

# Communications Technologies in Collaborative Design

by

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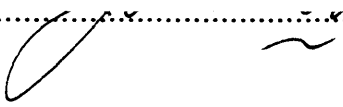
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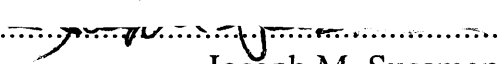
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## **Abstract**

Building design has become a complex process involving the coordination of many specialists from numerous disciplines. Breakdowns in communication of information and coordination of design activities can have profound consequences on the cost and quality of the resulting facilities.

Emerging communications technologies present potentially powerful tools to assist in the coordination of multi-disciplinary design teams, by providing a structured, tractable vehicle for communications between team members. These computer based applications implicitly structure the design activities to which they are applied. When a computational formalism accurately reflects the structure of the activity it is intended to support, these computer applications can be a powerful assistant. When inaccurate assumptions are made in their development, computer applications can inhibit important aspects of activities toward which they are directed.

This thesis presents a methodology for the development of computational systems to support collaboration and communication in design. First, theories of design practice, as well as aspects of communications and coordination theory are presented. Several emerging technologies are discussed in regard to their potential application to the unique requirements of design. A survey of precedent communications systems which have responded to issues pertinent to collaborative design are subsequently considered.

Finally, a series of collaborative design activities which have been conducted using communications technologies are presented. These case studies present important new directions for design, by demonstrating a model for the integration of a wide range of academic and professional expertise in the design process.

By fostering environments which encourage the exchange of information among participants, communications technologies can assist in the development of designs which address a broad range of performance considerations in an integrated manner. At the same time, the use of communications technologies can provide a means for improved coordination of the inherently complex collaborative design process.

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## TABLE OF CONTENTS

|  |           |
|--|-----------|
| TABLE OF CONTENTS  | 1         |
| LIST OF FIGURES  | 2         |
| <b>I. INTRODUCTION</b>   | <b>3</b>  |
| <b>A. THE RE-EMERGENCE OF DESIGN</b>                                   | <b>3</b>  |
| <b>B. GLOBALIZATION OF DESIGN PROCESSES</b>                            | <b>4</b>  |
| <b>C. COORDINATION ASPECTS OF DESIGN</b>                               | <b>5</b>  |
| <b>D. FORMAL MODELS OF DESIGN PROCESSES</b>                            | <b>6</b>  |
| <b>II. THE STATE OF COMPUTING IN THE DESIGN INDUSTRY</b>               | <b>12</b> |
| <b>III. COMMUNICATIONS ISSUES IN DESIGN ACTIVITIES</b>                 | <b>17</b> |
| <b>A. DISCOURSE THEORY AND DESIGN COMMUNICATIONS</b>                   | <b>18</b> |
| <b>B. SYNCHRONOUS VS. ASYNCHRONOUS COMMUNICATIONS</b>                  | <b>22</b> |
| <b>C. REMOTE VS. CO-LOCATED COMMUNICATIONS</b>                         | <b>24</b> |
| <b>D. CONTENT</b>  | <b>24</b> |
| <b>IV. AVAILABLE COMMUNICATIONS TECHNOLOGIES</b>                       | <b>26</b> |
| <b>A. DISTRIBUTION NETWORKS AND BANDWIDTH</b>                          | <b>26</b> |
| <b>B. COMMUNICATIONS MEDIA</b>   | <b>30</b> |
| <b>C. SYNCHRONOUS COMMUNICATIONS TECHNOLOGIES</b>                      | <b>30</b> |
| <b>D. ASYNCHRONOUS COMMUNICATIONS SUPPORT - DESIGN DATABASES</b>       | <b>35</b> |
| <b>V. PRECEDENT COMPUTER SUPPORTED COLLABORATIVE WORK SYSTEMS</b>      | <b>39</b> |
| <b>A. BRAINSTORMING AND IDEA DEVELOPMENT TOOLS</b>                     | <b>39</b> |
| <b>B. MEDIASPACE</b>   | <b>41</b> |
| <b>C. CLEARBOARD</b>   | <b>43</b> |
| <b>VI. CASE STUDIES IN COLLABORATIVE DESIGN COMMUNICATIONS</b>         | <b>45</b> |
| <b>A. THE COLLABORATIVE DESIGN STUDIO</b>                              | <b>45</b> |
| <b>B. MODEL FOR COMMUNICATIONS TECHNOLOGIES IN PROFESSIONAL DESIGN</b> | <b>64</b> |
| <b>VII. CONCLUSIONS</b>  | <b>75</b> |
| <b>VIII. BIBLIOGRAPHY</b>  | <b>76</b> |

## LIST OF FIGURES

|  |    |
|--|----|
| Figure 1: Effects of Communication on Perception of Design Problem.    | 6  |
| Figure 2: Structured Process Analysis Model                            | 7  |
| Figure 3: Generic Design Process Model                                 | 9  |
| Figure 4: Formal Methods for Design Synthesis [Pugh, 1990]             | 10 |
| Figure 5: Linearly Structured Design Process Models                    | 11 |
| Figure 6: Computer Use Among Design Firms                              | 12 |
| Figure 7: Desktop Synchronous Communications Technologies              | 33 |
| Figure 8: gIBIS Communications Model [Conklin and Begeman, 1988]       | 39 |
| Figure 9: Clearboard -1 Architecture [Ishii, 1992]                     | 43 |
| Figure 10: Collaborative Design Studio Methodology                     | 47 |
| Figure 11: Design Studio of the Future Communications Network          | 49 |
| Figure 12 : Lotus Notes Design Database - Overview                     | 50 |
| Figure 13: Expanded Course Notes Database                              | 50 |
| Figure 14: Expanded Team Design Database                               | 51 |
| Figure 15: Design Studio Core Computing Infrastructure                 | 53 |
| Figure 16: Interaction with Remote Expert - Video Capture of Database  | 56 |
| Figure 17: Transmission of Sketches                                    | 56 |
| Figure 18: Final Review Arena Layout                                   | 59 |
| Figure 19: Final Review Technical Schematic                            | 60 |
| Figure 20. Final Juried Review Proceedings                             | 62 |
| Figure 21: Professional Practice Communications Approach Process Model | 66 |
| Figure 22: Professional Design Communications System Schematic         | 74 |

# **I.INTRODUCTION**

## **A.The Re-emergence of Design**

Design methodology first became a subject of intensive study in the 1950s. The expansion of the American economy after the second world war, coupled with the simultaneous reconstruction of Asian and European nations, created unprecedented market for designed products and built facilities. These economic forces engendered similar emphasis on the study of design in academic settings. During the 1970s and 1980s, the slowing of economic development fostered a realignment of corporate attitudes toward design and innovation. The emphasis on short term profits created an environment where capital outlays for the development of new products were seen as detrimental to the bottom line. Product development activities were re-oriented toward conservative, incremental improvement of existing product lines [Dick, 1995].

The 1990s have seen a re-emergence of interest in design issues. Global competition has created an environment where continual innovation in product design is seen as necessary for the maintenance of market position. Increasing customer demand for improved products has fostered a demand for creative solutions in product development. At the same time, economic and litigative forces have created a new appreciation of the costs incurred by faulty design. A wealth of studies indicate that the majority of product costs are set during the design phase of product development [Nevins, 1989; Boothroyd, 1982]. The complexity of today's products and facilities, combined with the continual segmentation of disciplines into more and more specialized areas of expertise, results in an environment where the involvement of specialized expertise in design is increasingly imperative. But with the increased requirements for specialized expertise comes an increased complexity in the nature of inter-specialist coordination and communication. The combined effects of these pressures have created an increased interest in the coordination and management of design teams.

## **B. Globalization of Design Processes**

The globalization of product markets have brought corresponding globalized approaches product design. Several reasons for distributing design activities across widely disparate geographical areas can be identified:

- **Intellectual considerations** The best people to address specific design or production issues may be distributed around the world. Bringing these resources together dictates either that personnel be re-situated, or that communications abilities be brought between remotely located people and institutions.
- **Material resource considerations** Materials of production may be developed in different regions. These materials, and the corresponding expertise for manipulating these materials, is necessarily bound to geographically distributed areas.
- **Economic considerations** The cost of labor for performing some phases of a facility's development may be significantly less expensive in one region of the world than in another. For example, computer aided drafting skills and the hardware for operating CAD applications are now widely distributed around the world. The cost of labor for performing computer aided drafting tasks is significantly lower in developing countries. These drafting services are increasingly performed in developing nations. In order to maintain quick turn around of these services, computer based communications such as faxes and file transfer are utilized. The net result is a comparable quality product to that generated locally, at a fraction of the cost.
- **Consumer considerations** The end products of design are frequently targeted or customized toward consumers in specific geographical regions. Buildings are of course built in specific locations, while the best intellectual resources required to assemble a building may be located remotely. However, expertise in code mandated procedures, or in consumer preferences of the destination market must be included in the design team. Usually, these resources are available only at the targeted geographical region.

## **C. Coordination Aspects of Design**

“Design is fundamentally a collaborative, interdisciplinary, geographically distributed, multimedia activity.” W. J. Mitchell [1995]

The complexity of today’s products and facilities has resulted in two opposing pressures on design processes. On one hand, the demands for specific performance criteria necessitates an understanding of the product in terms of the specialized knowledge which mark today’s distinct disciplines. At the same time, these same requirements demand superior understanding of the total performance of the product as an integrated whole.

Coordination of design operations, including communication among participants in the design process and management of the overall process, become necessary to mitigate this polarity. Studies show that poor coordination among design participants can have profound consequences on the performance of the resulting product. A Design Professionals Insurance Company manual on loss prevention states that the majority of claims against design professionals stems from, or is exacerbated by, failures in coordination and communication, including:

- Failures in directions
- Poor planning or schedules and costs
- Lack of controls on the results of design activities
- Poor relationships with clients, contractors and vendors

Hensey's study of communications in design [1981] points to the fundamental role communications serve in overcoming such failures. In Hensey's view (Figure 1), the specialization of individual designers' perspectives result in conflicts and incompatibilities between their views of the design problem. Each individual's view or perception makes sense to him or her, based on that individual's unique background, experience, responsibilities, and the credible information available to the individual at the time. Through communication, individuals' views and perceptions are brought into closer alignment, as each learns new facts, opinions and priorities of the other participants.

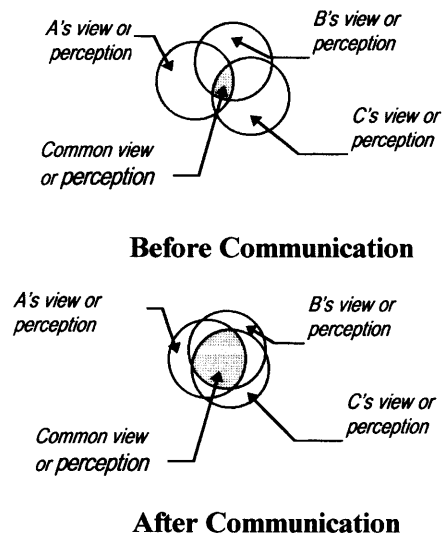


Figure 1: Effects of Communication on Perception of Design Problem. [Hensey, 1981]

Mintzberg's study [1975] similarly underscores the importance of communications skills in management activities. Managers spend fully 60 - 80% of their time engaged in communications. Much of this activity occurs through informal communications such as accidental encounters and exchanges with co-workers, in addition to formal communications such as focused group meetings, memos, or design documents.

#### D. Formal Models of Design Processes

Despite the long tradition of design and its study, much of the nature of design activities remains ill understood. Specific tasks represented within the scope of design activities, such as drafting, rendering and analysis present well defined cognitive issues. Computational efforts to assist or automate elements of these tasks have been relatively successful, and have had significant impact on design industries. Yet more fundamental aspects of the design process, such as the creative and synthetic aspects of design, remain



problematic. Numerous efforts to automate elements of design practice above the task level have been largely unsuccessful [Bruegman, 1989]. Kuhn [1970] concludes that design is at a pre-science phase of development, requiring a series of phases of development before a well coherent body of law, theory and application can emerge. It is apparent from these studies that the role of the human actors engaged in real world activities such as negotiation and consensus forming will remain a fundamental component of design processes.

The ill defined nature of design processes presents difficult terrain for their computational support. The wide range of activities comprising design suggest that the computational support of design processes will necessitate a variety of supporting tools and media. The question of how this range of tools can be integrated into a cohesive system will be fundamental to the development of technologies for the support of collaborative design.

### 1. Structured Process Models

The development of computational strategies to support design processes necessitates generating a formal description of the process, so that the strategy can be encoded in a computationally tractable manner. Such a model will generally exhibit features of structured process analysis [Yourden, 1989]. A

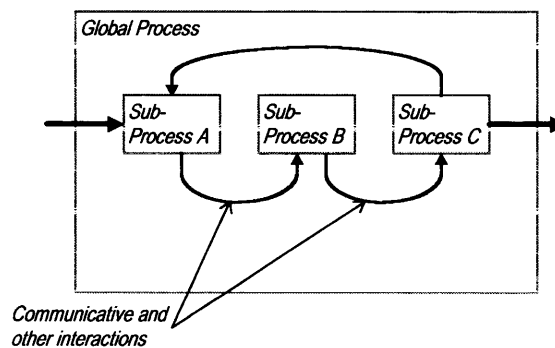


Figure 2: Structured Process Analysis Model

global process is decomposed into a set of component or sub-processes (Figure 2). Each component process is allocated a set of resources, including personnel, finances, equipment, etc. In turn, the identified group of personnel are allocated responsibility for successful completion of the sub-process. *Interactions*

are identified between processes. In design processes, where the products generated are largely information based, communicative activities represent the majority of interactions between personnel groups. Responsibility for successful transmission of information across sub-processes must in some sense fall on both the parties generating and receiving the communication. This structured view of a process may be recursively refined; a sub-process can be further decomposed to identify its internal organization of sub-processes and their interactions. The model must thus satisfy a number of possibly conflicting criteria:

- **Comprehensiveness** - the model should identify and distinguish between all major categories of sub-processes and interactions at the selected level of decomposition.
- **Simplicity** - the model should do so while limiting the number of identified elements. Thus the identified process elements must be general enough in scope to encapsulate a variety of sub-process and interactions.
- **Decomposition** - the criteria for process decomposition at a given level of granularity must be consistent.

Structured process models can serve to highlight, emphasize or generalize certain features of the inherently complex real world design processes they represent. The organization of elements in the process model can in turn be mapped to an organization of components in a supporting computational system. The effectiveness of a computational system in supporting real world activities is thus dependent on its underlying process model's effectiveness in capturing critical aspects of the activity.

## 2. Design Process Organization

Design processes have been frequently assessed in terms of *concept generation*, *analysis* and *synthesis* phases (Figure 3).

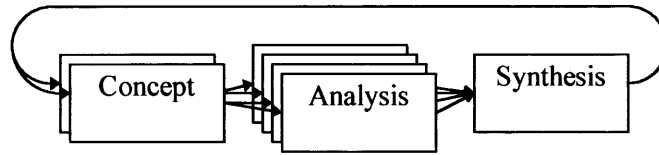


Figure 3: Generic Design Process Model

This decomposition provides a quite general

model applicable to virtually any sort of design process, and highlights the distinctly different qualities apparent in different phases of design.

During conceptual design, initial proposals are created which are intended to satisfy the designed product's performance criteria. These proposals may be complementary, focusing on different aspects of the design problem. Alternatively conceptual design activities may also be directed toward the generation of multiple design alternatives. Concept generation is considered to be the most creative phase of the design process. Suh [1990] lists the following qualities necessary for individual creativity in design: multidisciplinary perspective, a vast storage of knowledge rooted in many fields, and ability to utilize analogies to extrapolate from known solutions to new solutions. Conceptual design may be undertaken by individual designers, or collaboratively. Clearly, benefit can be gained by the coordinated involvement of several designers lending different fields of expertise. However, given the limited current understanding of creative design, these interactions are difficult to support through explicitly structured communicative mechanisms. Formal information such as design briefs, codes or construction documents are utilized during concept generation. But these sorts of information are best considered to be *input* to conceptual design. The products of conceptual design are typically sketches or verbal resolutions of intentions.

In contrast, the activities of the analysis phase of design processes are perhaps the best understood, and the most structured. In this phase, specific aspects of the conceptual design are subjected to analytical methods

to predict the performance of the future product. These analytical methods are usually founded on well developed architectural or engineering knowledge. Many of these methods have been developed to a level of rigor where automated computer methods can match or exceed the capabilities of manual techniques. Examples of such computer based analytical methods include structural and energy analysis, three dimensional computer rendering, and dynamic simulation of mechanical assemblies. The analytic procedures and required performance results are often explicitly formulated in legally binding codes, such as the Uniform Building Code for architectural design and the American Institute of Steel Construction's Load Reduction Factor Specification. Analytical activities typically can be conducted by an individual designer suitably trained in the appropriate discipline. Communications requirements in this phase are thus minimal, assuming that features of the conceptual design have been adequately detailed.

| Selection Criteria      | Concepts                |                      |              |                            |                    |                   |                    |
|-------------------------|-------------------------|----------------------|--------------|----------------------------|--------------------|-------------------|--------------------|
|                         | A<br>Master<br>Cylinder | B<br>Rubber<br>Brake | C<br>Ratchet | D (ref.)<br>Plunge<br>Stop | E<br>Swash<br>Ring | F<br>Lever<br>Set | G<br>Dial<br>Screw |
| Ease of handling        | 0                       | 0                    | -            | 0                          | 0                  | -                 | -                  |
| Ease of use             | 0                       | -                    | -            | 0                          | 0                  | +                 | 0                  |
| Readability of settings | 0                       | 0                    | +            | 0                          | +                  | 0                 | +                  |
| Dose metering accuracy  | 0                       | 0                    | 0            | 0                          | -                  | 0                 | 0                  |
| Durability              | 0                       | 0                    | 0            | 0                          | 0                  | +                 | 0                  |
| Ease of manufacture     | +                       | -                    | -            | 0                          | 0                  | -                 | 0                  |
| Portability             | +                       | +                    | 0            | 0                          | +                  | 0                 | 0                  |
| Sum +'s                 | 2                       | 1                    | 1            | 0                          | 2                  | 2                 | 1                  |
| Sum 0's                 | 5                       | 4                    | 3            | 7                          | 4                  | 3                 | 5                  |
| Sum -'s                 | 0                       | 2                    | 3            | 0                          | 1                  | 2                 | 1                  |
| Net Score               | 2                       | -1                   | -2           | 0                          | 1                  | 0                 | 0                  |
| Rank                    | 1                       | 6                    | 7            | 3                          | 2                  | 3                 | 3                  |
| Continue?               | Yes                     | No                   | No           | Combine                    | Yes                | Combine           | Revise             |

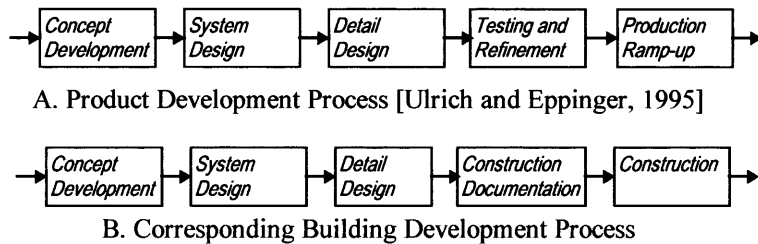
Figure 4: Formal Methods for Design Synthesis [Pugh, 1990]

In the synthesis phase, results of analysis are compared with the initial projections for the products' specification developed in the conceptual phase. During synthetic activities, representatives of all parties involved in the design must reconvene, so that analytical results can be presented and discussed in general terms understandable by all and, if necessary, defended or negotiated by the responsible parties. Representatives of the parties must be able to resolve the assumptions and findings of one another's

analytical efforts with their own. Although elements of this negotiation and synthesis are ill understood, several rigorous formal techniques have been developed to assist in synthetic decision making. Such techniques include Pugh's selection matrix [1990], shown in Figure 4. Design concepts' performances are graded for a number of criteria, on the basis of results derived during the analysis phase. Their resulting scores and ranking provide an empirical basis on which the merits of a given design approach can be decided.

The results of the design synthesis phase may result in a satisfactory design specification, which terminates the design process. Frequently, however, the results of synthesis require further iterations of concept development and analysis.

Figure 5 shows another standard model of design and development processes.



In contrast with the model shown in Figure 3, this model views the design process as an essentially temporally linear process, with minimal interactions

Figure 5: Linearly Structured Design Process Models

between process phases.. The interactions between the component processes in Figure 5 represent successful completion of the component process. Formalized specifications for elements of these interactions frequently exist. Examples include the relatively well defined conventions of construction and bid documents, and formal mechanisms such as transmittals, and scheduled inspections by government bodies. Within each of the major component processes shown, iterative design cycles such as shown in Figure 3 can be anticipated.

## II. THE STATE OF COMPUTING IN THE DESIGN INDUSTRY

The development of the personal computer in the 1980s and the wide area networking infrastructure in the 1990s have made computing an integral part of today's design and business practices. These technologies present a widely available infrastructure for the potential deployment of computer mediated communications throughout design practices and the building industry. However, given the fragmented nature of current computing use in design, substantial development will be still necessary before computer mediated communications become an integral part of professional design practice.

Surveys show a wide variation of computing use in practice (Figure 6). A survey of architectural design firms in the United Kingdom [RIBA, 1995] shows that 90% of all firms utilize computers to some extent. Of the remaining 10%, two thirds were small one to two person shops; the remainder had up to eleven employees.

However, fully 28% of all practices surveyed did not use any form of CAD system. A survey by [Ross, 1993] shows similar findings. Although personal computers have achieved widespread use in

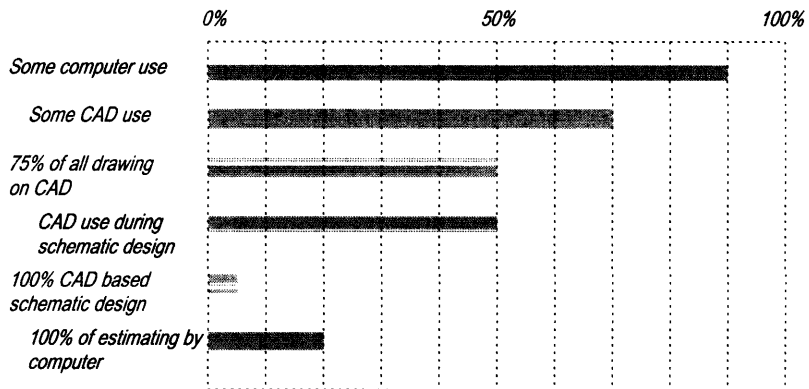


Figure 6: Computer Use Among Design Firms

architectural and engineering firms, deployment is incomplete. While computers are routinely used in word processing and accounting applications, significantly fewer firms utilize CAD applications for drafting; only about half of the firms surveyed utilize CAD throughout the design process. Again this use is

concentrated in larger organizations. The disparity of computing use between large and small firms can be attributed to a number of factors [Coyne, McLaughlin, Newton, 1996]. Projects taken on by individual practitioners are likely to smaller, less complex projects. In such projects, standardization of details and coordination required for systems' designs is likely to be minimal. Automation is also seen as detracting from the more intimate client - professional relationships in residential and other smaller projects. Larger firms require some consolidation of critical correspondences and accounting data. These factors present an initial indication that aspects of communication and coordination important considerations in decisions to use computing in design, as well as in cases where this use is declined.

Statistics are harder to come by for the use of newer communications applications by design firms. This is partly due to the exponential rate of change of these applications' adoption. Email is becoming prevalent in professional design firms, as a means for communication both within the firm as well as with collaborating enterprises. Similarly, file transfer of CAD and other documents is being utilized during collaboration between offices. A recent study by Salwen [1996] shows that many large civil engineering and construction firms have developed Web sites during the 1995 - 1996 period. These sites are considered principally a means for publicizing and marketing services.

It is clear from these studies that the full potential of these tools for coordinating and integrating all phases of design practices has yet to be achieved. There are several apparent impediments to this development:

- **Resistance to disclosure of proprietary information** In traditional design practice, the transmission of information between collaborating organizations is accomplished by the transfer of physical documents. This transfer is accompanied by a transmittal document. The receiving party also formally acknowledges receipt of the information. This transfer is considered a legally binding act; both the information transferred and the formal records of the transmittal documents are archived by both

parties in anticipation of potential litigative conflicts. The open environment for sharing project information fostered by communications technologies breaks down the formal distinctions of information ownership. When computer based documents developed by one practice are transferred to another practice and are further developed by the second practice, the division between the firms' information content becomes blurred. Formal mechanisms for determining information ownership and responsibility have not yet been established, and are likely to remain problematic. For this reason, design firms have shown reluctance to transfer computer based drawings to collaborating firms, although this sharing of information would obviously result in a more efficient overall design process.

- **Security concerns** The embrace of networked computing communications is similarly subject to concerns of information security. By allowing in house computing resources access to the Internet, a potential breach of security is provided. Relatively robust means of protecting internal networks from break-ins are available. But the perception of the possibility of security breaches is enough to inhibit the use of wide area computer based communications. Concerns about security of information are not limited to external intrusions. Firms typically limit access to financial and other administrative information among firm employees. The existence of even an internal computing network opens the question of whether or not information will be secure. These fears are typically voiced by high ranking firms members, who may not have the technical knowledge to make informed decisions about the feasibility of secure networked operations. System administrators who must assume responsibility for maintaining secure network operations may show similar reluctance to assume the risk of connecting to wide area communications networks.
- **Incompatibilities of existing systems** The number of available computing applications presents a bewildering array of choice to the consumer. To product developers, the computer software and



hardware market presents opposing requirements of standardization and differentiation. On one hand, a product can only achieve competitive advantage by differentiating its features from those of its competitors. On the other hand, the adoption of standards which provide compatibility between similarly focused products increases a product's usefulness and can present a means for extending the product's potential market base to consumers who already own competitor's products. Consumers of professional computing products currently expect that products will exhibit some level of compatibility. Government and consumer groups exert pressure for the development of standards which allow communication of information between products. Nonetheless, the state of the industry is such that discrepancies between the data models and features of competing products exist. Computer based communication among different organizations is hindered by such incompatibilities. A firm which has expended financial and personnel resources to procure and deploy one vendor's application will be unlikely to outlay further resources to procure a competitive product simply to allow communication with collaborating firms on a single project.

- **Necessity for accumulating critical mass of use** Communications technologies can only become embraced in professional practices when a proliferation of use has been attained. A firm which decides to use computer based communications as an integral part of its practice must expect to make a significant commitment in capital and personnel. The effective use of computer based communications requires a high ratio of computers to employees, otherwise the process will be self defeating. Email can not be a reliable means of communication unless resources are available for personnel to frequently access messages. Similarly, computer based communications between organizations will not be successful unless sufficient capabilities and social incentives exist in these organizations.

Despite these factors which have slowed the adoption of communications technologies by design firms it seems clear that computer based communications will be an important component of design and other

professional practices in the near future. As Coyne and McLaughlin point out, the initial adoption of CAD has been driven to no small extent by larger firms' perceptions that having CAD capabilities is required for marketing reasons, as a means of demonstrating that the firm is "state of the art". Only later did CAD become an important factor in these firms' productivity. Communications technologies are perhaps even more susceptible to this form of "technological determinism". Meanwhile, much of the infrastructure for the deployment of communications technology has already arrived at the practitioner's desktop. The additional cost of procuring communications technologies is minimal in comparison to that of the personal computer into which it is integrated. Thus sociological factors remain the important obstacles to the adoption of communications technologies in design. These can only be mitigated by an improved understanding of the complex role communications serves in practice, and the demonstration of computing technologies' capacities for supporting these factors.

### III. COMMUNICATIONS ISSUES IN DESIGN ACTIVITIES

It is often assumed that the approach to be taken in developing computer mediated communications (CMC) technologies is to duplicate communication modes arising in traditional co-located situations. This is an inaccurate assumption to make, for two reasons. First, although computer based communications are increasingly utilized in professional practices, there are still severe limitations to the types of communications these technologies provide. Specific limitations or colorations of these communications technologies will be discussed in Section IV.

More interesting is the fact that, by focusing and structuring communications, CMC technologies can provide certain advantages over traditional communications. Thus, although development efforts frequently concentrate on compensating for limitations of available communications technologies, some of these idiosyncrasies can be used to advantage. This structuring of communications provided by CMC technologies is a necessary consequence of the technologies' underlying computational formalisms. Specific aspects of communications will be explicitly addressed in the development of any CMC system; others will be given less explicit address, or entirely ignored, given the limits of computing resources available in the development of any given system. The structure of the resulting application will affect the corresponding structuring of the supported communicative acts. Some features of the communications will be augmented, while others are inhibited. When appropriately applied, CMC systems can improve communicative events, by highlighting desired aspects of the communications, and restricting less desirable aspects. When inappropriately applied, of course, the reverse is true: the system "gets in the way" of the aspects it is intended to support, while bringing to the fore unwanted interruptions. It is thus imperative in any CMC development effort to consider the activities which will be supported by the environment, establish which features of these activities are to be augmented and which are to be reduced, and select a suite of computational approaches which address these desires appropriately. Different types of interactions will

necessitate customization of the CMC approach. This issue will be addressed further below, in terms of the focus and control of communications, and through the discussion of various CMC systems.

## **A. Discourse Theory and Design Communications**

Discourse theory presents a particularly relevant body of study for consideration in developing approaches to the support of design communications. Broadly speaking, the analysis of discourse is “the analysis of language in use” [Brown & Yule, 1983]. As such it differs from traditional linguistics in that it concerns not only *transactional* aspects of communication - the ways in which information is structured and conveyed- but *interactional* aspects as well - issues such as social status, presenting versus hiding of information, gestural content, etc. Discourse approaches to the analysis of communications focus on larger order constructs than the specific sentential structures employed by communicators. In order for CMC systems to adequately address the requirements of design, aspects of discourse analysis need to be considered and supported. This section briefly identifies some of the interactional components of design communications which must be addressed by CMC systems directed at design communications.

### **1. Gesture**

Gestures are perhaps the most important non-verbal discourse cues for design communications. Gestures in traditional communications are physical cues constructed by spatial motions of the arms, hands and, by extension, pointing devices. Gestures are typically synchronized with verbal utterances. Several categories of gestures have been proposed [McNeill, 1992]. Of these, the most important for consideration in design communications are *deictic* gestures. Since design communications almost universally occur in reference to some spatial or virtual media, the support of deictic gestures is a critical component of any CMC system for design applications.

McNeill distinguishes other categories of gestures. Metaphoric and iconic gestures are movements of the hands which “resemble” qualities the subject of discussion. Emblematic gestures have defined symbolic meaning within a culture, such as the “O.K.” sign. Beat gestures are repetitive gestures which coincide with the “rhythmic” characteristics of the speech. Beat gestures are closely associated with cohesive gestures, which provide cues regarding the continuity of the speech act and the its thematic content. All of these gestures represent additional content contributing to the conveyance of meaning during communications. Gestures are a significant component of the added discourse content provided by “talking head” views in video conferencing, and influence *turn taking*, discussed in Section III.A.4 below.

## **2. Gesture Space**

*Gesture space* is the physical space accessible to the speaker, and the space over which gestures take place. In McNeill’s analysis, this is limited to the space where the arms and hands may be physically placed. In the discussion of deictic gestures we must consider an extended gesture space to include the locations of objects which can be pointed toward. Considerations of gestural space have broad implications for the organization of both traditional and computer mediated design interactions. In traditional, co-located settings, the extended gestural space is shared by the interlocutors. Traditional design interactions such as desk crits and reviews have well defined placements of reviewers, presenters and media to support the expected spatial interactions.

Gesture spaces arising in CMC systems currently present particular limitations relative to traditional communications. The “placement” of virtual design media and the “shared space” of non co-located interlocutors vastly complicates considerations of gesture space. Ineffective resolution of remote participants access to a shared gestural space can profoundly limit the effectiveness of the computer

mediated design discussion. However, some examples of CMC systems which have effectively resolved gesture space issues [Ishii, 1992, and Section V.C. below] actually present some improvements over traditional co-located gesture space, by allowing the communicators' gesture space to overlap or be situated in ways impossible in physically based settings.

### **3.Role and Footing**

In traditional design communications, the roles of participants such as presenter, reviewer, client, principal and supporting designer are well defined. The spatial organization of traditional design interactions supports and mirrors the organization of these roles. In computer mediated design communications, the organization of information channels must be developed with the differing participants' roles in mind. Participants who are presenting information will have different communications requirements than those of the participants who are simply reviewing or providing feedback. *Footing* [Goffman, 1983] extends the notion of roles to the considerations of the role a speaker assumes during a given expression. A participant may represent him or herself, or take the position of another party or parties who may or may not be participating in the discussion. Similarly, a speaker may direct an expression to the entire body of participants, or to a limited subset of the participants. The organization of communications channels in design interactions should support changes of footing. Communications channels which provide only for the broadcast of speakers' discussion uniformly to all participants will prohibit subtle changes in participants' interactions, and reduce the overall quality of the discussion.

### **4.Turn Taking**

In the discourse view, conversation is organized around control of the *primary communication channel*. At each point in time, one of the participants is in control of the conversation and is primarily speaking, while

the other participants are primarily listening. Exchange of speaker and listener roles during conversation is accomplished through turn taking cues. Some of these cues are verbal, such as the termination of a clause, followed by a pause, or an explicit request by the speaker for feedback. However, many turn taking cues used in co-located interactions are gestural. The speaker may look toward the listeners at the end of speaking. A listener desiring a speaking turn may exhibit animated gestures to indicate that he or she has something to say.

In computer mediated communications the smooth transition of turn taking is inhibited by limitations of the visual channels. Poor support of turn taking means poor support of the conversation, such as a visual channel remaining on the previous speaker while the conversation has been begun by another speaker. Various methods for the support of turn taking have been developed, including automatic voice activated selection among participants in multi-point video conferencing.

## **5.Focus**

The *focus* of discourse is “what the discussion is about”. In design interaction, the focus of discussion is frequently oriented toward some physical or computer based content. This is of course not always true, as discussion may progress to other issues in design for which no supporting media is available. CMC systems developed to support design interactions must have some strategy for supporting changes in transmission of content alongside changes in conversational focus. If a limited number of channels are available, then the channels must be switched between the media. If many channels are available, then some sort of cues may be required to establish which channel the point of conversational focus is located in.

## **B. Synchronous vs. Asynchronous Communications**

Perhaps the most basic characteristic of any CMC technology is the distinction between synchronous and asynchronous forms of communication. Broadly speaking, synchronous communication occurs when the parties utilizing the technology do so concurrently. Within synchronous communications sessions, communicators may rely on a variety of communicative and expressive devices, types of media or channels. Communication may be conveyed along audio / verbal channels, text based channels, visual reception and physical manipulation of CAD models, images or other design media, etc. During synchronous communication, interaction may be principally mono-directional - where one speaker or presenter is transmitted for reception by one or more parties, or bi-directional, where feedback is transmitted back to the presenter, and capacities for presentation and communication are provided to both sides of the communications pipeline. An obvious example of mono-directional, synchronous communication is traditional television or radio broadcast, where the transmission of communication is from presenter to audience only. A simple example of bi-directional communications capabilities is provided by normal telephone conversation, where the two communicating parties have essentially equal support by the communications medium. Synchronous communications can be point-to-point or multi-point. A single computer mediated design communications session can simultaneously exhibit multiple organizations of communications. For example, a session can be primarily focused around presentation by one individual at a particular location, capable of controlling and transmitting a full range of design content. The audience might be comprised of both reviewers with some response capabilities, as well as an audience with capabilities only for receiving the proceedings of the above two parties' interactions, and no capabilities for active participation and contribution.

Asynchronous interaction can be characterized as occurring when the act of content generation and the act of reception of content are temporally distinct events. A simple example of asynchronous communications



is provided by standard email, where messages are read by the receiving party at some time after the full completion and transmission of the message. A significantly different example of asynchronous communications is provided by early World Wide Web technologies, where information is posted on the Web, and can subsequently be downloaded for review by multiple parties. In limited Web server configurations, viewers have no capability for directly responding or contributing to the information presented on a given Web page. It is thus apparent that asynchronous communications are subject to similar classifications as synchronous communications, in terms of directionality and number and quality of participation.

Asynchronous communications systems necessitate the inclusion of some databasing or storage / retrieval system, in a way that synchronous communications systems do not. Asynchronously transmitted messages must be stored at least until they are initially accessed by the receiving party. Once accessed, it is desirable that the receiving party have capabilities for retaining the information for subsequent review. Ideally, the recipient should have additional databasing capacities of being able to categorize and search stored messages, and to associate the messages with other ongoing design developments and content.

It becomes apparent from the above discussion that the distinction between synchronous and asynchronous communications systems becomes quickly blurred, as transmitter and recipient become provided with more sophisticated means for manipulating and transmitting information. Interaction by telephone achieves an asynchronous component with the addition of telephone answering services. It is perhaps more fruitful to distinguish between qualities of transmission or control in synchronous versus asynchronous modes of a given systems' use, and to consider specific events during the use of a CMC system in terms of the support of synchronous and asynchronous communications provided.

### **C. Remote vs. Co-located Communications**

The distinction between whether communicators are remotely located or co-located seems at first to need no further clarification. However, the use of communications media complicates the question of spatial location. In particular, the question of interaction with electronic media at once brings up questions of “virtual space”. One might characterize communications in terms of the gesture space employed, and define remotely located activities to be ones where individual gesture spaces are bound into a shared gesture space by an intermediary electronic channel.

It might be assumed that CMC systems are to be used only in interactions between spatially remote communicators. However, once again the issue is not so simple. A design interaction may require communication both between co-located participants as well as communication with remote parties. Systems which are intended for communication between spatially distant locations may also need to address the capture and transmission of spatially co-located interactions, and address the means by which remote participants can be included into the ongoing flow of the co-located discussion. CMC systems also have use in situations where participants are spatially accessible to one another. Several of the brainstorming systems in Section V.A below are intended for sessions where all of the participants are located in the same room. In such applications, the implicit structuring provided by the CMC environment is utilized in bringing to the fore communicative aspects toward which the system is targeted.

### **D. Content**

For the purposes of this discussion, one can make a broad characterization of content types, in terms of physically versus digitally based content, with some blurring of distinctions arising in CMC applications.

Physical content may be considered to be information whose native form of production or form at the time of transmission is based on physical materials. Such information includes information arising in two dimensional drawings or sketches, and three dimensional prototypes. We might, for technical purposes of recording and transmission, include the voice and video images of the persons engaged in discussion in the category of physical content.

Digital content is quite varied in the context of design. Virtually any textual or computer based information pertaining to the development of the project may be transmitted to support the discussion. Certainly the most obvious of these sorts of information are the CAD based drawings generated by designers, renderings and other static image content, and computer generated animations. Similarly, engineering models and simulations may be transmitted, either directly from the generating applications, or as annotated images. Other digital content includes text files and spread sheet based information. Digitally stored video files and multimedia applications are also examples of digitally based content.

## **IV.AVAILABLE COMMUNICATIONS TECHNOLOGIES**

This section considers a number of the wide range of technologies available for the assembly into CMC environments. A number of categorizations are proposed by which highlight aspects of the available technologies. A given technical solution will exhibit characteristics of more than one type of category.

### **A. Distribution Networks and Bandwidth**

Bandwidth of the provided communications channels is perhaps the most important single aspect dictating the quality of interaction. The term bandwidth is used to mean simply the rate of information flow available between transmitting and receiving locations. Different types of media will present different bandwidth requirements. Bandwidth is dictated by the type of communications link established between the locations, multiplied by the number of links provided. Below several types of currently available distribution technologies and their corresponding transmission speeds are presented.

#### **1.POTS - Telephone Service**

The original, intended use of the POTS system as a means for transmission of voice has been augmented in recent years by the introduction of facsimile machines and digital modems. The POTS network is ubiquitously available both nationally and internationally. It is inexpensive, robust, and there are essentially no compatibility issues left unresolved either at the local equipment level or at the international distribution system level. A POTS connection is typically a dedicated, unshared link between two communications nodes. Thus a connection established over a POTS connection provides uninterrupted communications capabilities between two sites. While a POTS link provides adequate bandwidth for the transmission of voice, the demands of digital communications have quickly outstripped capabilities provided by this type of channel. A typical modem operating on a POTS connection is capable of transmitting and receiving up to

36 Kbit / sec of information. This is sufficient for the transmission of text based information (~ 200 bit / sec.), and medium quality audio signals (~14 Kbit / sec in digitally sampled form). By comparison, the information content of an (uncompressed) full screen graphic image at 640 x 480 pixels and 8 bit color depth is 2.5 Mbit/sec. Thus to send an image in uncompressed form over a POTS line would take over 1 minute. This speed is obviously too slow for any sort of real time interaction. A variety of compression schemes can be employed to compensate for the disparity between the transmissions requirements and capabilities. However, for reasonable interaction capabilities, POTS line communications should be avoided for all but audio communications or text based communications. It should be noted however, that a modem connection operating over a POTS line is currently the de-fact standard for both personal and small business data communications.

## **2.ISDN**

The ISDN standard was developed in response to the increased use of digital devices by consumers, and the correspondingly increased bandwidth requirements of digital applications. ISDN is a digital standard, which can operate over standard twisted pair wire connections from the end user to central distribution hubs. Thus ISDN represents a compromise solution from the telephone system perspective: increased transmission speeds are available, without requiring that the telephone network between the consumer location and the central distribution center be replaced. A standard ISDN channel is comprised of two data channels, each delivering 64 Kbit of information, for a total of 128 Kbit/sec.

ISDN availability is limited by distance between the customer location and the nearest ISDN distribution point. In general, the customer location must be within 2000 feet of the nearest distribution location before unacceptable degradation of signal occurs. ISDN capabilities were until recently rather difficult to order, expensive to install, had significant associated usage charges, and required relatively expensive termination

hardware. Numerous idiosyncrasies and incompatibilities existed between different types of equipment and line configurations. The situation is rapidly improving, as expertise and demand become more wide spread. Nonetheless, the ISDN based communications network remains tricky to install and operate - one can never be sure that a link between two locations using ISDN communications will be successful without testing. The improvement in bandwidth provided by the ISDN network, while considerable, still falls short of the demand of many applications. A single ISDN line provides 128 Kbit/sec of data transmission, roughly five times that of the standard 28K modem. This brings ISDN transmission into the low end of that acceptable for video communications, when compression schemes are employed. An ISDN connection, similar to a POTS connection, is a dedicated point to point connection: once the connection between the two points has been established, uninterrupted transmission of information can take place.

For increased bandwidth through ISDN channels, several ISDN lines may be combined through inverse multiplexing. This technology allows a single channel of content to be divided between multiple transmission channels, thereby increasing the bandwidth available to the source of information. Inverse multiplexing provides a feasible solution to the problem of achieving higher data transmission rates than that available from a single ISDN line, with a moderate increase in technical complexity and multiply higher costs for time usage. A three line, inverse multiplexed ISDN channel delivers 384 Kbit/sec of information, satisfactory for detailed transmission of information by compressed video technologies.

The price and complexity of installation for ISDN connections is much greater than that of POTS connections, so more commitment is required for installation of these lines. ISDN is also not yet available at all locations in the United States; in to some rural areas user demand is perceived by telephone service providers to be too low to justify the installation of ISDN distribution hubs. Currently, many medium size firms have opted for ISDN data connections to provide email or ftp data transmission capabilities.

### **3. T1 and Partial T1**

The 64 Kbit/sec segment of information, operating over CAT5 wire represents the essential building block of high bandwidth data transmission. These basic segments are combined in several ways, including the ISDN standard described above. Currently, T1 connections are being promoted as the standard for high end users' data requirements. T1 bundles twenty four 64 Kbit/sec channels together, allowing 1.5 megabit/sec communications. Partial T1 connections, providing a fewer number of channels are as easily available. Generally, pricing of partial T1 service is almost as expensive as T1. Some larger design offices operating in larger metropolitan areas have had T1 capabilities installed.

### **4. Point To Point Versus Switched Data Connections**

Having a large data pipeline does not necessarily mean that appropriate data transmission capabilities are available for a given type of CMC channel. An important distinction is to be made between point-to-point and switched connections. Point-to-point channels provide uninterrupted communications links between communicating sites. In contrast, switched data connections operate over shared network connections; The connection may be dropped or be discontinuous over the period of the communication. While almost all media types can be transmitted over either type of connection, discontinuities occurring in switched channels can degrade the quality of some media communications even if sufficient bandwidth is available. In particular, the transmission of physically based content such as sound and video is detrimentally affected by switched connections.

## **B. Communications Media**

A differentiation must be made between the content or semantic level information which is being transmitted and the media which is utilized for the transmission. Here again, a number of options in media exist for transmitting a particular type of content. The distinctions between these types of digital media have profound implications on the compression which can be achieved in their transmissions, the quality of received information, and user interface capabilities. For example, while textual computer based information may be transmitted in the form of its image as it appears on the computer screen, it is much more efficient to transmit this information as ASCII character based information and to then reconstruct the image on the viewing computer. Computer generated images may be transmitted digitally, with no loss of information but potentially large bandwidth requirements. Alternatively, digital images may be converted to analog video information through simple scan conversion of the monitor output. The resulting signal will be transmitted at a much higher speed, due to increased compression capabilities, however significant loss of detail may result from this conversion.

Similarly, views of CAD models may be transmitted as constantly updated image based information, or the model may be transmitted once and then updated view and focal point locations of the model may be transmitted. The views of the model can be regenerated at the desktop of all the communicators based on to reflect changes in viewpoint. The increased computational burden of the reconstructing the image on two machines is more than offset by the savings in transmission times.

## **C. Synchronous Communications Technologies**

Synchronous technologies support real time, face to face interaction between parties in spatially remote locations. A rudimentary, traditional version of synchronous communications technology is the standard telephone, which emulates capabilities for vocal communications. Recent technological developments have



broadly augmented these traditional capabilities, by supporting a variety of additional communication modes arising in professional practices.

### **1.Video Conferencing**

The most prominent example of these emerging technologies is video conferencing, which allows for the real time transmission of video images in conjunction with sound transmission. While the standard application of this technology is simply to provide for a “talking head” image synchronized with voice, many types of information are conducive to being captured as a video signal and transmitted over video communications lines. In the design practices, such information types include physical models, drawings, and computer images or animations captured from computer monitors. However, the quality of the video signal supported by video conferencing technologies is a significant issue for design communications - video quality acceptable for viewing a speaker in conjunction with voice transmission may not be acceptable for the viewing of detailed elements in a design proposal. Currently several video conferencing technologies exist, operating over several different communications networks. Three basic categories of video conferencing communications are currently available.

Several computer models can be purchased ready for Internet based video conferencing. Currently, however, the Internet is not capable of distributing video conferencing of acceptable quality, for two reasons. First, transmission rates vary widely across the Internet, but are often less than that required for video conferencing (roughly 100 - 300kBit) . More importantly, the current TCP/IP Internet protocol provides inconsistent distribution of data packets, resulting in broken, choppy video and sound transmission - up to several seconds of lapse in transmission can be anticipated. Since the disturbance is perceived more significantly in the audio channels than in the video, problems with Internet based video conferencing can be partially offset by using its use in conjunction with standard telephone conferencing and speaker phones.

Future network developments, including ATM, promise consistent packet streams. In summary, Internet based video conferencing offers inexpensive video transmission at relatively poor quality.

ISDN digital telephone based video conferencing offers the best current video conferencing solution, by delivering relatively high quality video and sound at reasonable prices. Two basic options exist for ISDN video conferencing. Desktop video conferencing is integrated directly into personal computers. This option allows video conferencing to be integrated with other computer based applications, through application sharing (Section IV.C.2), shared drawing boards, and PC based sound systems. Higher end systems operate over dedicated hardware, and can offer improved picture quality, albeit at a price premium. ISDN video conferencing systems allow integration of other video data, such as video document cameras and pre-recorded video cassette presentations. Several companies market video conferencing systems; current industry leaders include PictureTel and Intel. An industry standard protocol (H.320) was established in 1994 which ensures that virtually all ISDN based video conferencing systems can communicate with one another. However, different vendors may have higher level proprietary standards which will operate whenever their products communicate together.

Satellite based video conferencing is also available, which delivers broadcast quality video. This option is quite expensive, both in hardware and usage costs. For reasons of cost and limitations of availability, satellite based communications have not been pursued during any of the applications studied.

## 2. Synchronous Data Transmission

Increasingly, video conferencing technology is being integrated within the personal computer, utilizing hardware components already available in multimedia personal computers to provide for elements of the video transmission (Figure 7). With this migration of video conferencing technology

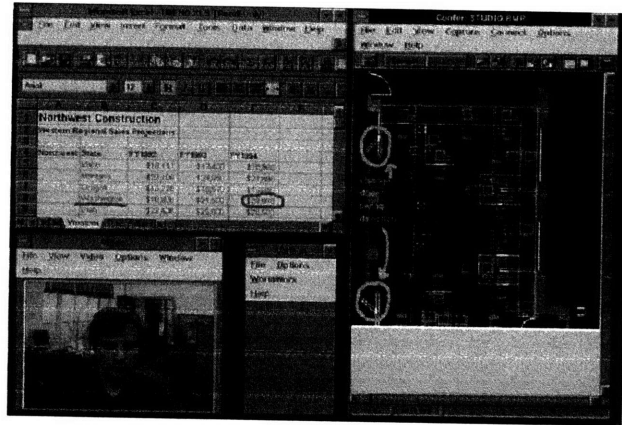


Figure 7: Desktop Synchronous Communications Technologies

to the desktop, auxiliary products are being developed to support other elements of computer based communication. One example of this technology is a simple *shared whiteboard*, which allows an image to be retrieved and collectively annotated by two or more parties.

A more interesting example is *application sharing*, a utility which allows for joint operation of any computing application by two or more spatially remote parties. In an application sharing session, the actual application program is run on one host machine in the conference. An image of the application window identical to that on the host computer is transmitted to the other remote computers engaged in the conference. Input events such as keyboard entries and mouse movements are transmitted back from the remote computers to the host computer, allowing remote parties to control the application running on the host computer. The result is relatively transparent operation of the application from both host and remote desktops. However, interaction with the application is limited by the bandwidth available for communication between the computers, as the monitor image must be transmitted from the host to remote computers. Limited bandwidth results in a remote view of the application which lags behind the actual operation of the application. As a result, application sharing is an excellent alternative to video based transmission for relatively static computer images, where the quality of the image is of primary importance.

Video based transmissions are in turn superior for transmitting animated information, where image quality can be sacrificed to maintain the speed of the action on the screen.

Several vendors offer these technologies, and in the near future a standard will be in place (T.120) which will allow multi-point application sharing among these different vendors' products. Currently most products provide only point - to - point (i.e. two site maximum) application sharing. Most of these products offer a built in shared drawing board - allowing parties to annotate of previously generated images - and file transferring capabilities. Products are distinguished from one another by the transmission networks supported and by the amount of built in data compression and hence speed increase. Some desktop video conferencing vendors offer built in application sharing, however these products share the bandwidth offered by the ISDN line and thus are limited in the speed that they can transmit data. In addition to ISDN transmission shared with video conferencing, available transmission options include both POTS (28.8 Kbit) and ISDN (128 Kbit) modem, and Internet based network support. These technologies have been developed principally for the PC and Macintosh platforms.

These recent trends in synchronous communications technologies point to interesting directions for the support of design communications. In particular, the emerging support for communication of high quality image based information lends itself well to design applications. In practice, the emphasis in design on large volumes of high quality image based information dictates that the demands of design communications will continue to confront the limits of synchronous communications capabilities for some time to come. CMC applications for design must seek means for getting around these limitations in order to adequately support design communications while still utilizing currently available technologies. Our studies have found that the use of synchronous communications for design can be significantly enhanced through the use of application sharing to share design database information, discussed below.

## **D.Asynchronous Communications Support - Design Databases**

The issue of how a body of design information can be jointly developed by multiple designers is central to the support of design collaboration. During collaborative design development, information generated by members of the design team must be readily available to the other team members, so that they can respond to proposed developments as they are occurring. Many problems arise in the support of asynchronous design collaboration. One issue *version maintenance*, the question of how information is incrementally updated. Other issues concern establishing security protocols for the kinds of interactions team partners are permitted to have with information being developed by a particular design team member, and the means by which the team is notified when significant changes have been implemented by an individual team member.

In translating professional design practices into computer based applications, the need for a common repository for design data becomes apparent. This need exists for both traditional CAD based design documents, as well as for other types of emerging multimedia design data such as animations, virtual reality models, mechanical simulations, structural analysis models, etc. Some of the major issues to be considered when selecting a design database include:

- Interoperability - which platforms can be supported
- Data Types - which sorts of drawings and multimedia are supported
- User interaction - what is involved in manipulating a media particular type
- Versioning - how are changes stored and coordinated
- Distributed storage and retrieval - where is the data stored? What is involved in retrieving data at a remote site?
- Security issues - who can view which information? Who can change which information?

The World Wide Web is an Internet based multimedia tool that has generated phenomenal interest over the past three years. Some of the appeal of the Web for design communications is that a) data can be both stored and retrieved from virtually any platform and b) the Web is quite flexible in the types of objects that can be stored and retrieved. The Web increasingly supports a wide range of multimedia data types, including VRML (virtual reality models), animations and video, as well as text and images. New “plug-in” features allow ever increasing types of information to be interacted with, while programming languages such as Java are beginning to allow the development of distributed applications. However, not all media types are supported on all platforms. The Web provides a fully distributed database architecture - data entries can be stored and retrieved from anywhere in the world, and linked to other data anywhere else.

Despite the wide spread appeal and acceptance of the Web, several shortcomings in the current generation of Web technology limit its capabilities for supporting collaborative design. These limitations fall chiefly on the authoring side of its capabilities - the means by which information can be placed on the Web. Although Web information can be easily viewed from remote locations, editing and generating Web pages must occur through accessing of the files at the server location and, typically, explicitly editing the hypertext code which forms the body of the Web page. Storing information on the Web is still somewhat laborious - multimedia objects must be stored in separate files and then referenced, and some crafting of the HTML text must still be done. However, newer authoring tools are improving the ease of publishing material on the Web. Additionally, the Web does not yet support the use of more sophisticated design applications such as CAD files, spread sheets and analysis packages. Many of these issues are the subject of current efforts within the Web development community, and significant advances in addressing these limitations are to be anticipated in the near future. Overall, the Web is inexpensive, easy to interact with and has a wide appeal, but placing data on the Web can be difficult, and editing features are still quite limited.

An alternative to current Web based technologies is offered by a set of tools called *groupware* applications. These tools are specifically developed to support the asynchronous communications requirements of professional business practices. Typically, groupware tools integrate standard electronic mailing capabilities with a database engine for storing and retrieving information. Appropriate security mechanisms are built in to allow selective viewing and editing capabilities by different parties.

One of the current industry leading groupware applications is Lotus Notes, offered by IBM / Lotus Development Corporation. The Notes system is organized as an extensible set of databases corresponding to particular categories of information. Lotus Notes is a mature product that offers an integrated solution for authoring reading, distributing and annotating of information. Notes comes with its own integrated email system, which can be linked to other Internet based email systems. Notes provides a relatively standard relational database architecture with a slick user interface. The basic piece of information in Lotus is the *Note*, a form with fields for entering information such as author, recipient, date, and other categories of information. Generally, a note contains a *rich text field*, which allows multiple media formats such as text, images and multimedia objects to be incorporated. One particularly appealing feature of Notes is its ability to embed complex data objects such as CAD drawings and spread sheets directly into the Notes page. These objects can be viewed by other members of the team, edited directly from within the Notes document, and saved back into the database as an updated version of the document.

Notes are organized into databases, and can be searched and viewed in a variety of ways. So, for example, the same information can be selectively viewed by project, author, project phase, cost, etc. Notes databases can be programmed to automate work flow. Thus when a form is completed, it can be mailed to the next person responsible, while the database tracks and records all of the communications throughout the work

flow. Notes has a very sophisticated permissions structure, so that the information viewable and editable by a particular person can be controlled.

The Notes database architecture is significantly different than that of the Web. Notes databases are contained in their entirety on a server computer. A client application retrieves overviews of the information in a database, Notes pages and multimedia objects selectively from the server. Databases can be “replicated” among servers serving individual offices. Thus the data can be accessed locally - allowing potentially faster access times - while still maintaining fidelity of the data among many locations. Notes supports the inclusion of references to Web based data in Notes databases, allowing some level of interoperability between Notes and the Web.

Other traditional databases such as Oracle and Sybase are also incorporating multimedia object capabilities and Web service into their data models. These databases are quite powerful, but have some restrictions on the flexibility of their use. Database writing is typically quite difficult, time consuming and expensive.



## V. PRECEDENT COMPUTER SUPPORTED COLLABORATIVE WORK SYSTEMS

This section discusses several notable experimental systems which have been applied to collaborative activities. These approaches, termed *computer supported collaborative work (CSCW)* systems, extend the concept of computer mediated communications to support specific types of collaborative tasks. The lessons learned from these systems' successes and failures will be discussed in relation to potential design applications.

### A. Brainstorming and idea development tools

Many of the formative CSCW systems have addressed the issue of group idea generation and decision making. Implicit in the development of these systems is the assumption that decision making can in fact be enhanced by conducting discussions through the structured communications channels afforded by CMC systems.

One of the first systems to aggressively address the idea of computer structured decision making was the IBIS (Issue Based Information Systems) approach [Rittel and Kunz, 1970]. In this approach, design processes are viewed as being “fundamentally a conversation among stakeholders (e.g.

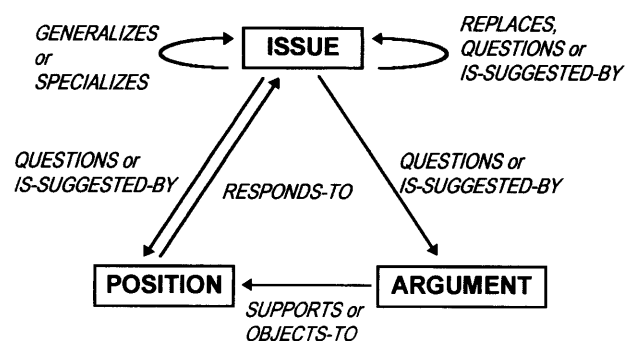


Figure 8: gIBIS Communications Model [Conklin and Begeman, 1988]

designers, customer, implementers, etc.) in which they bring their respective expertise and viewpoints to the resolution of design issues.” The IBIS model focuses on developing a means for structuring and recording these dialogs among different stakeholders. Communications among stakeholders are classified in several categories, including issues, positions, and arguments. There are a variety of types of links which can

relate one message to another message (Figure 8). The gIBIS (graphical IBIS) system, developed by [Conklin and Begeman, 1988], allows for the viewing and submission of messages into an IBIS based framework using a graphical user interface tool. This tool displays a view of the developing tree structure of arguments and responses.

Other experiments have concentrated on the use of CMC channels in synchronous, group problem solving interactions. These systems generally address questions of group productivity. A standard finding in group based interaction studies [Diehl and Stroebe, 1987] is that while group interaction may be beneficial to the quality of ideas generated, the raw output of ideas is in fact reduced during group interactions, relative to nominal groups with limited interactions. Interactional phenomena arising in group interactions which inhibit individual productivity are termed *input blocking*. Input blocking phenomena arise in group interactions due largely to the serial interaction nature of groups: the fact that at any time, only one member may be in charge of the floor at any time. Other inhibitors arise due to status issues among the participants. Several experimental systems focus on the means by which CMC systems can mitigate the detrimental aspects of group problem solving by allowing for parallel or anonymous contributions. The work of [Hymes and Olson, 1992] shows that the limitations of group interactions can be overcome by using parallel text input capabilities in conjunction with physical interaction channels. In their experiments, participants were located in separate rooms, connected by video and audio communications links. Text based interaction was conducted through ShrEdit [Neuwirth, Kaufer, 1990], a synchronous, multi-user text based system running over networked Macintosh computers. Their results show net content generation of groups interacting with physical channels and simultaneous text based input to be similar to nominal group's interactions, where no interaction between group participants was possible.

[Dourish and Bellotti, 1992] discuss issues of awareness and coordination of group participant's activities through ECM channels. In their experiments, groups of three designers were given the task of designing a

24-hour unstaffed “automatic” post office. The designers were asked to devise a plan for the post office - the ways in which it would work and the services it would provide - and to compile a list of issues for further investigation. Thus, while interaction was not limited to text based communications, the end product was to be developed through the collaborative text based interface. The ShrEdit interface allowed for multiple text windows, which could be publicly or privately viewed and edited. Findings of this study show many subtle relationships between the interactions occurring in the “physical” channels and those in the digital, text based channels where the product was being developed. It was found that the physical channels were used by the participants to provide a range of cues to the other participants, including feedback on the text that participants were typing, and as a means for orienting team members toward text based activity being generated by the individual designer. The study addresses the reliance of shared awareness of other group members activities, in contrast to “strong “ role and activity structuring models exemplified by gIBIS.

## **B. MediaSpace**

The MediaSpace experiment [Bly, Harrison, Irwin, 1993], developed at Xerox PARC, presented one of the first experiments to critically look at the use of video based informal communications in the workplace. The focal point of the MediaSpace project was a video and audio link between two common spaces in PARC’s Palo Alto and Portland offices. Video switches provided the additional ability to transfer the video connection to monitors located in personal office spaces. The video and audio links could be used in conjunction with a relatively traditional digital data network for file transfer. Their results identified several aspects of system use:

- **Peripheral awareness.** The link allowed peripheral or background video and audio cues to be received from the remote site. Awareness of these cues provided an overview of activities occurring at the remote site, and the opportunity to join in if desired.
- **Chance encounters.** The MediaSpace link provided an opportunity for unscheduled conversation between workers. As people passed through the commons areas at both sites, they would glance into the monitors, in much the same way that they would glance about when walking down a physical hallway. When people were simultaneously in the far end commons space, an opportunity was presented to establish conversation.
- **Group Discussion.** This use is reflected in the standard applications of today's video conferencing systems. However, the widespread availability of the video connections throughout the two sites allowed for spontaneous, unscheduled group discussions.
- **Structured Presentations.** The media link was additionally connected to PARC's main conference facility. This allowed presentations occurring in the conference facility to be transmitted to private offices and the commons at both locations.
- **Social Activities.** Commons lunches and office parties were held concurrently at both facilities, linked through the video / audio connection.

The MediaSpace project provides an example of the way in which communications links can support informal communications as well as formal communications. One particularly important observation is that informal communications require flexibility and continuity of access not required for the support of formal communications. Additionally, it is apparent that the shared space provided by the communication link seems to acquire but also influence the characteristics the social spaces in which it is embedded.

### C. Clearboard

The Clearboard system, developed by Hiroshi Ishii at NTT, presents one of the more interesting examples where resolution of the gestural and spatial issues arising in remote

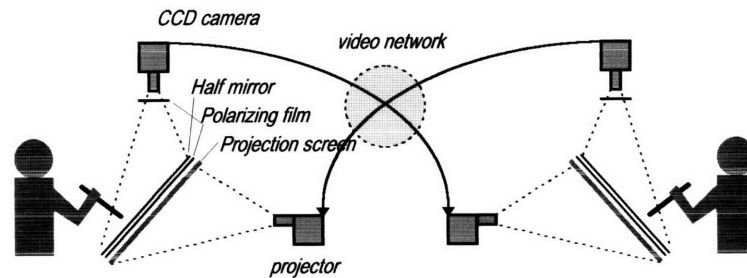


Figure 9: Clearboard -1 Architecture [Ishii, 1992]

design and work activities have been attempted. Figure 9 shows the Clearboard system architecture. Two remotely located designers each work on drawing surfaces comprised of a large half-mirrored panes of glass. A video camera located above the semi-transparent work surface captures both a reflected view of the designer and his or her drawing and writing. This recording is transmitted using video links to a second designer and is back projected onto that designer's work surface. Video processing is used to insure that feedback between the recordings and projections of the two designers does not occur. Video processing is also used to reverse the displayed view of each designer. In the reversed view, the remote designer appears to be behind the work surface of the viewing designer, drawing "in reverse", so that the marks the remote designer makes appear in normal orientation to the viewer.

The major advances offered by this system are the treatment of the designers' shared media space, and the spatial relationships developed between the two designers. The media space appears to be in between the two designers, and the physical and gestural spaces of the two designers are unified, through the metaphor of working on opposite sides of a clear piece of glass. The designers can perceive one another's pointing, drawing and other gestures, and also detect facial expressions and, significantly, one another's direction of gaze. Ishii discusses at length this issue of "gaze awareness", whereby in using the system the collaborators can draw on visual cues directed toward the physical media and each other. While the introduction of gaze

awareness certainly presents an interesting and useful communicative cue, it is unclear that gaze awareness has as significant a place in traditional, co-located design activities as Ishii implies. Also interesting in Ishii's work is the emergence of peculiar social conventions, whereby designers are reluctant to draw directly over the face of the other participant, although this act would not be perceived by the other designer.

## **VI.CASE STUDIES IN COLLABORATIVE DESIGN COMMUNICATIONS**

This section presents two case studies of the use of communications technologies in collaborative design. First an interdisciplinary, collaborative design course conducted at MIT will be discussed, in terms of the sociological goals of the studio, the technologies employed, activities conducted, and lessons learned. Based on this experience, a second effort has been undertaken, directed at applying communications technologies to professional design practices. The initial results of this effort will be discussed in Section VI.B.

### **A.The Collaborative Design Studio**

During the Spring term of 1995, a design studio was conducted at MIT which focused on of the role of the computer as potential intermediary force at the crossroads of design activities. This studio course, termed the Collaborative Design Studio, brought together faculty and students from the Departments of Architecture, Mechanical Engineering, and Civil Engineering at MIT in an effort to explore emerging trends in computing applications to design arising in these fields.

Over the course of the studio, a wide range of design tools and methods, both traditional and computer based, were utilized by the students. The approach taken in the studio was not to limit the tools utilized to a “paperless”, exclusively computer based environment, but rather to explore the ways in which traditional design media could interface with the computer environment. The computer based design environment was viewed as a central intermediary agent, or filter, through which traditional and computer based tools were integrated.

## **1. A Meeting of Design Cultures, Methods and Values**

In initial conversations during the development of the studio, it became apparent that the design methodologies presented by these three departments presented significantly different approaches to the question of “what is design”. These differences fall into several categories.

We might define *design values* to be the collection of issues important to a particular discipline. Architectural design education, for example, focuses on the esthetic issues of space and context, and the interface between the materials and systems used in a project and the qualities these materials lend to spatial and contextual issues. Mechanical Engineering design education concentrates in part on the interface between the mechanical performance of a design and the functional specification which the designed assembly is intended to fulfill. Issues of cost, production process, design tolerances and the effects of statistical deviations from the design specification are important issues in the design of mechanical products. Civil Engineering design has traditionally focused on the use of specific problem solving methods in verifying the structural performance of constructed assemblies. Significant issues are in predicting the structural behavior of materials and elements built out of these materials, disclosing failure modes for these materials and assemblies, and developing systems of assembled elements which deliver stable, determinate performance.

The three disciplines also demonstrate a rich range of problem solving tools and *design methods*, both traditional and computer based, which have been developed to address their respective design values. Architects increasingly utilize visualization and animation tools to understand the spatial and material qualities of proposed designed spaces, and utilize CAD drafting tools for documenting their designs. Structural engineers use finite element static and dynamic analysis tools to predict the structural behavior of assemblies. Mechanical engineering designers employ mechanical simulation and structural dynamics



applications, computational fluid dynamics (CFD) applications for air, fluid and energy flow analysis, and parametric modeling tools for developing and documenting designs.

Finally, the three departments offer significantly different *design cultures* which have developed over the long histories of these disciplines. In the architectural discipline, the atelier culture offers a unique way of working. Students are given spaces within design studios, where it is expected that they will spend a major part of their time during the term. The studio is a second home, where they will work, eat, and sometimes sleep. The design studio becomes a community, where students can see and discuss the work of other students as it is being developed, a place where faculty and visitors wander through, offering advice and criticism. The structural engineering curriculum contrasts this culture with a more traditional Socratic format: design problem solving skills are developed through a sequence of technique building courses. Courses are structured through lectures, with problem set homework assignments building experience in applying analytical techniques to discrete example problems. The mechanical engineering curriculum presents a pedagogical format somewhere in between the architecture and civil engineering models, with both lecture courses and laboratory based design courses.

A principal goal of the studio was to seek a design methodology and educational model merging the approaches and values of the three disciplines (Figure 10).

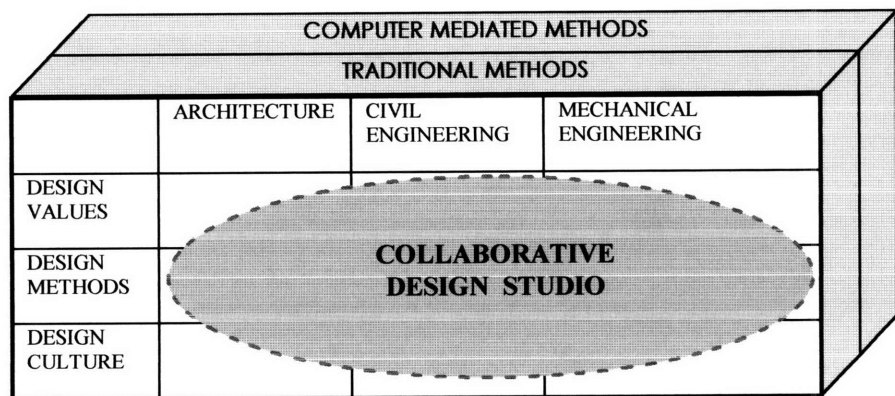


Figure 10: Collaborative Design Studio Methodology

Students were organized

in inter-disciplinary design teams, with students from each of the design disciplines represented in each of the teams. Design problems intended to highlight issues of all three disciplines were pursued during the course of the studio. A series of lectures and workshops discussing a range of engineering issues, conducted by faculty and experienced professional engineers, presented supporting techniques and issues. An integrated suite of computing software tools was developed to support the design and analysis activities of the three disciplines. At the beginning of studio, little was known about an appropriate model for the actual design activities and interactions between collaborators. Studio participants were generally aware of the traditional architectural model, with the architect serving as primary designer and engineers providing supporting expertise, but this model was discouraged during the studio. Rather, the studio sought to develop a working collaborative methodology integrating both architectural and engineering design expertise throughout all phases of the design process. Day to day coordination and working methods of the design teams were largely left up to the student designers. The students were asked to document their methods of collaboration and the decisions that had been arrived at.

## 2.Design Communications Infrastructure

Over the course of the studio, use was made of a suite of communications technologies which are currently being developed at MIT as part of the Design Studio of the Future initiative.

This communications infrastructure is built on several assembled networking technologies, including a

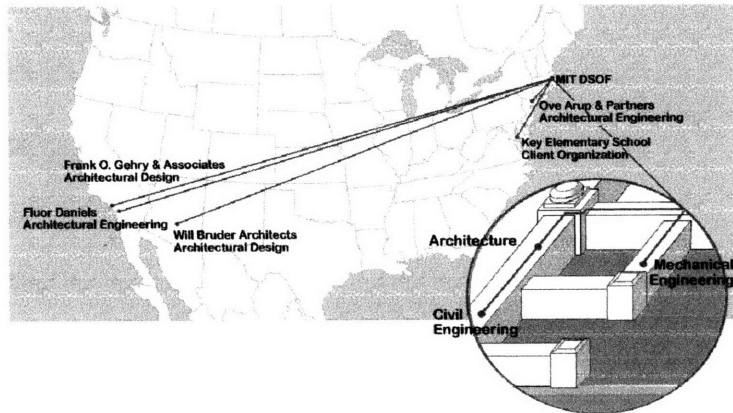


Figure 11: Design Studio of the Future Communications Network

TCP/IP based data network with gateways to the Internet, a campus wide digital telephone network tied to the international ISDN network, and a switched analog video network devoted to broadcast quality video conferencing communications. These communications links (Figure 11) tie together the computing and design resources around the MIT campus, including the Departments of Architecture's design studios, a design computing research center located in the Department of Civil Engineering, and the Department of Mechanical Engineering's prototyping facilities. These networks furthermore extend MIT's studio network to other design resources around the country. The DSOF studio network currently has five installed external sites: two in internationally acclaimed architecture studios, two in building engineering firms. A fifth external site is located at a studio "client organization" - an inner city K-12 school located in Washington, DC. These external connections support a flow of design ideas and expertise between MIT and the professional world, allowing the expertise of practitioners to be accessed by the student teams, and providing a means by which the studio computing / communications infrastructure can be interacted with and evaluated by practicing architects and engineers.

## a) Asynchronous Communications Support

Lotus Notes was introduced into the studio in order to support the asynchronous communications within the student design teams and between students, faculty, and professionals.

Figure 12 shows the basic organization of

databases utilized in the studio. The top row of database icons contain general studio support

information and utility databases, including a database linking to resources on the World Wide Web. The second and third rows of databases contain student project data.

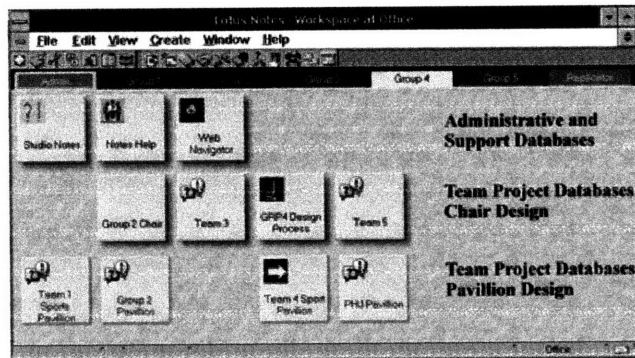


Figure 12 : Lotus Notes Design Database - Overview

A database of course information was developed, providing a central repository for studio wide communications. Figure 13 shows some of the information in the studio course notes database, and demonstrates the organization of information. The top left panel of Figure 13 shows an overview listing of the entries in the database. The course

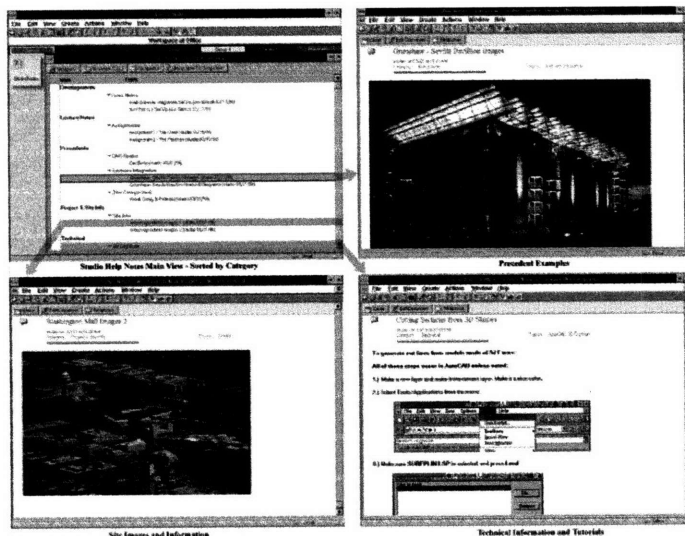


Figure 13: Expanded Course Notes Database

notes database contains a variety of information

relevant to all of the student team projects, including precedent design examples, site information, and technical help documents. Other information in this database included lecture notes, assignments, and project briefs.

Individual project databases were developed by the student teams. These project databases served several functions in the studio. First, the databases functioned as a communal “sketch book” - a place where students could store results of digital design explorations. Team members could review the work being developed without having to meet face to face. Second, the databases were utilized as a means for organizing and delivering presentations to local and remote audiences. During these presentations, students would usually present the pages in slide show format, stepping through the images in the database while discussing the material being presented. During juror or faculty response, particular images could be revisited by selecting the page from a view listing. The databases similarly served as an archive of student work conducted over the course of the term. The information generated by the students teams, and the corresponding structured slide show presentations of this material, provide a permanent record of all digital work from the studio.

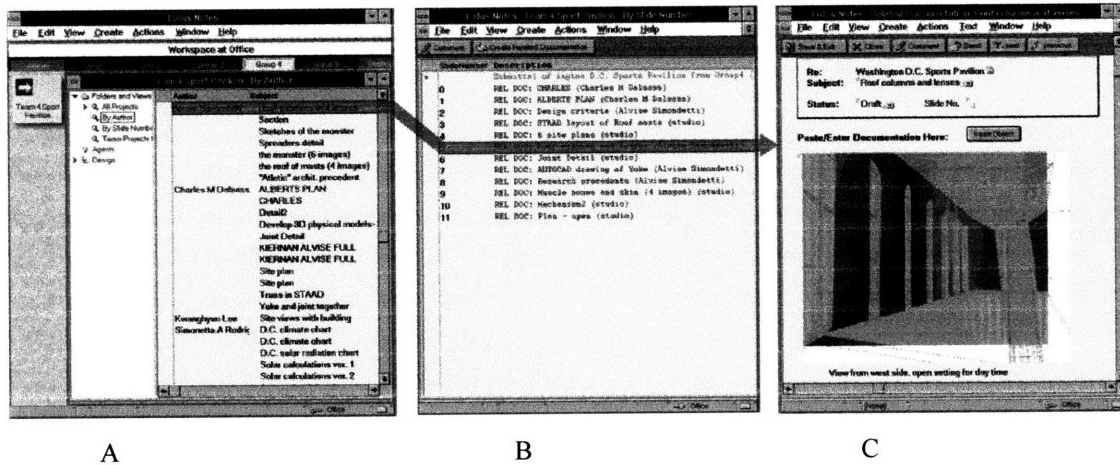


Figure 14: Expanded Team Design Database

Figure 14 shows one of the team project databases, with information viewed in two different ways, corresponding to two different communication activities. Figure 14A shows the project information organized by student entering the information, allowing faculty to view the work of individual students within the project. Figure 14B shows the same information organized into a sequence for presentation.

Selected entries in the project database have been assigned a number in the presentation. The listing automatically organizes the selected Notes into a slide show, and hides the entries which have not been selected. Figure 14C shows a Note referenced by both of the two listings.

Results of using the Lotus Notes groupware within the Collaborative Design Studio were mixed. While several design teams embraced the use of the groupware based approach in developing their designs, other groups felt encumbered by elements of the environment, including the difficulty of mastering its user interface, and perceived limitations in formatting the visual appearance of the presentation in comparison to the capabilities afforded by the World Wide Web. Some teams gravitated to use of the Web in organizing presentations for synchronous communications sessions.

Notes additionally provides mechanisms for comments and annotation to be added to individual entries by other team members, faculty and critics. It was anticipated that these annotation capabilities would become an important means for communication with the students by faculty and professionals. However, this potentially useful feature was not utilized as fully as expected during the studio, partly due to the extensive cultural awareness of the already deployed campus wide email facilities. It should also be noted that in the interim since the end of the studio, Notes' Web integration capabilities have been improved. Notes databases can now be accessed from any standard Web browser. It is anticipated that these capabilities for further integration of the design database system within the existing campus computing culture would have resulted in a smoother road to its adoption by the studio community.

## **b) Synchronous / Asynchronous Systems Integration**

The broad range of issues addressed in the studio necessitated the use of a correspondingly large set of computer based methods. The current state of the design industries is such that a wide variety of computing options exist for approaching a given design issue. The advanced level students comprising the majority of the studio participants had already had experience with one or more CAD applications, and in many cases preferred using a particular application with which they were familiar. Students were encouraged to bring their expertise in particular computing resources to the studio. At the same time, the wide range of computing options posed a problem for achieving an integrated solution satisfying the communications requirements of the studio. To satisfy the base requirements for the studio, a core, integrated set of computing and communications tools was developed. Auxiliary technologies were integrated into this framework to varying degrees. At the minimum, results generated by auxiliary tools could be integrated through the use of standard text and image file formats, transported from the applications on which they were generated to database repositories over wide area networks.

The integrated computing environment can be considered in terms of several layers of computing technologies (Figure 15). At the lowest layer, computers were linked by two major communications backbones: a TCP/IP based Wide Area Network - linked to the Internet - provided switched data packet communications for off line transmission

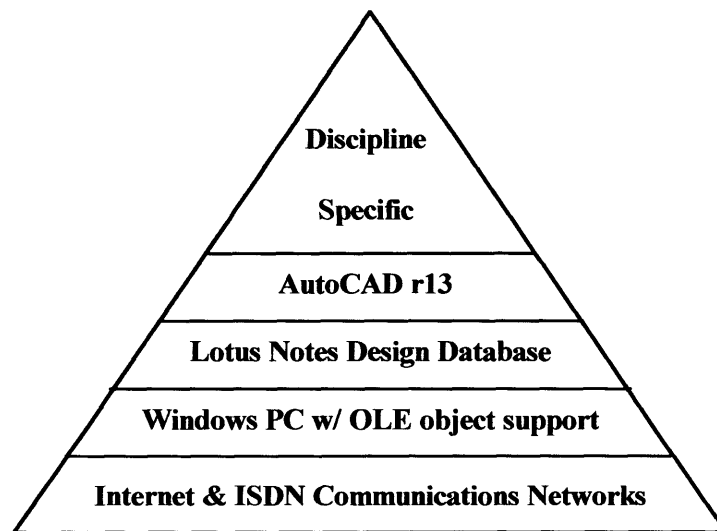


Figure 15: Design Studio Core Computing Infrastructure

of data between computing applications and data storage and retrieval services. During synchronous communications, an ISDN digital telephone network provided dedicated, steady stream communications between collaborators. The Windows 3.1 and NT operating systems operating on Intel Pentium based PCs provided the next layer of integration, by offering a unifying user interface for CAD, imaging and analysis tools. The Object Linking and Embedding (OLE) technology, provided by the Windows operating system, allowed object level integration of tools. Application sharing technology allowed the design database and embedded applications to be synchronously shared between collaborators operating remotely located machines. Finally, at the highest levels of the environment, applications embedded in AutoCAD r13, an OLE compatible Windows application, provided discipline specific CAD applications.

### **c) Design Studio Communications Activities**

The assembled suite of computing and communications technologies were employed during the studio to support two principal types of communicative activities:

- *Intra-group design documentation and communication.*

The design databases served as a means for storage and structuring of design information related to the student group projects. Use of the communications capabilities provided was limited, perhaps for two reasons. First, the fact that the group members were co-located, and that significant amounts of scheduled studio time was available to meet and discuss in person, removed the necessity of communications through digital means for the bulk of group members' interactions. Only late in the studio, as pressures from other classes began to mount and less meeting time could be scheduled, did some groups begin to comment that they could see the designs developing in the database, as fellow group members added information. Even then, commenting and response capabilities of the design database were not utilized. These experiences underscore the findings of [Grunding, 1988], that technologies which require significant changes in



existing modes of work and interaction will encounter resistance, even if technical advances provide additional capabilities.

Groups did successfully utilize the groupware database as a means for the incremental storage and consolidation of design information. The OLE object embedding capabilities and capabilities for cutting and pasting screen images directly from CAD models into the database were perceived by some groups as an improvement over the more labor intensive means for the incorporation of design media in World Wide Web pages. However, this benefit was in no small way offset by the added complexity of the groupware user interface, and the limitations of customizing linking and page layout relative to the World Wide Web.

- *As a means for enabling synchronous communications with remotely located experts.*

This use of the studio's computer based communications proved quite successful. The design databases were utilized in this context for assembling and subsequently presenting design data to remotely located experts. The capabilities provided by the Notes application allowed results from a variety of CAD applications to be integrated within a common, relatively easy to use interface. Integration between this interface and application sharing capabilities in turn allowed the data to be accessed, displayed and discussed with the remotely located experts. The assembled data was transmitted to the remote sites via two means. First, scan conversion of the local computer display was transmitted to the remote sites as a video signal (Figure 16).

The databased information was simultaneously transmitted using application sharing capabilities. This allowed a relatively poor quality image of the information to be immediately viewed and discussed with the remote participant, while a slower but more detailed view of the information was being transmitted.

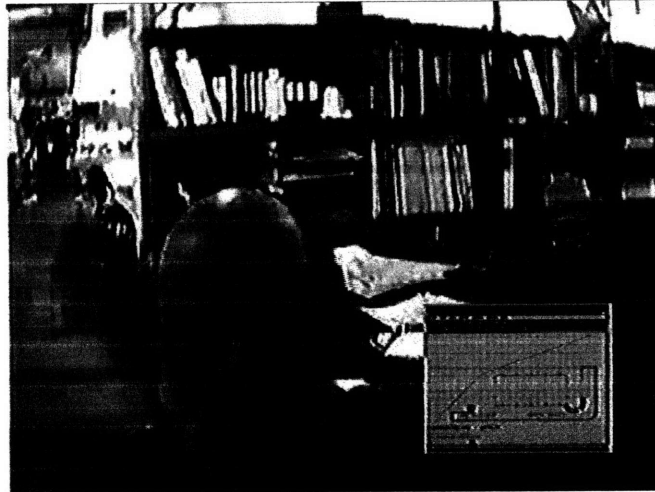


Figure 16: Interaction with Remote Expert - Video Capture of Database

In keeping with the overall studio philosophy, capabilities for the transmission of physically based information and interactions were also supported. Document cameras allowed for models and sketches to be captured as video signal, and transmitted using the video

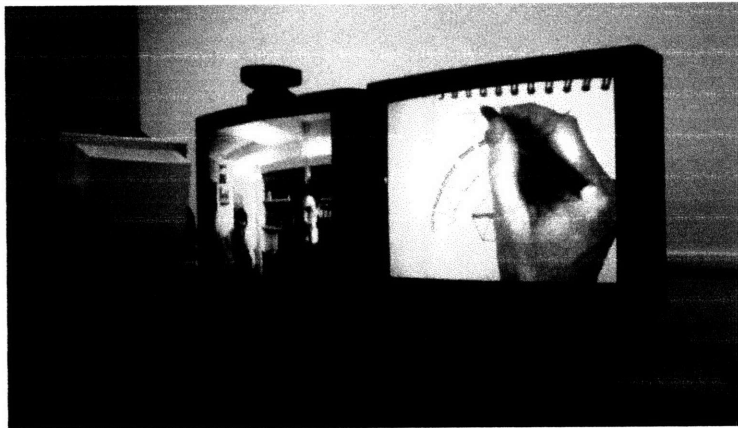


Figure 17: Transmission of Sketches During Remote Consultations

conferencing capabilities (Figure 17). Provisions for the integration of physical media in the communications allowed for the student presenters to make gestural references toward the media being presented, orienting the viewers to particular aspects of interest within the media.

The communications links with remote experts were used in two ways over the course of the studio. First, informal “virtual desk crits” were carried out on a weekly basis during the second half of the term. This allowed the remote critics to participate in the ongoing development of the student projects. Equally importantly, the communications links provided access to the day to day activities of the participating

professional offices, allowing access not only to the expertise of the individual principal designers working with the students but to the larger pool of experts working in the offices as well. These sessions allowed relatively informal interactions between the student designers and remote critics. Control of the communications technologies was left to the students and practitioners. The technologies could be experimented with by all parties, and technical interruptions were of little consequence to the proceedings.

#### **d) Final Review**

Design communications were similarly utilized during focused design reviews, linking the student design teams with jurors at both local and remote sites. The studio's final review presented an opportunity and challenge for integrating all of the elements of the studio. Architectural studio final reviews are quite formal, highly orchestrated proceedings, where the designers' work during the term is presented in an arena to an assembled jury or panel of experts. The students show their work to the jury in a formal presentation, and then accept criticism, and possibly defend their designs, in a second, more free form round table discussion by the panelists.

The unique elements of the studio presented particular challenges for the orchestration of the final review proceedings. The professionals who had been affiliated with the studio throughout the course were encouraged to participate in the final review proceedings. The final review's organization needed to address the unique qualities of synchronous communications in such a way that remote jurors were as fully engaged in the proceedings as possible. At the same time, it was important that the quality of the review proceedings was not sacrificed in allowing for remote participation.

During traditional reviews, design work comprised of two dimensional drawings is “pinned up” on presentation boards located behind the presenter. The entire body of work is available for discussion throughout both phases of the presentation. This allows the designer to draw from the full body of work in a relatively unstructured way, comparing results evidenced in one drawing with information from another drawing. Similarly, reviewers have the full body of work available throughout the discussion.

The studio’s focus on the development of computer based information presented a need for departure from this model. Since a significant part of the designs were developed in digital format, it was necessary that suitable arrangements be made for the presentation of this material in its original digital form. The variety of computer based media that the students had developed over the term - images, simulations, animations and physical models - necessitated that the assembled technologies be as flexible as possible in accommodating the diversity of student work. Again, the limitations imposed by the participation of the remote jurors reinforced the requirement that these jurors be able to follow along with the proceedings, and receive the highest quality presentations possible in a format similar to that being presented to the local jury. At the same time, physical presentations - in particular the physical prototypes that had been generated over the course of the studio - needed to be supported as well.

It was particularly important that the students presenting were as comfortable with the format as possible. Final reviews are inherently stressful occasions for the students, who may be tired from spending long hours doing final preparations of their work, and may be anxious about presenting in front of audiences. While the students had previous experience in the traditional review format, the inclusion of untraditional technological elements into the design review format presented somewhat unknown territory. An effort was therefore made to make students as comfortable with these elements as possible - through previous video conferenced desk crits, by assisting the students in structuring their presentations to allow for electronically

mediated communications during the review, and by making the technological elements as unobtrusive, failure proof and “user friendly” as possible during the review.

The organization arrived at (Figures 18 and 19) drew heavily on the arena format of traditional juried reviews, with several notable differences. First, video capturing of the proceedings for the remote jurors’ participation necessitated that elements of a video recording studio be integrated into the arena. This included the use of stage lighting, microphones and video cameras targeted at the presenters, the information being presented, and the locally assembled jurors. Two manned video cameras with zoom capabilities were “cross positioned” to capture the activities of the presenters and the local jurors. The main camera captured the presenters and their interactions with the digital media and physical models.

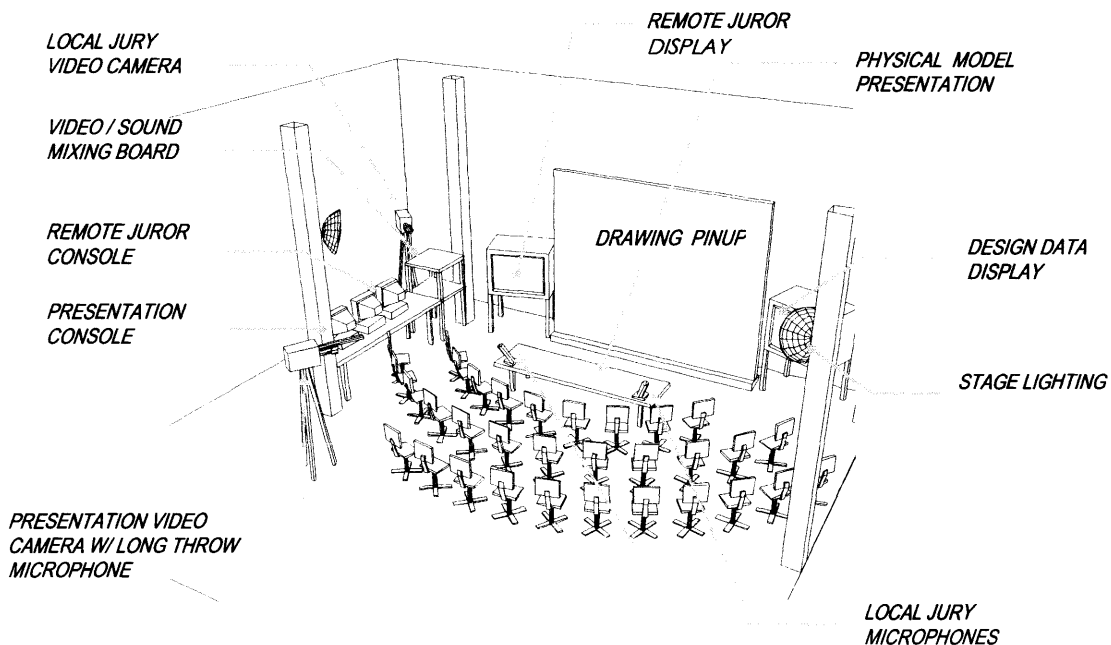


Figure 18: Final Review Arena Layout

Presentation of the digitally based media was controlled from a computer off stage, in a central control area. This presentation could be either controlled by the technical staff, or by one of the student team

members. A large screen video monitor was placed in the stage area, providing a prominent location for the presentation of digital media. The presenters were able to interact with this display, by pointing at elements of their designs on the video display. This interaction was captured by the main camera and transmitted to the remote jurors. Physical prototypes were likewise captured by the main camera for presentation to the remote jurors.

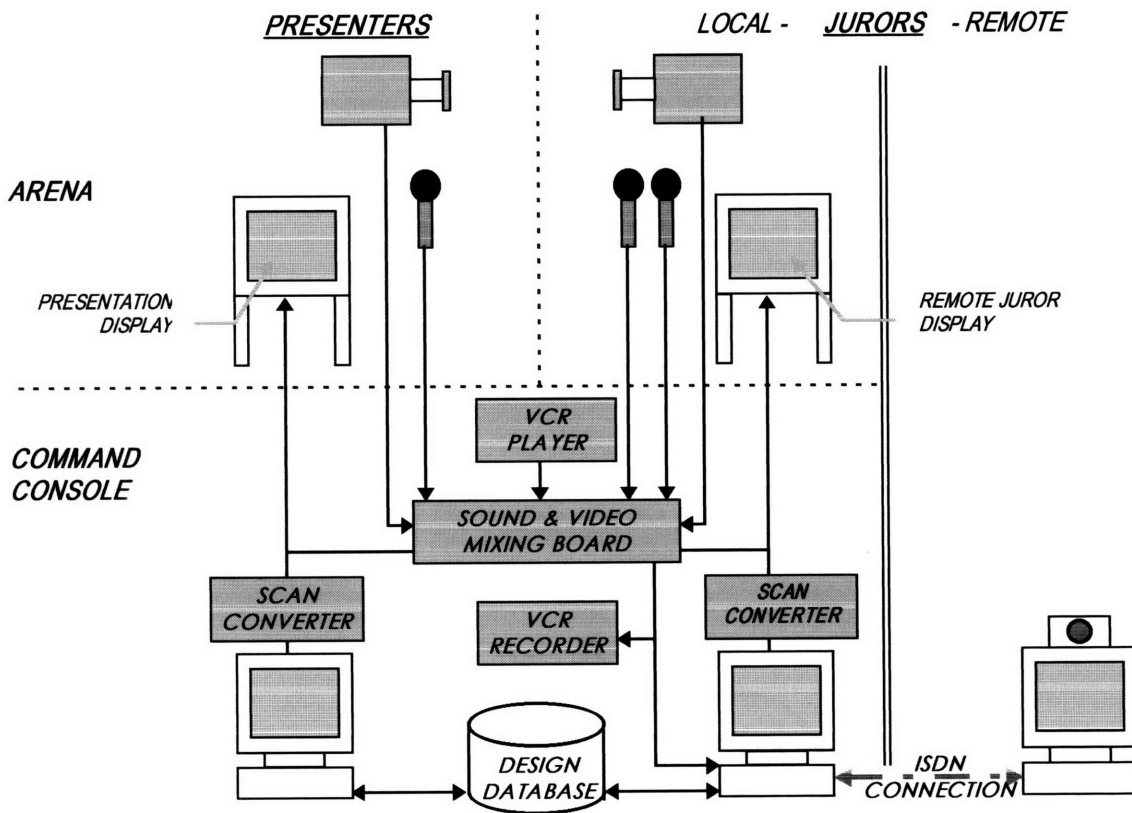


Figure 19: Final Review Technical Schematic

The local channels of information (presenter video and audio, jury video and audio, digital presentation) were mixed using a conventional video editing system, and routed to the audio and video inputs of the desktop video conferencing equipment, also located in the control area. The remote jurors' interactions were fed from the video conferencing equipment to a second large screen video monitor, and through an audio amplifier to external speakers located on the presentation stage. Additionally, the digital presentation

was transmitted in digital format to the remote jurors via application sharing technology. This allowed the remote jurors to view the presentations in a higher quality form than that allowed by the mixed video presentation, and to interact with the presentations, moving to areas of interest in the presentation.

The use of design databases throughout the term was drawn upon in developing the student presentations for the final review. In addition to making other final preparations, students were encouraged to develop an explicit strategy for organizing the presentation of their digital material. This organization could be “hard-coded” into the database, by creating a custom, sequenced listing of the information selected to be presented during the review. During the presentation, the students stepped through this information in the previously developed sequence. During discussion, the listing allowed rapid access of a desired pieces of information, which could be brought up to support discussion of a particular issue.

There are both obvious drawbacks and advantages offered by this approach. The limitations of “screen real estate” - the amount of information that can be shown at any one time on a monitor - limits the ability for the presenter or critic to draw on the full body of design information during discussion. In order to minimize the impediments imposed by this limitation, it is imperative that design information be quickly retrievable from the database at the request of review participants. Several presenters opted to print out and pin up selected views of their designs that were felt to be critical for providing the context of the design.

There are perceived to be benefits gained from utilizing a more structured presentation format afforded by the digital medium. In traditional design reviews, students frequently give little thought to the sequence in which they will present the prepared material. During the presentation, the student can have difficulty delivering the key issues at play in the design, or lose focus and have difficulty presenting at all. The inherent structuring of the digital presentation requires that students develop a chronology and organization

to the material that they present. In many cases this can serve to focus the designers thoughts about what are the key issues leading to their particular designs, and help the student to construct the argument supporting these decisions.



Figure 20. Final Juried Review Proceedings

During these sessions, the smooth and synchronized procession of events demanded highly coordinated control of the technologies. For this reason, control of the equipment, including accessing of information from the databases and operation of cameras, was left to technical personnel.

### **3. Results and Conclusions**

The ongoing use of computer based communications throughout the studio provided a number of interesting experiences and observations. In particular, the use of relatively sophisticated databasing applications to support intensive, team based design represented unknown territory before the studio was conducted. A particular challenge for the future continues to be providing more intuitive means for the control and customization of technologies which have been developed without the designer in mind. The power of groupware technologies for fostering design communications is offset by lack of ability to control the visual



appearance of the presentation in these environments, in comparison to the relatively high degrees of visual control offered in Web based presentations. The groupware system provided a relatively easy means for incorporating data into the database. This ease of assembly of information was, however, offset by the complexity of the groupware application's user interface, relative to that of a Web browser.

Our experiences to date with groupware as a means for supporting asynchronous communications among designers have thus been inconclusive. One obvious factor in our experiences has been the relative ease of direct, face to face communications by the co-located designers in the studio, and the cultural acceptance of other, less sophisticated information sharing capabilities provided by the standard campus wide computing network.

Experiences with communications between campus based designers and remotely situated experts in professional offices have been much more encouraging. The communications links provided a means for both accessing the expertise of these individuals, as well as a means by which students could "get to know" the individuals and their professional cultures. Within this context, the integrated approach to communications has served its function quite well.

## **B. Model for Communications Technologies in Professional Design**

### **1. Introduction**

The academic based experiments discussed in Section VI.A. demonstrated the viability of emerging computing communications technologies to support geographically distributed design activities. The communications links to professional firms provided a means for the studio's professional associates to evaluate this use of communications technologies. One of the firms was sufficiently convinced of the demonstrated technological approach to begin development of similar capabilities to support their professional practices. This section discusses efforts to date to develop communications technologies to support this firm's professional design activities.

### **2. Professional Design Communications Requirements**

The requirements for professional design communications are significantly different than those of their academically based counterparts. The use of CMC technologies in the professional setting raises a number of concerns for the professionals who are considering bringing these technologies into their practice.

The firm engaged in developing these capabilities is an internationally recognized, medium sized architectural design firm. The firm is distinguished in designing quite unique buildings, often employing curvilinear forms and unusual materials in their designs. The unusual forms employed by this firm resist traditional means of design documentation. The firm has developed a unique design method to generate their distinctive building forms. In this process, much of design activities occur through the manipulation of small scale physical models. When the essential form of the building has been established in the physical model, the design is translated into a computer based surface model using a three dimensional digitizing arm. Sections are cut through this surface model, providing outlines of the building surface in two

dimensions. Conventional plans and sections are developed from these outlines. The firm also employs some computer aided manufacturing of the materials used in the buildings.

The complex nature of the building forms places unusually high demands on coordination and communication, both with the firm's clients and with their consultants. Many questions arise during development of the design which must be incrementally clarified. Without the use of advanced communications technologies, these questions must be addressed through face to face meetings. Breaks in communications between meetings result in a slowed overall design process.

The firm's reliance on physical models as the definitive description of the design during concept development places unique demands on the firm's communications methods. Design discussions frequently occur through interaction with a physical model. This means that either discussions must be conducted at the firm's office, or the models must be transported to other meeting sites. The firm already utilizes a fiber optic video camera, to allow the interior spaces of the model to be viewed. Although computer based models are used in the process of developing construction documents, these models are not considered to be acceptable for design presentations.

The firm's principal associates see computer mediated communications as a way to facilitate the increased level of coordination with clients and contractors. A strategy has been developed for using CMC technologies to assist in all phases of one building project. The project has an accelerated project schedule, and a fixed opening date for the facility. Some of the factors important to the development of the CMC support strategy for the project are:

- The technologies utilized must provide demonstrable project cost and time savings at each phase of the project.

- A staged deployment strategy must be developed, where technologies are deployed incrementally to address the emerging communications requirements of the project.

### 3. Development Strategy

This section discusses details of the communications strategy developed to support the firm’s design practice. The strategy is organized by a three phase design process



Figure 21: Professional Practice Communications Approach Process Model

model (Figure 21). The entire building development process is expected to last 19 months. Different communications requirements have been identified for each phase of the design process. Possible technical approaches to addressing the support of these phases’ requirements are identified.

The following, general support requirements have been identified for all phases of the project:

- Face to face, real time discussions , including viewing and hearing of discussion participants.
- Gestures toward design information, including physically pointing at particular elements in design information, red-lining and annotating
- Asynchronous storing, accessing and transferring of drawings
- Computer model generating, viewing and manipulating
- Coordination of collaborators activities

## **Phase I. Conceptual Design and Design Development**

- Phase Duration: months 0 - 3
- Usage requirements: 1 to 2 sessions per week.
- Cost benefits: reduced travel expenses by all parties.

### **A. “Face to face”, real time discussions between project participants.**

Discussions must be “multi-point” - several sites will participate in the discussions. Initially, discussions must be possible simultaneously between architect, client and construction manager. During subsequent phases, communication with other project participants such as structural engineer and display designers will be required.

Feasible technical approach: multi-point or “Hollywood Squares” video conferencing

### **B. Presentation of building form during conceptual development**

During Phase I, the architect will need to present aspects of the building form to the client and project manager, so that decisions relating to the overall form can be made. Presentation by the architect to the client and construction manager will be principally through presentation of a physical building model. The architect will achieve this through real time display of the building model by video camera, or the presentation of previously prepared and videotaped sequences.

Feasible technical approach: auxiliary inputs to video conferencing system.

C. Client interaction with the building form.

Client and construction manager must be able to interact with the building form, indicating particular elements of the building model being presented in I.B. This interaction requires capabilities for pointing at and / or drawing on the images being viewed.

Feasible technical approach: Shared drawing “whiteboard” interaction with captured stills from video conferencing.

D. Discussion of physical documents

Architect, client and construction manager must be able to present physical, two dimensional documents for discussion by the other parties, with similar interaction requirements as I.C above.

Feasible technical approach: overhead mounted document camera with auxiliary input into video conferencing system, shared whiteboard from I.C.

E. Discussion of computer based media.

Architect, client and construction manager must be able to present additional computer based documents for discussion by other parties, such as text documents, spread sheets, computer based drawings and presentations. Similar interaction requirements as I.C above are required.

Feasible technical approach: application sharing technologies with sketching / annotating capabilities.

F. Archiving of on-line proceedings.

Discussions occurring through I.A -I.E above must be archived to provide a record of design decisions.

These records must in turn be retrievable during subsequent discussions.

Feasible technical approach: video recording in analog or digital format.

## **Phase II. Design Development**

- Phase duration: months 3 to 7
- Usage requirements: 1 session per office per day.
- Cost benefits: accelerated decision making process, reduced travel costs.

By Phase II, overall formal criteria for the facility will have been established. The specific details of the design will in turn be developed. This use will require communications of greater frequency, usually between fewer parties. These discussions will typically be point-to-point communications between client, architect, civil engineer, construction manager, display designer, etc. Communications requirements will include I.A - I.F above, plus the following:

### A. Asynchronous communications

Message sending and archiving, including transmission of 2D computer based images will need to be supported.

Feasible technical approach: Email messaging system with multimedia object support.

### B. Communications scheduling

The volume of details which will need to be resolved during this phase of the project will necessitate improved abilities for scheduling and initiating real-time video communications.

Feasible technical approach: Video conferencing scheduling and initiating capabilities integrated in messaging system.

### C. Communications, storage and retrieval of computer based design data

During Phase II, the generation of computer based design data by all parties will be increased relative to Phase I. A method for storing, retrieving and discussing this data must be developed which integrates into the professional practices and computing infrastructure of all parties.

During this phase, archiving issues will be enhanced. Mechanisms must be arrived at by which decisions made through digital communications are certified as being committed to by communicating parties.

Feasible technical approach: groupware database integrated with email and application sharing capabilities.

Paper based or electronically “signed off” transmittals in conjunction with data sharing.

### **Phase III. Building Construction**

- Phase duration: months 7 to 19.
- Usage requirements: 2-3 sessions per office per day.
- Cost benefits: significantly accelerated decision making during construction phase resulting in large reductions in construction costs.

During this phase of the project, interface with the physical elements being built on site is expected. Again due to the complexity of the proposed facility, issues will frequently arise on site for which construction managers will need additional input from the client, architects, engineers and back to the construction



manager's home office. Communications requirements will include all those specified for Phase I and II above. Additional requirements:

A. Direct visual access to construction site.

Client and architect will require easy and rapid accessibility to the construction site activities, in order to ensure that the facility is being built in accordance with their expectations. Personal communications between parties on and off the construction site will be required, as per I.A above. Additionally, visual access will be required to all areas of the construction site, to allow for inspection and discussion of details under construction.

Feasible technical approach: Video conferencing installation at site per I.A - I.D above. Portable camera, video camera / recorder or digital camera for inspection of outlying areas of site.

B. Transmission of design data to the site.

Designed responses to developments occurring at the construction site will need to be transmitted to construction personnel. This data will principally be in the form of 2D and 3D detail drawings, or text based schedules.

Feasible technical approach: Data storage, transmission, retrieval and discussion capabilities as per II.C above, in conjunction with on site printing or facsimile capabilities.

#### 4. DESIGN NETWORK SPECIFICATION

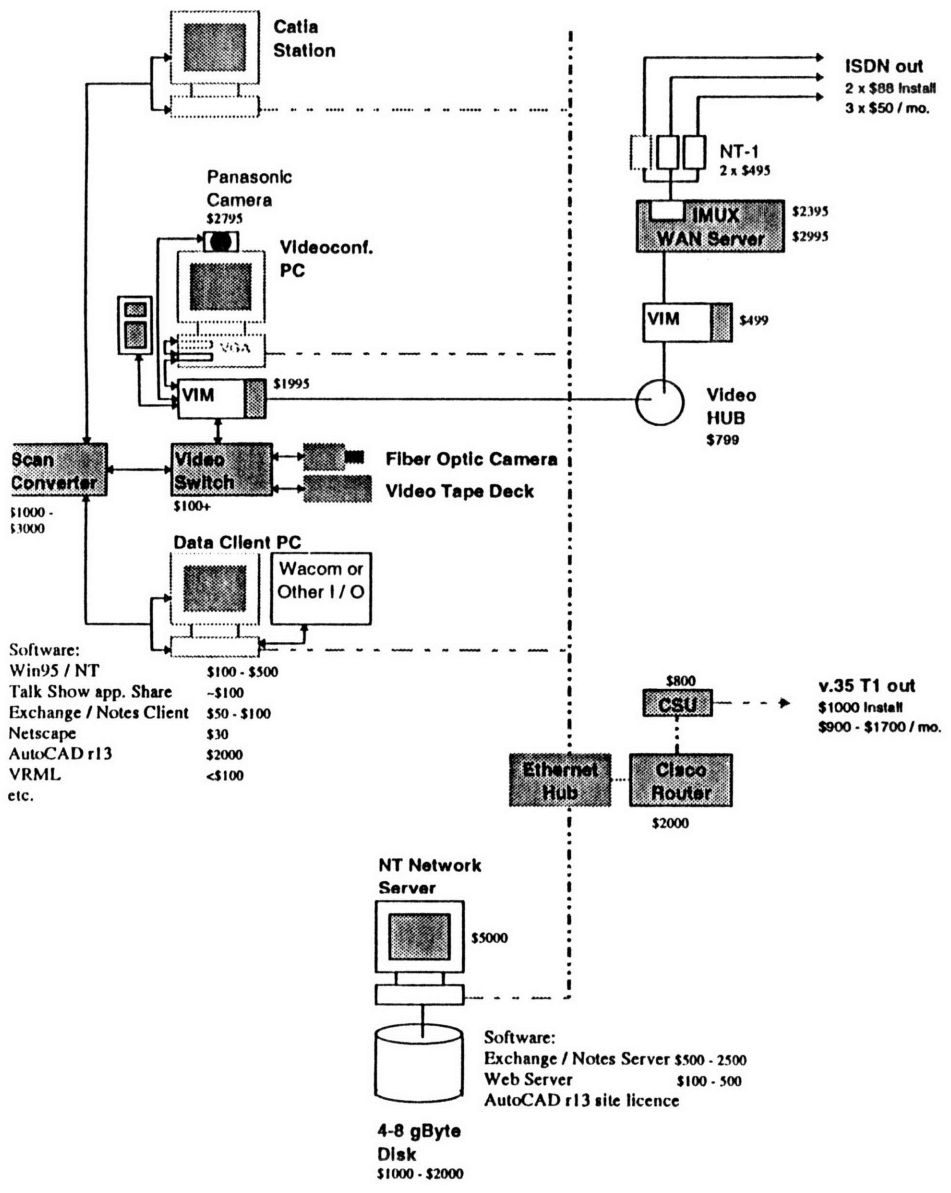
Table 1 provides a specification for a set of technologies offering a basic set of capabilities for remote design collaboration. A diagram of this configuration is shown in Figure 22.

|   |
|---|
| <p><b>Designer / Engineer / Client Workstation - PC Platform (Preferred)</b></p> <ol style="list-style-type: none"><li>1. Computer<br/>100 MHz Pentium PC<br/>Windows 95 Operating system<br/>32 mByte RAM<br/>2 GByte hard drive<br/>24 bit graphics card<br/>Sound card<br/>Microphone</li><li>2. Communications channels (per site):<br/>ISDN digital telephone line<br/>Internet access (min. 100 Kbit to all other sites), simultaneous<br/>with video conferencing interaction (may require additional ISDN line)</li><li>3. Video conferencing<br/>PictureTel PCS-200, or<br/>Intel ProShare (all sites should select the identical system)</li><li>4. Application Sharing Software<br/>LiveTalk or<br/>Intel ProShare( currently included with Lotus Notes)</li><li>5. Design Databasing<br/>Lotus Notes r4 client<br/>Netscape 3.0 Navigator Gold<br/>Additional Netscape plug ins for viewing VRML, CAD, video data</li><li>6. Application Software<br/>Microsoft Office<br/>AutoCAD r13 c4<br/>Adobe Photoshop or<br/>Lview Pro (share ware)<br/>Additional Web authoring software</li></ol> |
| <p><b>Designer / Engineer / Client Workstation - Unix Platforms</b></p> <ol style="list-style-type: none"><li>1. Computer<br/>Any Unix Workstation - SGI Preferred</li><li>2. Communications channels (per site):<br/>Internet access (min. 100 kBit to all other sites)</li><li>3. Video conferencing optional- Basically only Internet based available<br/>Video camera<br/>Video capture card<br/>Microphone<br/>Speaker<br/>Sound card<br/>Internet based video software<br/>NV (network video)</li></ol>   |

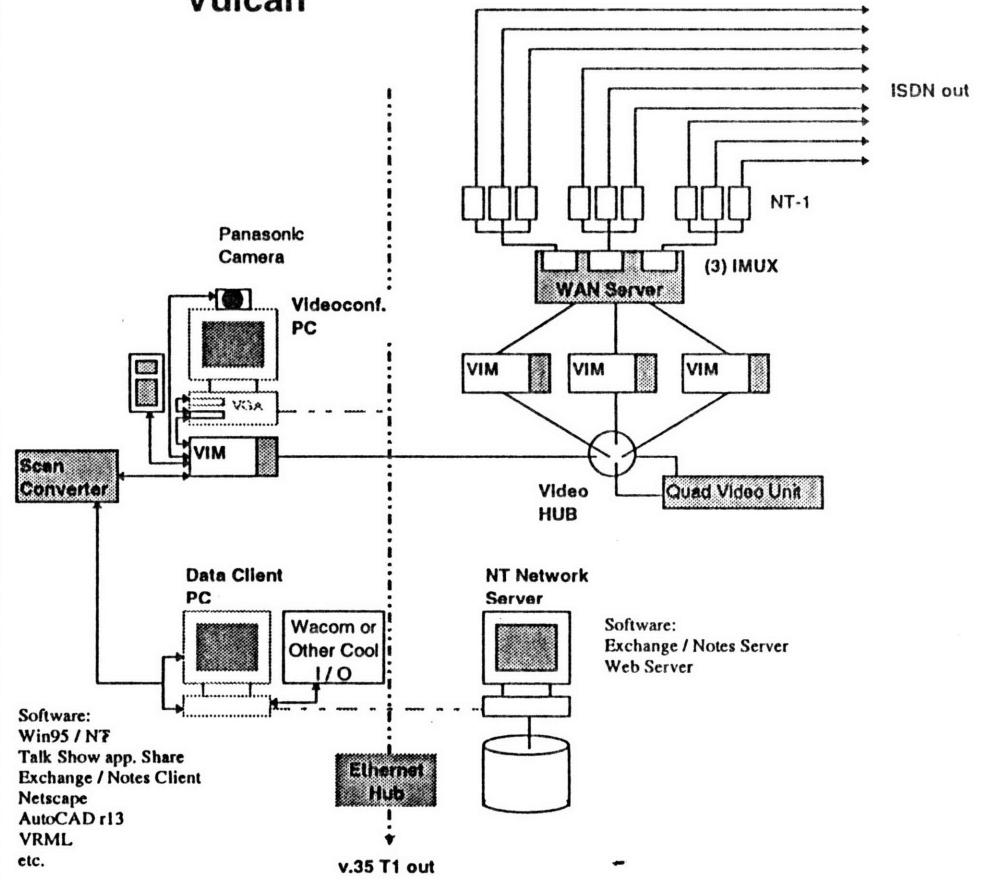
|  |
|--|
| <p>InPerson (SGI)</p> <p>4. Application Sharing Software<br/>NCSA shared drawing board<br/>Web page synchronization</p> <p>5. Design Databasing<br/>Lotus Notes r4 client<br/>Netscape 3.0 Navigator Gold<br/>Additional Netscape plug ins for viewing VRML, CAD, video data</p> <p>6. Application Software<br/>AutoCAD r13 c4<br/>Xview image editing shareware</p>   |
| <p><b>SERVERS - 1 Per Architectural or Engineering Office</b></p> <p>Note: Server may also function as file / application server, but Notes / Web communications performance may be affected</p> <p>1. Computer<br/>100 MHz Pentium PC<br/>Windows NT Operating system<br/>32 mByte RAM<br/>4 GByte hard drive min.</p> <p>2. Communications<br/>Internet access<br/>Email server - Lotus Notes mail may be sufficient</p> <p>3. Design Database<br/>Lotus Notes Server r4<br/>Web Server<br/>Note: if Unix machine available, Web server running on Unix preferred<br/>Web based collaboration software (e.g. HyperNews, Collabora)</p> |
| <p><b>Local Area Network Configuration</b></p> <p>Main performance required: shared drive between clients and Web server<br/>Additional performance: application serving<br/>Possible options:</p> <p>1. Microsoft NT Server w/ Microsoft network - either Windows for Workgroups, NT or Win95</p> <p>2. AFS w/ NT connection, PCs running Microsoft network</p> <p>3. AFS w/ Novell LanWorkplace</p>  |
| <p><b>Additional Features</b></p> <p>Video Scan Converter<br/>Additional Zoom Video Camera<br/>Video Recorder<br/>Document video camera<br/>AutoDesk 3D Studio - for VRML model generation<br/>Intergraph with shared model viewing</p>  |

Table 1: Professional Design Communications System Specification

# FOGA



# Vulcan



# Minimum Installation

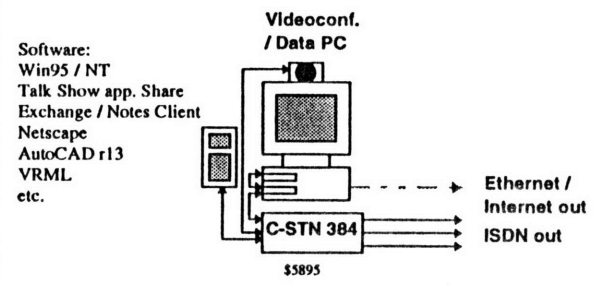


Figure 22: Professional Design Communications System Schematic

## VII. CONCLUSIONS

This thesis has outlined a methodology for developing computer mediated communications systems for application to design activities. The communications requirements of design practices are significantly more complex than those of many other business practices, due largely to the increased requirements of sharing sophisticated design media.

Different design processes will require radically different computational support strategies. In developing design communications systems, benefits can be achieved by considering the structuring of the design process: the different phases which comprise the overall process, the activities occurring in a given phase, and the traditional communications mechanisms which been developed to support these activities. Once this organization has been identified, corresponding communications technologies can be developed to support the design process' communications requirements.

The case studies which have been undertaken at MIT during the past two years have shown that the use of sophisticated computer mediated communications systems can improve the effectiveness of design processes and the quality of products which are developed. CMC technologies can assist in fostering communication among designers with differing professional backgrounds, and provide a means for improved management and coordination of the overall process in which these designers participate.

The future of CMC systems in design looks promising. Professionals' awareness of the potential benefits of computer based communications continues to increase, while prices for entry level CMC systems continue to drop. At the same time, effective of computer mediated communications requires some changes to traditional design processes, largely due to the openness of information exchange which these systems suggest. The full resolution of these issues in professional practice remain unresolved at this time. It is suggested that joint academic / professional design projects can have significant impact on the adoption of CMC technologies by professional design practices, by providing hands on experience in the use of these technologies to practitioners and students alike.

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