use of technology was also considered. It was found that although progress is being made in the adoption of IT and communications technologies there is little evidence of the usage of technologies such as Telepresence and Collaborative Virtual Environments. However, it was also found that the use of many of the technologies that a Telepresence Environment would rely upon is becoming more widespread. These include Web-based services, e-mail, electronic document management systems and the necessary network infrastructure.

The third objective was to develop an architecture for a Telepresence-based Collaborative Communications system for construction project teams. In determining the applicability of Telepresence, a number of scenarios that described how the technology could be utilised were introduced. These were used along with the experience gained from the CICC project to produce a system specification. This was basically a description of what the Telepresence Environment should do. Briefly, the aim of the Environment is to provide a collaborative space for personnel that integrates access to people and information. Visual representations of the construction project and of project team members (i.e. the users) within the Environment provide the users with access to underlying project data (such as drawings, schedules, rationale, etc.) and to the other users via integrated communication channels. Also of importance is the stated aim that the Environment would promote awareness of project personnel and information by manipulating the user's view on the environment towards representations of project elements or people that were deemed to be of interest. Following these high level descriptions of functionality, detailed investigations into the technicalities of the integration of communication channels and project information systems and the maintenance of user interest profiles were carried out. This process resulted in an understanding of the key components that were required to deliver the stated functionality and the way in which these components were to interact with each other. The unification of these components formed the conceptual architecture for the Telepresence Environment.

The fourth research objective concerned the development of a prototype or concept demonstrator to illustrate the goals of the infrastructure. The rationale behind this approach was that the concepts proposed by the Telepresence Environment were considered to be somewhat in advance of those employed by existing tools widely used in the industry. Thus a 'proof of concept' stage was required consisting of the production of a concept demonstrator and its subsequent evaluation. A full description of the process of developing the concept demonstrator was given. The first stage in this process was a definition of the architecture of the demonstrator. A translation was made between the components of the conceptual architecture and those of the demonstrator. This included the recognition of which actions would need to be simulated in the demonstrator given the available time and the absence of a real project scenario within which to test the system. A storyboard was produced which described a typical usage session. This was instrumental in determining the required capabilities of the demonstrator as well as the appearance of the interface. A detailed description of the Java applet development process was given. This is the main component of the demonstrator and the vast majority of the time taken to produce the demonstrator was devoted to its production (including its interface with the VRML model).

The final research objective was to evaluate the prototype with industry practitioners and potential users using appropriate techniques. Chapter Six details the process involved in the selection of the evaluation methods. A number of different evaluation techniques were considered. The eventual approach taken was described with justifications for its selection. As stated above a 'proof of concept' style evaluation was adopted. This involved presenting the concept demonstrator to a group of potential users thus illustrating the proposed capabilities of a fully working system. The presentation was followed by the completion of a questionnaire by the audience. The results of the questionnaire were then collated and used to determine whether the objectives had been achieved.

On the whole, the results from the evaluation process were very positive. Specifically, it can be concluded that:

- the environment and the features within it do support Telepresence;
- the methods used to deliver information about people and project data are both appropriate and suitably well implemented;
- the environment provides communication tools that are useful and well integrated;
- the user is supported in fulfilling their project role with an improved awareness of project participants and activities;
- the adoption of the environment would improve the prospects of a project achieving, at least, some of the goals of Concurrent Engineering; and
- the environment would indeed be widely used by design and management teams.

The evaluation confirmed that, despite some reservations surrounding the issues of information overload and the lack of validation of the concepts in a real project setting, the Telepresence Environment would be an important facilitator of effective communication in a Concurrent Life-Cycle Design and Construction setting.

7.2 Conclusions

The following conclusions can be drawn from the research:

1. The Telepresence Environment is a unique and innovative approach to enabling communication on construction projects. It is a medium that allows non-collocated construction personnel to collaborate at a level approaching that of co-located colleagues. Chance encounters are seen as vital to the success of an organisation. This unplanned form of communication occurs frequently when colleagues are co-located or are located at the 'workface' (i.e. the construction site in this case). The Telepresence Environment allows this form of communication to occur in the disparate organisations that are

common in the construction industry. It promotes to the user an awareness of other people or project information that it deems to be of interest to them. The user is then able to act upon this 'chance encounter' via the Environment. As well as acting as an integrator for people, the environment also integrates communication and project information services into a common user-interface. This allows the user who wishes to act upon a 'chance encounter' to easily access the appropriate project document or drawing or to speak to and collaborate with the appropriate people. The improved collaboration and communication that is enabled by the Telepresence Environment will allow the decisions made by project personnel to be more informed. This will in turn lead to an improved product with fewer mistakes made.

2. Telepresence technology is an effective way of facilitating communication within a Concurrent Life-Cycle Design and Construction environment. The adoption of Concurrent Engineering within the construction industry will increase the level of communication that is required between the parties involved. The nature of the industry is such that the parties involved in projects will generally not be co-located throughout the design and construction phases. As a result an increased reliance is placed upon telecommunications technology. Telepresence is one technology that is particularly suited to adoption in this environment. It provides users with a shared 3D environment that allows virtual co-location and the ability to interact with virtual objects within it. Construction is inherently three-dimensional in that it is concerned with the production of complex 3-D facilities. As such, a technology that can represent facilities in the same manner is appropriate. The importance of chance encounters to an organisation was identified above. These are of particular importance in a CLDC environment where greater co-ordination is proposed along with early problem discovery and early decision making. Telepresence allows these encounters to be enabled in an unobtrusive way with the use of movement around a 3D space and toward recognisable objects within it.

3. A telecommunications infrastructure for CE in construction provides an effective means to deliver the necessary improvements in communication. The importance of communication

to the success of CE has already been established. Telepresence is one communications technology that is appropriate but there are several others that should also be applied such as video, audio and data conferencing, virtual and augmented reality and project models. An appropriate telecommunications infrastructure will enable all of these technologies to be deployed in an integrated way. From the user's perspective this involves an integration of the services at the user-interface, allowing them to switch between appropriate communication channels as they see fit. The emergence of Web-enabled services has provided the means for this to be delivered. The infrastructure also provides a level of 'back-end' integration. This allows project information systems to interwork with communications services providing capabilities such as universal directories and authentication of users and access to necessary project information from within a communication service.

7.3 Further Development

The following are areas that need to be considered for future research.

7.3.1 Extensions to Prototype

In order to evolve from the concept demonstrator into a fully working system that can eventually be trialled in a real project setting, there are a number of steps that must first be carried out. The first of these should be to carry out further software development work to fulfil the requirements of the conceptual architecture. The four components of the architecture that require development are:

- **Environment Server.** This needs to be developed into a component that can store the state of the environment and can send and receive event messages to and from the various clients that are connected to it. It will also need to act upon events received from the agent server. The Forum Contact Space that was described in Section 3.4.3. contains a server component that carries out most of the required functions and as such would be appropriate for use in this situation. It would need to be adapted to serve the virtual world developed for the prototype and to deliver the necessary project-based data.

- **Client**. This needs to be developed to send and receive event messages to and from the server. As with the server, the Forum Contact Space has a client component that could be adapted for use in this situation. Again, the set of events that it handles would need to be extended, as would the methods for the presentation of data.

- **Agent System.** The Forum Contact Space Agent system had already been suggested as a candidate for the required Agent Server and Profile Builder. The case for its use is further strengthened if the other Contact Space components are employed since it can easily integrate with them. It too would require adapting (as discussed in Section 4.6.2.5) in order to cope with the meta-data obtained from documents accessed in the Document Management System.

- **Communication Services.** A simple text chat system like that illustrated in the prototype is already provided in the Contact Space. Other services such as Audiographic conferencing, provided by the Forum Meeting Space can be readily integrated, particularly as this technology is moving towards a Web-based delivery mechanism. Requests to set-up a meeting would be handled by the Enviroment Server which would communicate with a Conferencing server via an API.

Once a fully working system is available, further evaluation processes can then be carried out upon it. As stated in Section 6.2.2 a short 'hands-on' evaluation session with industry practitioners followed by an interview would give limited information about the broad benefits of the Environment due to the lack of co-users and real project information. However, this style of session could still provide some benefit. It would enable information about e.g. the quality of the user interface, the communication services and the style of information delivery to be acquired. These factors are important and could improve the chances of eventual adoption by industry practitioners.

There are specific research areas that only a trial in a real project setting would be able to provide sufficient evaluation of. These are identified below with a summary of what further research is required:

- The Environment currently uses a single model to represent the project. This provides a fairly high level view with sub-classifications of it based around major features e.g. South wing. The trial should attempt to evaluate whether this method is sufficient or whether improvements could be made that could inject more meaning from the point of view of the various disciplines (e.g. architectural, structural). It may be appropriate to allow members of the different disciplines to select their preferred view of the model.

- The generation of user profiles within the Environment is carried out by a modification of the agent system used in the Forum Contact Space. The modification consists of allowing the collection and processing of meta-information from the documents and drawings accessed by the user. The trial and evaluation should consider whether this method of maintaining user profiles is appropriate. This might involve allowing those involved in the trial to express an opinion on whether events that they are made aware of by the agent system are considered by them to be relevant.

- The links to underlying data in the model are currently based on classifications of work and trade package from the document management system. This method relies upon these classifications being at a sufficient level of granularity such that objects in the model can be assigned to them. This approach is based-upon the 'currently feasible topology' shown in Figure 4.1.2. The full-scale trial process would allow the approach to be evaluated, again using feedback from the users concerning the quality of links between the visualisation and design information. Developments such as those in the OSCON project [Aouad et al, 1997] may make it possible to automatically generate these links. It may be appropriate to explore this approach in future research on the Telepresence Environment.

7.3.2 Developments in Telepresence for Construction

As well as the further developments that are applicable to the prototype, there are also a number of more general areas in the field of Telepresence that require attention. Some of these are now briefly discussed.

The deployment of network infrastructure that is sufficient to deliver, to projects, the services described in this thesis should be carried out. The network requirements of these services are an appropriate topic for further research. The results discussed in Section 3.7 do indicate that many players in the industry are making the necessary investment in this area. The deployment by the Telecommunications industry of technologies such as ADSL (Asymmetric Digital Subscriber Line) and cable modems should allow rapid strides to be made in enabling high-speed project Extranets to be set up.

Investment should also be made in the services that these networks will enable. Unfortunately the up-front costs that are associated with ICT investment can be prohibitive, particularly to the smaller players in the industry or where projects are of a duration that is deemed too short to make the investment cost-effective. The Application Service Provider (ASP) market is one that is experiencing high growth at present. This market basically involves an organisation renting services from a third party solution provider and thus massively reducing the up-front costs. These services might consist of managed computer or network hardware or network-based supported software solutions. This market is highly applicable to the Construction industry because of the short-duration projects and small companies that are often involved in them. The delivery of Telepresence and related technologies via this scenario is one that could be researched further.

The Telepresence Environment described in this thesis is designed for desk-based users with their own computer. This scenario is only applicable to a portion of the personnel on a typical project. Many people will spend a large amount of their time away from their desk, either travelling to meetings or on-site. If the Environment is to support people whilst they are away from their desks then an additional form of information delivery is required. Mobile Internet services are beginning to emerge. At present, WAP (Wireless Application Protocol) services are available that provide text-based Internet services on a mobile phone. In the near future, so called Third Generation (3G) mobile networks will greatly increase the bandwidth available to mobile users. Much richer services will become available with hand-held computers or PDAs (Personal Digital Assistants) becoming the device the mobile user accesses them with.

The delivery of project-related information to the mobile user would be a worthwhile topic for future research. This could begin with providing text-based information over WAP and extend to include richer services such as data or video in preparation for 3G mobile. These developments also increase the potential of technologies such as Augmented Reality. One aspect of AR might be to provide project information to a mobile user from a network database. This could be delivered to the user over a high bandwidth mobile network removing the need for a wireless LAN to be in place to serve them.

This research project has largely focused on the technical aspects of the Telepresence Environment. An additional research area that should be addressed is that of the human factors associated with its deployment. One of the main aims of the project is to change the way people in the industry work, moving away from the insular nature of traditional processes such as 'over the wall' towards a more open, collaborative approach. This shift requires a change in culture to both the organisations and the people working in them. Such changes can rarely occur without difficulties. A Human Factors study should attempt to identify issues related to these changes as well as other issues such as the usability of the technology.

In the light of the research presented in this thesis and the developments suggested in this section it is recommended that the construction industry make wider use of collaborative communication technology and in particular, Telepresence. A number of technologies have been identified that could and should be readily applied to construction projects such as the People and Information Finder, Conference Call Presence and Web-based Document Management Systems. The industry should continue its increased investment in technologies such as these and in the networks and infrastructure that are required to support them. The improved infrastructure will also allow more advanced technologies to be implemented. One such technology is, of course, Telepresence and its potential benefits have been clearly stated in this thesis. Some of these benefits are as yet unproved and as a result the industry should carry out trials and research in order to make informed decisions about the development and eventual adoption of Telepresence.

7.4 Closing Comments

The successful adoption of Concurrent Engineering within the construction industry should vastly improve both the cost-effectiveness and quality of its products. In order for this to happen, a much greater use of Information and Communication Technologies is required. The research documented in this thesis shows that of particular importance is the adoption of a Telepresence Environment that can enable project participants to collaborate effectively and make well informed decisions. Its use within a communications infrastructure for Concurrent Life-Cycle Design and Construction projects will transform the industry, enabling the goals of Concurrent Engineering to be achieved. In particular, it will facilitate collaboration on projects by making it easier to access both project information and project participants.

References

Adjei-Kumi, T. & Retik, A. (1997) 'A Library-based 4D Visualisation of Construction Processes', *Proceedings of the IEEE Conference on Information Visualisation*, London, UK, 27-29 Aug., pp 315-321.

Anumba, C.J., Baron, G. & Duke, A.K. (1997) 'Information and Communication Technologies to Facilitate Concurrent Engineering in Construction', *BT Technology Journal*, Vol. 15, No. 3, pp 199-207.

Anumba, C.J., Bouchlaghem, N.M., White, J. and Duke, A.K. (2000) 'Perspectives on an Integrated Construction Project Model', *International Journal of Co-operative Information Systems*, Vol. 9, No.3, pp 283-313.

Anumba, C.J. & Duke, A.K. (1997a) 'Structural Engineering in Cyberspace: enabling information and communications technologies', *Journal of the Institution of Structural Engineers*, Vol. 75, no. 15, 5th August, pp 259-263.

Anumba, C.J. & Duke, A.K. (1997b) 'Telepresence in Virtual Project Team Communications', *Proceedings of the ECCE Symposium on Computers in the Practice of Building and Civil Engineering*, Lahti, Finland, 3-5 September, pp 80-84.

Anumba, C.J. & Duke, A.K. (2000)'Telepresence in Concurrent Lifecycle design and Construction', *Artificial Intelligence in Engineering, Special Issue on Collaborative and Concurrent Engineering*, Vol. 14, no. 3, July, pp 221-32.

Anumba, C.J., Duke, A.K., Bouchlaghem, N.M. & Whyte, J.K. (2000) 'Perspectives on an Integrated Construction Project Model', *International Journal of Cooperative Information Systems*, Vol. 9, No. 3, pp 283-313.

Anumba, C. J. & Evbuomwan, N. F. O. (1996) 'Multiple Views of Design Information in CAD Systems', *Proceedings of the 12th International Conference on CAD/CAM, Robotics and Factories of the Future*, Middlesex University, London, 14-16th August 1996.

Anumba, C.J. & Evbuomwan, N.F.O. (1999) 'A Taxonomy for Communication Facets in Concurrent Life-Cycle Design and Construction', *Computer-Aided Civil and Infrastructure Engineering (special issue on 'Collaborative and Concurrent Engineering')*, Vol. 14, pp 37-44.

Anumba, C.J. & Scott, D. 'Performance Evaluation of a Knowledge-Based System for Subsidence Management', To be published.

Anumba, C.J. & Watson, A.S. (1992) 'An Innovative Approach Towards Designer-Oriented CAD Systems', *The Structural Engineer*, Vol. 70, No. 9, pp 165-169.

Aouad, G., Child, T., Marir, F. & Brandon, P. (1997) 'Developing a Virtual Reality Interface for an Integrated Project Database Environment', *Proceedings of the IEEE Conference on Information Visualisation*, London, UK, 27-29 Aug., pp 192-197.

Bowles, B.A. (1994) 'Collaborative Working and Integrated Communication Services in the UK manufacturing sector, *BT Technology Journal*, Vol. 12, No. 3, pp 73-8.

Breuer, J. & Fischer, M. (1994) 'Managerial Aspect of Information Technology Strategies in A/E/C Firms': *Journal of Management in Engineering*, July/August, pp 52-59.

Broughton, T. (1990) 'Simultaneous engineering in aero gas turbine design and manufacture', *Proceedings of the 1st International Conference on Concurrent Engineering*, 4-5 December, London, pp 25-36.

Building Centre Trust & DETR (1999) 'IT Usage in The Construction Team', *Construction Research Communications Ltd*, London.

Campbell, D.A. (2000) 'Architectural Construction Documents on the Web: VRML as a Case Study', *Automation in Construction 9*, pp 129-138.

Cochrane, P., Heatley, D.J.T. & Cameron, K.H. (1993) 'Telepresence - Visual Telecommunications into the Next Century', *Proceedings of the 4th IEE Conference on Telecommunications*, Manchester, pp 175-180.

Construct I.T. Centre of Excellence (1996) 'Benchmarking Best Practice Report : Construction Site Process'.

Cooter M. (1995) 'Building Up Technology', *Communications Networks*, May, pp 67-68.

Crabtree, B., Soltysiak, S., and Thint, M. (1999) 'Adaptive Personal Agents', *Personal Technology Journal, Special Issue on Personal Information Agents*, Vol. 2, No.3, December, pp 141-151.

Crowley, A. & Watson, A. (1996) 'A Guide to Painless Computer Integration', *The Structural Engineer*, Vol. 74, No. 3, pp 50-52.

Davies, N.J. & Weeks, R. (1998) 'ProSum - profile-based text summarization', *First Automatic Text Summarization Conference (SUMMAC-1)*, Virginia, USA.

Deasley, P.D. & Lettice, F. (1997) 'A Concurrent Engineering Approach To Construction: Learning From Cases In Manufacturing Industry' in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference*, Institution of Structural Engineers, London, pp 296-305.

Duke, A. (1996) *'Finger Server Issues'*, Internal Report, British Telecommunications Laboratories, Martlesham Heath, Ipswich.

Duke, A.K. (1998) 'A People & Information Finder for Virtual Construction Project Teams', *British Telecommunications Engineering*, vol. 17, no. 3, October, pp 198-203.

Duke, A.K. & Anumba, C.J. (1997) 'Enabling Collaboration for Virtual Construction Project Teams', in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference*, Institution of Structural Engineers, London, pp 163-172.

Duke, A.K. & Anumba, C.J. (1999) 'A Telepresence-Based Environment for Concurrent Engineering Construction Projects', *Advances in Concurrent Engineering, Proceedings CE99*, Chawdhry, P.K., Ghodous P. & Vandorpe D, (Eds). University of Bath, UK, 1-3 September, pp 360-367.

Duke, A.K., Bowskill, J. & Anumba, C.J. (1998) 'Telepresence-Based Support for Concurrent Engineering in Construction', Computing in Civil Engineering, *Proceedings of the ASCE International Computing Congress*, Boston, pp 549-560.

Duncombe, L. (1997) 'The BAA Project Process - A Partnership Approach' in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference*, Institution of Structural Engineers, London, pp 288-295.

Eason K. (1988) *'Information technology and Organisational Change'*, Taylor & Francis, London.

Edwards, D.J., Shaw, T., Holt, G.D. (1996) 'Electronic Document Management Systems and the Management of UK Construction Projects', *Building Research and Information*, Vol. 24, Number 5, pp 287-292.

Egan, J. (1998) *'Rethinking Construction'*, DETR.

Evbuomwan N. F. O. & Anumba C. J. (1995) 'Concurrent Life-cycle Design and Construction', *Developments in Computer-Aided Design and Modelling for Civil Engineering*, Topping B. H. V. (Ed.), Civil-Comp Press, Edinburgh, pp 93-102.

Evbuomwan, N.F.O. & Anumba, C.J.: (1996) 'Towards a concurrent engineering model for design-and-build projects', *The Structural Engineer*, Vol. 74, No. 5, pp 73-78.

Evbuomwan, N.F.O. & Anumba, C.J. (1998) 'An Integrated Framework for Concurrent Life-Cycle Design and Construction', *Advances in Software Engineering*, Vol. 29, No. 7-9, Aug. - Nov., pp 587-597.

Faraj, I. & Alshawi, M. (1997) 'Virtual Reality in Support of Project Life-Cycle', Proceedings of the *IEEE Conference on Information Visualisation*, London, UK, 27-29 Aug., pp 288-292.

Gardner, P. (1996a) 'Current use of Information Technology in Structural Engineering Consultancies', *Information Representation and Delivery in Civil and Structural Engineering Design*, Kumar, B., MacLeod, I.A. & Retik, A. (Eds.), 14-16 August, pp 143-146.

Gardner, P. (1996b) 'Advanced Engineering Computing and the Implications for Engineering Design Consultancies', *Information Representation and Delivery in Civil and Structural Engineering Design*, Kumar, B., MacLeod, I.A. & Retik, A. (Eds.), 14-16 August, pp 147-151.

Gibson, W. (1984) *'Nueromancer'*, HarperCollins, London, UK.

Goodman, R. E. & Chinowsky, P. S. (1996) 'Managing Interdisciplinary Project Teams through the Web', *Proceedings of Computing in Civil Engineering*, June 17-19, Anaheim, California pp 452-458.

Guensler, R. (1996) 'Facilitating Workgroup Activities Through the Internet', *Proceedings of Computing in Civil Engineering*, June 17-19, Anaheim, California pp 459-465.

HSE (1995) *'The Construction, Design and Management (CDM) Regulations'*, Health & Safety Executive.

Hannus, M. (1996) *'Islands of Automation in Construction'*, Published on the Web at: http://www.vtt.fi/cic/ratas/islands.html

Healy, J. & Orr, T.L.L. (1996) 'Information Technology Use in Consulting Engineering Firms in the Republic of Ireland', *Information Representation and Delivery in Civil and Structural Engineering Design*, Kumar B. & Retik A. (Eds.), 14-16 August, pp 163-170.

Howard, R., Kiviniemi, A. & Samuelson, O. (1998) 'Surveys of IT in the Construction Industry and Experience of the IT Barometer in Scandinavia', Itcon Vol. 3, Bjork, B.C. (ed), pp 45-56. Published on the Web at: http://www.itcon.org/1998/4/

Huxor, A. (1998) 'An Active Worlds Interface to BSCW, to Enhance Chance Encounter', *Proceedings of the 1998 Collaborative Virtual Environments Conference*, 17-19 June, Manchester, UK, pp 87-93.

Jamieson, M.J., Thorpe A. & Tyler A. (1996) 'Communication and Collaboration Technologies in UK Subcontracting Organisations', *Proceedings, of the 3rd Canadian Conference on Computing in Civil and Building Engineering*, Montreal, Quebec, Canada, pp 760-775.

Kamara, J.M., Anumba, C.J. & Evbuomwan, N.F.O. (1997) 'Considerations for the effective implementation of Concurrent Engineering in Construction' in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference*, Institution of Structural Engineers, London, pp 33-44.

Katz, T., Downie, J.H., Bowskill, J. & Shurville, S.J. (1994) 'An Approach to Flexibility Using Constraints Management and Collaborative Design Tools', in Medhat (ed), *Proceedings of the International Conference on Concurrent Engineering and Electronic Design Automation (CEEDA '94)*, Bournemouth, UK, 7-8 April, pp 139-144.

Klinker, G., Stricker, D. & Reiners, D. (1998) 'AR for Exterior Construction Applications', *AR and Wearable Computers*, Barfield, W. & Caudell, T. (eds.), Erlbaum Press.

Koller, D., Klinker, G., Rose, E. Breen, D., Whitaker, R., & Tuceryn, M. (1997) 'Real-time Vision-Based Camera Tracking for Augmented Reality Applications', *Proceedings of the Symposium on Virtual Reality Software and Technology (VRST-97)*, Lausanne, Switzerland, September 15-17, pp 87-94.

Latham, M (1994) *'Constructing The Team'*, Final report of the government / industry review of procurement and contractural arrangements in the UK construction industry.

Lee, J., Hadipriono, F.C. & Larew, R.E. (1997) 'Implementing VRML and Object-Oriented Techniques in a Pavement Construction Management System', *Proceedings of the 1997 International Conference on Simulation in Engineering Education (ICSEE '97)*, 12-15 Jan., pp 165-170.

Leevers, D., Crotty, R., Duke, A., Klinker, G., Kvam, P., Fernando, T., Rosenburg, D. (1998) *'CICC – Final Report'*, published on the web at: http://www.vers.co.uk/CICC/cicc.htm

Lemay, L. & Perkins, C.L. (1996) *'Teach Yourself Java in 21 Days'*, Sams.net, Indianapolis.

Levin, R. (1998) 'Constructive Computing', *Information Week*, No. 700, Sep. 14, pp 113-120.

Li, H. (1996) 'The role of the IT manager in construction process re-engineering', *Building Research and Information*, Volume 24, Number 2, pp 124-128.

Li, H. & Love, P.E.D. (1998) 'Visualisation of Building Interior Design to Reduce Rework', *Proceedings of the IEEE Conference on Information Visualisation*, London, UK, 29-31 July, pp187-191.

Love, P.E.D. & Gunasekaran, A. (1996) 'Towards Concurrency and Integration in the Construction Industry', *Third ISPE International Conference on Concurrent Engineering*, Toronto, Canada, 26-28 Aug, pp 232-239.

Maher, M. L. (1994) 'Collaboration and Computer Aided Engineering', Bridging the Generations, Rehak D. (Ed.*), International Workshop on the Future Directions of Computer-Aided Engineering*, Carnegie Mellon University, Pittsburgh, pp 137-142.

Mantovani, G. (1996) *'Communication Environment: From Everyday to Virtual'*, Taylor & Francis, London.

McGrath, A. (1998) 'The Forum', *Siggroup Bulletin*, Vol. 19, No. 3, December. ACM Press, New York, pp 21-25.

McKinney, K., Fischer, M. & Kunz, J. (1998) 'Visualisation of Construction Planning Information', *Proceedings of International Conference on Intelligent User Interfaces*, San Francisco, USA, 6-9 Jan, pp 135-138.

Merriam-Webster On-Line Dictionary. (2001) Published on the web at: http://www.webster.com/cgi-bin/dictionary.

Miles, J.C., Moore, C.J., Kotb, A.S.M., & Jaberian-Hamedani, A. (2000) 'End User Evaluation of Engineering Knowledge Based Systems', *Civil Engineering & Environmental Systems*, Vol. 17, No. 4, pp 293-317.

Milgram, P & Kishino, F. (1994) 'A Taxonomy of Mixed Reality Visual Displays', *IEICE Transactions on Information Systems*, E77-D, No.12, December, pp 1321-1329.

Morris C. (Ed.) (1992) *Academic Press Dictionary of Science and Technology,* Academic Press, London.

Mortlock, A., Machin, D, McConnell, S. & Sheppard, P. (1997) 'Virtual Conferencing', *BT Technology Journal*, Vol. 15, No. 4, October, pp 120-129.

Munkvold, B.E. (1996) 'An assessment of Selected Empirical Research On Computer-Mediated Communication, Related to Distributed Teamwork in Concurrenct Engineering', *Proceedings of the 3rd IPSE International Conference on Concurrent Engineering: Research & Applications*, Toronto, Canada, pp 48-56.

Oliver, S., Betts, M. (1996) 'An Information Technology Forecast for the Architectural Profession', *Automation in Construction 4* , pp 263-279.

Parke, I. (1997) 'The Evolution of Conferencing', *BT Technology Journal,* Vol. 15, No. 4, October, pp 19-25.

Pearson, A. (1998) 'Model Contractors', *Building Services Journal,* Vol. 20, No. 10, Oct., pp 31-33.

Peña-Mora F., Anumba C.J., Solari, J., Duke, A.K. (2001) 'An Integrated Telepresence Environment for Collaboration in Construction', *Engineering with Computer – Special Issue in Honour of Professor Steven Fenves* (in press).

Pietroforte, R. (1997) 'Communication and Governance in the Building Process', *Construction Management and Economics* 15, pp 71-82.

Powell, J. (1995) 'IT Research For Construction As A Manufacturing Process: An EPSRC view', *Proceedings of the IEE Colloquium on Knowledge-Based Approaches To Automation In Construction*, IEE, London, pp 8/1-8/5.

Prased, B. (1997) 'Seven Enabling Principles of Concurrency and Simultaneity in Concurrent Engineering' in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference, Institution of Structural Engineers*, London, pp 1-12.

Quinn, J.B., Anderson, P. & Finkelstein, S. (1996) 'Managing Professional Intellect: Making the Most of the Best', *Harvard Business Review*, Mar-April, pp 71-83.

Radjou, N. (1999) 'Collaboration Beyond Email', *The Forrester Report*, December.

Rivard, H. (2000) 'A Survey of the Impact of Information Technology on the Conadian Architecture, Engineering and Construction Industry', Itcon Vol. 5, Bjork, B.C. (ed), pp 37-56. Published on the Web at: http://www.itcon.org/2000/3/

Rogers, A.S. (1994) 'Virtuosi - Virtual Reality Support for Groupworking', *BT Technology Journal*, Vol. 13, No. 3, pp 81-89.

Rogers, A.S. (1995) 'Virtual Reality - The New Media?', *BT Technology Journal*, Vol. 13, No. 4, pp 132-137.

Russ, M. (1997) 'Desktop Conversations – The Future of Multimedia Conferencing', *BT Technology Journal*, Vol. 15, No. 4, October, pp 42-50.

Somerville I. (1992) *'Software Engineering'*, Addison-Wesley, Wokingham.

Sørensen, L. S. & Andersen, T. (1996) 'The Current State of Computing in Building Design and Construction: A Detailed Survey', *Information Representation and Delivery in Civil and Structural Engineering Design*, Kumar, B.& Retik, A. (Eds.), 14-16 August, pp 171 176.

Stevens, W. R. (1992) *'Advanced Programming in the UNIX Environment'.* Addison-Wesley.

Tracey, I. (1996) *'Structure, Networking and Presentation Issues'*, Internal Report, British Telecommunications Laboratories, Martlesham Heath, Ipswich.

Traill, D.M., Bowskill, J.M. & Lawrence, P.J. (1997) 'Interactive Collaborative Media Environments', *BT Technology Journal*, Vol. 15, No. 4, October, pp 130-139.

Vivacqua, A.S. (1999) 'Agents For Expertise Location', *Proceedings 1999 AAAI Spring Symposium on Intelligent Agents in Cyberspace*, Technical Report SS-99-03, Stanford, CA, USA, March, pp 9-13.

Walker, G. R. & Sheppard, P.J. (1997) 'Telepresence – The Future of Telephony', *BT Technology Journal*, Vol. 15, No. 4, October, pp 11-18.

Winner, R.I., Penell, J.P., Bertrand, H.E. & Slusarczuk, M.M.G. (1998) 'The role of concurrent engineering in weapons system acquisition', *IDA Report R-338*, Institute of Defense Analysis, Alexandria, Virginia, USA.

Whyte, J., Bouchlaghem, D. & Thorpe, T. (1998) 'Visualising Residential Development using Desktop Virtual Reality', *Proceedings of the IEEE Conference on Information Visualisation*, London, UK, 29-31 July, pp 40-43.

Appendix A - Evaluation Presentation

Telepresence Environment
for Construction Project Teams

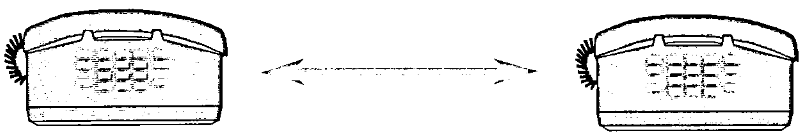
Evaluation Session

Alistair Duke

Summary

- What is Telepresence?
- Concurrent Engineering
- The Telepresence Environment
- Demonstration
- Evaluation

What Is Telepresence?



the state of being present at a distance

What is Telepresence?

"The Facility which enables collaborating parties to be virtually located within a given (3D) environment, in which they are able to interact with one another or with virtual objects that are also present in the environment. The intended aim is to create the illusion of being there"

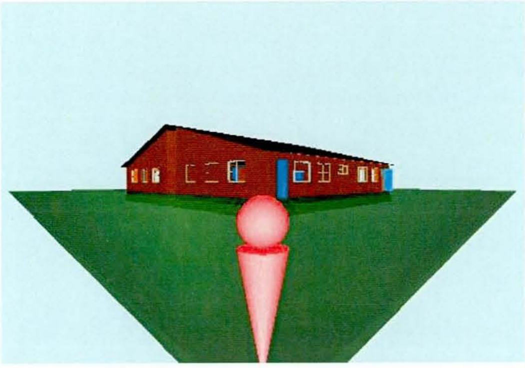
Concurrent Engineering

- **Non-collocated Organisations**
- **Downstream issues addressed early on in the project life-cycle**
- **Increased Reliance on Communications Technologies**
- **Support for ad hoc communication and information cues**

The Telepresence Environment

- Collaborative Virtual Environment
- 3D representation of building
- Representations of other users (avatars)
- 'Always on' technology
- Users view determined by Agent based upon current interests or focus
- Integrated people and project information

The Demonstration



Appendix B - Evaluation Questionnaire

A Telepresence Environment for Construction Project Teams

Evaluation Questionnaire

This evaluation questionnaire should be completed following a demonstration of the Telepresence Environment for Construction Project Teams.

First, please complete the following information about yourself:

No of years of practical experience in the Construction Industry______________________________

Description of role carried out or position held (e.g. design consultant, project manager, site engineer)

____

Area of experience (e.g. civil engineering, building, etc)

____

Now complete the following questions based on the demonstration you have just seen. Where a scale is provided, please circle the level to which you agree or disagree with the statement. 1 refers to a low ranking and 5 refers to high ranking.

	Ranking – Please Circle				
	Strongly Disagree		Neutral		Strongly Agree
1. Virtual Environment					
1.1 The environment supports the feeling of Telepresence.	1	2	3	4	5
1.2 The building model itself supports Telepresence.	1	2	3	4	5
1.3 The user avatars support Telepresence.	1	2	3	4	5
1.4 The feature locations (e.g. Roof, South Wing) represent the project and its workpackages well.	1	2	3	4	5
1.5 The feature locations are sufficient in number	1	2	3	4	5
1.6 How could the environment be improved?					
1.7 What other features could be added to the environment?					
2. Delivery of Project & People Information					
2.1 The project information is adequately encapsulated in the environment	1	2	3	4	5
2.2 It is useful to be able to click on project features and go directly to the relevant part of a Document Management System	1	2	3	4	5

	Strongly Disagree		Neutral		Strongly Agree
2.3 The people information is adequately linked to the environment	1	2	3	4	5
2.4 It is useful to be co-located in the environment with those who have similar interests or focus	1	2	3	4	5
2.5 It is useful to be able to communicate with these people in an ad-hoc manner.	1	2	3	4	5
2.6 It is useful for users to be informed about events that are of relevance via the environment (e.g. A N Other has joined the environment, A N Other has added an RFI on document XYZ).	1	2	3	4	5
2.7 The way in which events are presented to the user in the environment i.e. via navigation to feature with accompanying text is very good.	1	2	3	4	5
2.8 Please suggest how this aspect of the system could be improved.					
3. Communication tools (Text chat, Audiographic conferencing, other tools available via homepage)					
3.1 The communication tools integrated into the environment are adequate.	1	2	3	4	5
3.2 These tools are well integrated into the environment.	1	2	3	4	5
3.3 What other communication tools might be useful?					
4. Supporting the User					
The environment allows the user to maintain an awareness of the following:					
4.1 People on the project.	1	2	3	4	5
4.2 The status of project documents.	1	2	3	4	5
4.3 The project in general.	1	2	3	4	5
4.4 The environment improves the ability of the user to fulfil their role on a virtual construction project team.	1	2	3	4	5
4.5 Please suggest how this aspect of the system could be improved.					

5. Supporting the Project	Strongly Disagree		Neutral		Strongly Agree
5.1 The environment would improve communication in a Concurrent Engineering project setting.	1	2	3	4	5
5.2 The environment would support a Concurrent Engineering project in achieving the following goals:					
5.2.1 Faster decision-making.	1	2	3	4	5
5.2.2 Quicker access to participants.	1	2	3	4	5
5.2.3 Earlier consideration of downstream issues.	1	2	3	4	5
5.2.4 A reduction in mistakes made	1	2	3	4	5
5.2.5 A better understanding of requirements.	1	2	3	4	5
5.2.6 Better project co-ordination.	1	2	3	4	5
5.2.7 Faster delivery of project information.	1	2	3	4	5
5.3 Please suggest how this aspect of the system could be improved.					
6. General					
6.1 Industry practitioners would make use of such an environment?	1	2	3	4	5
6.2 What might discourage people from using it?					
6.3 State any groups or professions that would be **more** likely to use such a system and explain why.					
6.4 State any groups or professions that would be **less** likely to use such a system and explain why.					

Thank you very much for your feedback.

Appendix C – Publications

Journals

Anumba, C.J., Baron, G. & Duke, A.K. (1997) 'Information and Communication Technologies to Facilitate Concurrent Engineering in Construction', *BT Technology Journal*, Vol. 15, No. 3, pp 199-207.

Anumba, C.J. & Duke, A.K. (1997) 'Structural Engineering in Cyberspace: enabling information and communications technologies', *Journal of the Institution of Structural Engineers*, Vol. 75, no. 15, 5th August, pp 259-263.

Anumba, C.J. & Duke, A.K. (2000)'Telepresence in Concurrent Lifecycle design and Construction', *Artificial Intelligence in Engineering, Special Issue on Collaborative and Concurrent Engineering*, Vol. 14, no. 3, July, pp 221-32.

Anumba, C.J., Duke, A.K., Bouchlaghem, N.M. & Whyte, J.K. (2000) 'Perspectives on an Integrated Construction Project Model', *International Journal of Cooperative Information Systems*, Vol. 9, No. 3, pp 283-313.

Duke, A.K. (1998) 'A People & Information Finder for Virtual Construction Project Teams', *British Telecommunications Engineering*, vol. 17, no. 3, October, pp 198-203.

Peña-Mora F., Anumba C.J., Solari, J., Duke, A.K. (2001) 'An Integrated Telepresence Environment for Collaboration in Construction', *Engineering with Computer – Special Issue in Honour of Professor Steven Fenves* (in press).

Conferences

Anumba, C.J. & Duke, A.K. (1997) 'Internet and Intranet Usage in a Communnications Infrastructure for Virtual Construction Project Teams', *Proceedings of the IEEE Workshop on Enabling Technologies for Virtual Enterprises, WETICE '97*, MIT, USA, 18-20 June, 1997, pp 56-61.

Anumba, C.J. & Duke, A.K. (1997) 'Telepresence in Virtual Project Team Communications', *Proceedings of the ECCE Symposium on Computers in the Practice of Building and Civil Engineering*, Lahti, Finland, 3-5 September, pp 80-84.

Duke, A.K. & Anumba, C.J. (1997) 'Enabling Collaboration for Virtual Construction Project Teams', in Anumba, C.J. & Evbuomwan, N.F.O. (eds), *Concurrent Engineering in Construction: Proceedings of the 1st International Conference*, Institution of Structural Engineers, London, pp 163-172.

Duke, A.K. & Anumba, C.J. (1999) 'A Telepresence-Based Environment for Concurrent Engineering Construction Projects', *Advances in Concurrent Engineering, Proceedings CE99*, Chawdhry, P.K., Ghodous P. & Vandorpe D, (Eds). University of Bath, UK, 1-3 September, pp 360-367.

Duke, A.K., Bowskill, J. & Anumba, C.J. (1998) 'Telepresence-Based Support for Concurrent Engineering in Construction', Computing in Civil Engineering, *Proceedings of the ASCE International Computing Congress*, Boston, pp 549-560.

Appendix D - Abbreviations

3G	Third Generation Mobile
ACTS	Advanced Communications Technologies and Services
ADSL	Asymmetric Digital Subscriber Line
API	Application Programming Interface
AP-IA	Availability of Person - Intelligent Agent
ASP	Application Service Provider
AR	Augmented Reality
BAA	British Airports Authority
BT	British Telecommunications Plc
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAIRO	Collaborative Agent Interaction control and synchROnization
CDM	Construction Design and Management
CE	Concurrent Engineering
CICC	Collaborative Integrated Communications for Construction
CLDC	Concurrent Life-Cycle Design and Construction
CMC	Computer-Mediated Communication
CMS	Constraint Management Systems
CPU	Central Processing Unit
CVE	Collaborative Virtual Environment
DXF	Drawing eXchange Format
EAI	External Authoring Interface
E-Mail	Electronic Mail

EDM	Electronic Document Management
FE	Finite Element
FIFO	First In – First Out
FTP	File Transfer Protocol
HSE	Health & Safety Executive
HTML	Hypertext Mark-up Language
HTTP	Hypertext Transfer Protocol
ICQ	'I Seek You'
ICT	Information and Communications Technologies
IMPP	Instant Messaging and Presence Protocol
I/O	Input/Output
IP	Internet Protocol
IPC	Inter-Process Communication
ISDN	Integrated Services Digital Network
IT	Information Technology
JDBC	Java DataBase Connectivity protocol
KBS	Knowledge Based System
LAN	Local Area Network
MAPI	Messaging Application Programming Interface
MDT	Multi-Disciplinary Teams
MIT	Massachusetts Institute of Technology
MSN	Microsoft Network
MR	Mixed Reality

MS	Microsoft
ODBC	Open DataBase Connectivity protocol
PC	Personal Computer
PIF	People and Information Finder
PM	Product Model / Project Model
RFI	Request For Information
SME	Small or Medium sized Enterprise
SMTP	Simple Mail Transfer Protocol
SPACE	Simultaneous Prototype for an Integrated Construction Environment
SQL	Structured Query Language
STEP	STandards for the Exchange of Project data
TCP	Transfer Control Protocol
TCP/IP	TCP over IP
URL	Universal Resource Locator
VR	Virtual Reality
VRML	Virtual Reality Modelling Language
WAN	Wide Area Network
WAP	Wireless Application Protocol
WYSISIS	What You See Is What I See
WWW	World Wide Web

Appendix E - Glossary

Agent - A computer application that makes decisions on behalf of a user. Often referred to as an intelligent agent.

Audiographic Conferencing - A communications system that provides an audio channel for conference participants as well as a graphical view of the conference upon a computer, allowing it to be controlled.

Augmented Reality - A technology that allows the user's view of the world to be augmented with extra information of generally a visual or audible nature.

Avatar - The representation of a person in a Collaborative Virtual Environment

Collaborative Virtual Environment - A computer generated (3D) environment that allows users to interact with each other and with virtual objects.

Computer Telephony Integration - Technologies that allow telephone calls to be initiated and controlled from a computer and its associated applications.

Electronic Document Management - A computer application that allows electronic documents to be stored in an ordered fashion with associated control of access and process.

Extranet - A form of network that combines the restricted networks of individual companies or organisations into a wider network - allowing them to collaborate upon a project.

Fire-wall - A mechanism for controlling access across network boundaries - typically between the public Internet and a company's Intranet.

Forum Contact Space - A research project carried out by BTexaCT that focused upon providing a communication environment for distributed workgroups.

Forum Meeting Space - A research project that involved developing a 3D meeting room for Audiographic conferences.

Internet - The global network of computers that facilitates, for example, the World Wide Web and global E-Mail

Intranet - The network of an organisation based upon Internet technology but separate from the Internet or with controlled access to and from it.

Java - The Internet programming language and associated technology that allows programs to be run within a web browser and separate from the local file system of a computer. This allows applications to be downloaded and executed safely and regardless of the operating system of the computer.

LAN - Local Area Network. The connection between computers (within a small geographical area) that allows the transfer of data between them.

Object Orientation - A form of programming or database where data is represented as objects of a class. Each object has properties that can be set to describe it.

People and Information Finder - a technology proposed and developed with the CICC project that allowed users to access project personnel and data via the web browser.

Project Model - A facility that allows all information about a project to be stored centrally such that it's consistency is maintained.

Telepresence - A technology that allows users to be virtually located within a computer generated (3D) environment.

Thread - A portion of a software process that can be executed in isolation from other threads of the process. Threads are particularly suitable for handling user-input as they can wait whilst allowing other program operations to continue.

Unix - An operating system widely used on 'Workstation' computers from Sun, Silicon Graphics, IBM, etc.

Virtual Reality - the simulation of a real or imagined environment that can be experienced in 3D.

VRML - Virtual Reality Modelling Language. The language used to create and control 3D VR environments on the Internet.

WAN - Wide Area Network. A geographically dispersed network often involving the interconnection of Local Area Networks.

WWW - World Wide Web. The global collection of multimedia pages on the Internet. Most pages contain links (known as hyperlinks) to other resources.