Collaboration and Coordination in Architectural Design: approaches to computer mediated work

Gross, M. , E. Do, R. McCall, W. Citrin, P. Hamill, A. Warmack, and K. Kuczun.

TeamCAD symposium on collaborative CAD

Graphics, Visualization, and Usability Center, Georgia Tech

May 12-13, 1997. pp 17-24.

design machine group
University of Washington
Seattle WA USA 98195-5720
http://depts.washington.edu/dmachine

Collaboration and Coordination in Architectural Design: approaches to computer mediated team work

Mark D. Gross[3], Ellen Yi-Luen Do[2], Raymond J. McCall[3], Wayne V. Citrin[1,3],Paul Hamill[1], Adrienne Warmack, Kyle S. Kuczun

Sundance Laboratory for Computing in Design and Planning, College of Architecture and Planning, University of Colorado

[1] and Department of Electrical and Computer Engineering, University of Colorado, Boulder, CO
[2] and College of Architecture, Georgia Institute of Technology, Atlanta GA
[3] and Institute of Cognitive Science, University of Colorado, Boulder, CO

Introduction: collaboration in architectural design

Virtual Design Studio

In 1993 and 1994, instructors and students of architecture at several universities around the world* collaborated briefly on two "virtual design studio" projects. Using off-the-shelf technology of the time—email, CU-See-Me internet video, international conference calls, and exchange of CAD drawings, images, and Quicktime animations—this ambitious project explored the possibility of bringing together diverse members of an international design team together to collaborate on a short term (two week) project. Central to the "Virtual Design Studio" was a 'digital pinup board', an area where participating designers could post and view drawings and textual comments; video links and email exchange provided the media for direct communication media about designs. A report on the project [21] makes clear that the process was not without technical difficulties: a significant amount of communication concerned scheduling and coordinating file formats; disappointingly little was devoted to discussions of design issues. Although it's clear that many of the minor technical problems that inevitably plague a forward-looking effort like the Virtual Design Studio will be solved in the near term, the project also reveals the need for research on software and design practices to make computer mediated design collaboration realize its attractive promise.

William J. Mitchell, Dean of the MIT School of Architecture and Planning, and a participant in the Virtual Design Studio experiments, identified four developing technologies that underlie the computer-mediated collaboration that the Virtual Design Studio experiment heralds. These are: pervasive computer networking, digital video, the integration of video with computation, and handheld wireless digital communication [18]. Mitchell sees these components changing the prevailing paradigm in computer aided design from traditional computer graphics involving a single designer interacting with a machine to construct CAD drawings and models, to a process of computer-mediated negotiation among multiple players.

Mitchell correctly identifies key hardware technologies that are making international design collaboration possible; most projects (including ours) in collaborative CAD do employ one or more of these technologies. However, the Virtual Design Studio project also makes it clear that effective design collaboration demands more than merely connecting the members of a team with the highest possible bandwidth. Successful collaborative design also requires attention to the organization of design process and product, that is, to the methods and representations used in design. In short, computer mediated collaboration will not succeed on the back of technology alone.

---

* Hong Kong University, Escola Técnica Superior d'Arquitectura de Barcelona, University of British Columbia, Washington University, Harvard Graduate School of Design, and Massachusetts Intitute of Technology.

Therefore to Mitchell's four technologies we add three observations about their effective use in collaborative design. First, the interface that a collaborative design system presents to its users is a critical determinant of its potential for success. Designers lack extensive and sophisticated computing experience; their productivity will correlate directly with the usability of the interface. Ideally, a collaborative design system should present as simple an interface as the designer's familiar pencil and paper. However, it must also make it easy for a designer to access the extended capabilities that computer support can provide: constraint checking, simultaneous work with (possibly remote) other designers, filing and indexing, iterative changes and versioning, etc. As drawing remains a primary means of communication among designers, we have begun there. In our discussion of synchronous collaborative work we discuss drawing as an interface to collaborative design.

Second, as designers work they produce a lot of data, and it is essential to find ways to capture, structure, and index this data so that all members of a team can use it. As one participant comments, "In the VDS project a mountain of files were generated by participants from different universities. It was a difficult task determining which and how some of these files related to each other. (Which floor plan goes with which section or surface model?)" [21] (Renato Garcia, p 34). More is needed than a public area where collaborators can post their work. Designers need to be able to quickly, easily, and in some cases automatically construct links and annotations among these postings that capture the relationships among the individual drawings, photographs, and comments that comprise the collaborative design document. We take these issues up below in discussing our work on asynchronous collaboration and the construction of digital design databases of artifacts and argumentation.

Finally, a design team must coordinate its efforts explicitly: the effective functioning of a team requires that designers to agree to work in certain ways. At a basic level, the team must determine protocols for communication (turn-taking, file formats, scheduling). At the level of the design artifact, the team must agree about areas of design responsibility—who will make what decisions and what rules shall govern the decisions designers make? We take up these issues below, in describing our work on design coordination.

In the following sections we report on three projects that deal respectively with synchronous collaborative design, asynchronous collaborative design, and design coordination. In each of these sections, we provide an overview of the project, directing the interested reader to our more detailed reports on the work. We conclude with a description of several current efforts that suggest connections among these projects, and perhaps a way to incorporate them into a larger framework for collaborative design.

Synchronous Collaborative Design

Same time (synchronous) collaboration in design is perhaps the most obvious form of collaboration that computers can support and extend. In traditional architectural design settings, design team members sit together to hear a presentation, discuss design issues, and sometimes, sketch a preliminary design that can then be carried out in detail by one or more team members after the meeting. Traditionally these meetings take place around a conference table, but recently, technologies such as video teleconferencing, fax, Liveboard, and computer mediated meeting spaces have made it possible to hold meetings for synchronous collaboration among design team members who are geographically dispersed. The earliest efforts to support synchronous collaboration in architectural design employed video links between collaborating designers' offices [11]; several other recent projects have focused on integrating live video of distributed team members with shared drawings and text [1, 12, 20]. Like others [6] [17] we have concentrated on freehand drawing because we believe it is a natural and familiar way for designers to interact, especially in the early stages of design.

The Electronic Cocktail Napkin is a program that supports collaborative freehand sketching and drawing on digitizing pads with pens [8]. It combines paint and draw features: users draw whatever they want, unrestricted by menus of graphic primitives; yet marks users make can be selected, dragged, resized, and rotated, and combined into groups or configurations. The Cocktail Napkin supports simulated tracing paper and underlays, constraint based drawing, sketchbooks, and a pin-up bulletin board. But (unlike earlier shared drawing programs) the Napkin also provides trainable recognition, user programmable parsing, and contextual interpretation of diagrams as input to simulation programs and visual libraries. Thus diagrams and sketches are primary means of entering designs into 'knowledge based' tools and arguing about them.

Figure 1. Designers engaged in informal sketching with the Electronic Cocktail Napkin.

The Cocktail Napkin program provides several collaborative drawing modes. First, two designers can share a single drawing surface—a digitizing tablet. The designers use digitizing pens that can be distinguished by the software and the program tracks authorship of different parts of the drawing. This mode is similar to two designers sketching together on a cocktail napkin or the back of an envelope in an informal brainstorming session. In a second mode for collaborative drawing the designers still share a drawing space, but each holds their own tablet and pen. The third mode involves two programs running on separate machines, connected (point-point) over a local area network. In this mode both designers run a version of the program on their own machines, and the programs exchange drawing and editing commands using a protocol we devised for graphics interchange. We have also built a version of the collaborative drawing program that runs between a hand held wireless PDA (personal digital assistant: an Apple Newton) and a host, or between two PDA's, providing a portable digital sketchbook, connected with a central database or with other designers.

Figure 2. Collaborative drawing with a wired Mac and a wireless PDA connected by a radio frequency modem.

Asynchronous Collaborative Design

A rather different kind of support for collaborative design involves asynchronous work. Short-term asynchrony enables people in different time zones or on different schedules to participate at their own convenience, rather than coordinating schedules to hold on line design meeting at a specific time. Long term asynchrony enables the collaboration of designers over an extended design calendar, and over the life cycle of a product. This enables designers who join the team later to gain access to design rationale of designers who participated earlier, but who may have left the project or moved on to other issues. Long term asynchronous communication can also enable collaboration among different generations of designers on similar projects—that might have significant overlap in design issues and therefore be sources of important lessons.

To support long-term asynchronous collaboration it is crucial to provide an archive or repository that functions as a group memory. Then designers engaged later in the design life cycle can understand reasons for what might otherwise be obscure decisions taken by earlier designers. To be effective the group memory should record both what was done in a project and why, recording both design decisions and rationale underlying those decisions. Means are thus needed for effectively and efficiently creating these records and for indexing them when they are needed. As designers *do not know what they do not know* , effective systems for asynchronous collaboration must *actively call designers' attention to information they need* if they fail to search for it.

The PHIDIAS hypermedia system [14-16] supports both short term and long term, asynchronous collaboration. PHIDIAS — Procedural Hierarchy of Issues/Design Intelligence Augmentation System — enables designers of large complex artifacts both to do design and to store and retrieve rationale about design decisions. PHIDIAS employs 'task based indexing' in which rationale is linked both to design objects and design tasks associated with those objects. For example, rationale for moving a wall is linked both the wall and to a representation of the task of moving it. Task based indexing enables the system to call designers' attention to design rationale that is useful for the tasks they undertake and the decisions they make while designing.

The PHIDIAS system is organized around Procedural Hierarchy of Issues, a variant of Horst Rittel's Issue Based Information Systems (IBIS)[19]: information about an artifact is organized as a hierarchy of issues, answers, and arguments. PHIDIAS can be usefully compared with other issue based information systems such as gIBIS [4] and SYBL [13]. PHIDIAS is a fine grained hypermedia system, like gIBIS and SYBL, and unlike the World Wide Web, which has page-level granularity. PHIDIAS differs from gIBIS and SYBL in that it uses fine-grained networks to support vector graphics and knowledge based computation on semantic networks.

Earlier work on PHIDIAS has resulted in a single-user system that can be used to enter new design rationale, in the form of issues, answers, and arguments. It included a structured editor for textual design rationale, facilities for producing three-dimensional models and entering audio and video as nodes in the hypermedia design argument structure. The current PHIDIAS system has been extended to respond dynamically to queries received over the world wide web, providing design rationale on-the-fly to Java enabled clients.

PHIDIAS has been used to construct a large issue base of design rationale about space based habitation, providing NASA's Man Space Information System documents in an electronic format , structured as an issue base. To assist users in collaborating and coordinating their work the system supports 'argumentative agents' that detect overlaps in the concerns of different participants in a design process, notify these participants of overlapping concerns, and enable and support sustained communication among these people to deal collaboratively with the overlaps. Three kinds of argumentative agents have been devised: advocates, knowledge based critics that examine and critique partially formed solutions; scouts, which watch for and report on new information entered anywhere in the issue base; and reporters, which report on activity in certain parts of the issue base, for example, for attempts by other designers to change parts of a design.

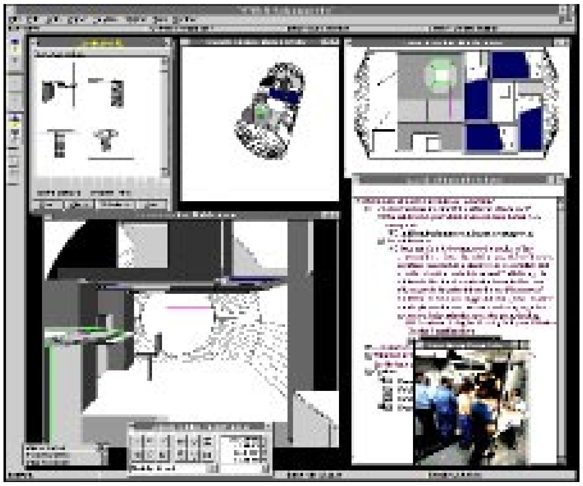


Figure 3. The PHIDIAS HyperCAD system structures a database of design artifacts and argumentation.

Design Coordination

Orthogonal to the synchronous-asynchronous distinction of collaborative design outlined above is the approach of design coordination. Our Construction Kit Builder (CKB) project explores this way of supporting team design under the premise that *a-priori* agreements among team members can avoid many conflicts that might otherwise arise and need to be resolved during designing.

Complex artifacts, e.g., buildings, are assemblies of many different systems, each with its own particular characteristics, and each the responsibility of different design team members. For example, one designer might be in charge of laying out partition walls, while another is to design the electrical distribution system, and a third will be responsible for laying out the system of heating and ventilating ducts. In a conventional CAD process, each subsystem layout will be done separately, then combined together (for example, on separate layers of a CAD drawing) and checked for interference conflicts either by hand or using a 3D interference checker built into the CAD program. This process postpones the discovery of conflicts until most of the design work is complete, and therefore resolutions and repairs are likely to be ad-hoc and / or costly. Even if the designers were networked sharing a single CAD database, physical interference problems could not be detected until the second component is placed, and resolutions would still be negotiated in a one off manner.

To avoid this sort of conflict, in the first place the design team members must reach agreements about the placement of physical components into the design. Before beginning to lay out the design, the team must agree on allowable locations for the components of each system. As many of the systems are pervasive—ventilating ducts must reach all parts of the building—it is useful to establish a scheme of three-dimensional zones that can be allocated to the components of the various systems. For example, a zone that occurs every 12 feet is allocated to carry the ventilating ducts. Many of the ad-hoc interference conflicts can be avoided by using dedicated spatial channels for each of the systems that must be laid out in the building. Any interference conflicts that do occur will happen at zone intersections, where the condition can be anticipated and a standard resolution designed.

To support this scheme, each designer's CAD editor must be programmed with the rules for placement and assembly of their particular system. The HVAC designer who is laying out a system of ducts, fans, and vents works with a standard catalog of components that go together in certain ways, and that (according to the team's agreed-upon rules) can be placed only in certain zones in the building. By programming the CAD editor with these rules, the HVAC designer can proceed fairly independently of other system designers, knowing that interference conflicts will be minimized and only occur in certain locations.

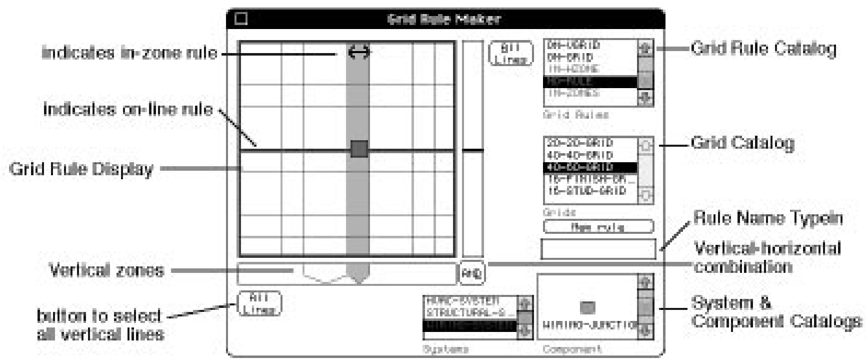


Figure 4. The Construction Kit builder provides a design team the means to express and enforce rules to coordinate the placement and assembly of the components of different systems.

We have built a program to demonstrate these ideas. Construction Kit Builder (CKB) [7, 9] is a CAD program that operates at two levels. At the lower (layout) level, it is simply a design editor, in which a designer can select components from a catalog and lay them out to make a design. However, the designer is restricted to placing elements only in certain locations (zones) and assembling them in certain ways. At the higher (coordination) level, Construction Kit Builder enables the design team coordinator to assign placement and assembly rules to the components of each system, for example, restricting ventilating components to one set of zones, and electrical components to another.

Design rules that enforce the placement of different systems' components in different zones, and the assembly of the components of each system are implemented using algebraic constraints, which apply locally when the designer lays out components. Placement constraints are attached to systems and inherited by individual components and assembly constraints apply to specific pairs of components. The constraint machinery is simple propagation, though more sophisticated techniques naturally could be applied. But sophisticated constraint solving is not the point. Rather, we aim to show how the layout concerns of a design team can be partitioned based on simple *a-priori* agreements about the placement of components, thereby sidestepping what otherwise might later become thorny conflicts.

Current and Future Work

Several interesting connections between these originally independent projects have emerged and we are exploring the potential for combinations, some described below. For example, in HyperSketch, we explore the use of freehand sketches as nodes in a hyper document. In Retrieving Cases with Diagrams, we look at how drawings can be used as queries to large design databases. And in Digital Design Notebooks, we combine our work on collaborative drawing work a design archive to support asynchronous collaboration.

HyperSketch - drawings as nodes in a CAD hyper document
We have observed that in the course of a design session a single designer may produce as many as a hundred sketches, generated sequentially. In team work, several designers may work at this

activity more or less in parallel, and come together from time to time to compare notes and integrate their designs. Sketches are linked conceptually: often each successive sketch made by a single designer responds to some perceived problem or opportunity in the previous drawing. In our HyperSketch prototype, sketches are stored as nodes in a hyper document, with links that indicate the sequence in which they were made. Additional links can also indicate relationships among sketches such as 'design alternative', 'fixes problem in', elaboration of', and 'abstraction of'.

HyperSketch makes it easy for the designer to specify these and other relationships among sketches. Many of these relationships are created automatically by the system, e.g., 'traced from', 'temporal successor', and 'design alternative to'. Members of a design team working separately can browse the sketches others have made, establish labeled links between these sketches and their own. The sketches themselves can be annotated with text (e.g., arguments about and comments on the designs), and the resulting structure of linked and labeled sketches then shared as a repository of information about the design.

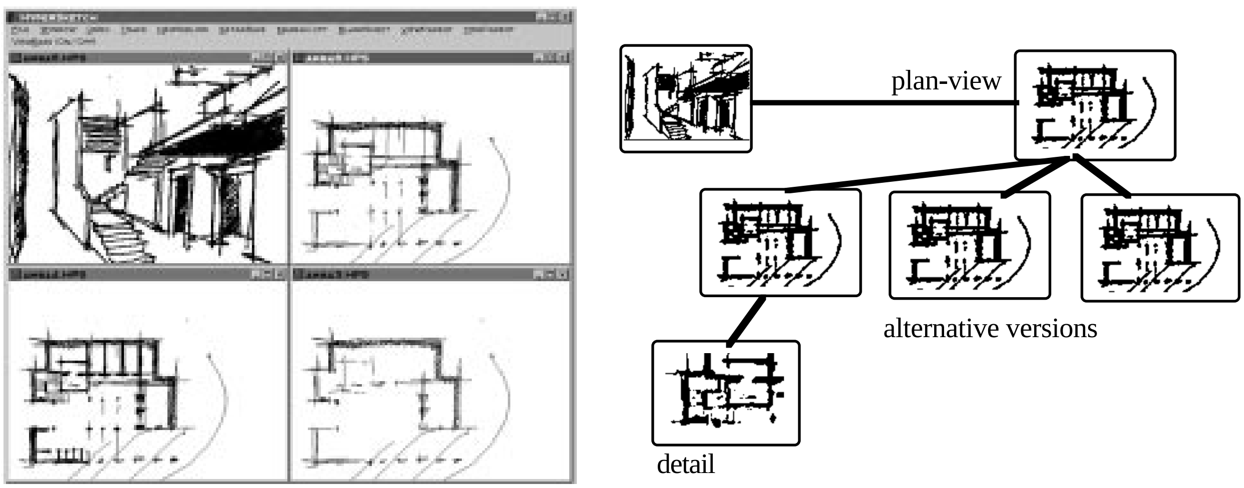


Figure 5. In HyperSketch, designers' freehand drawings are linked as nodes in a hyperdocument graph.

Retrieving Cases with Diagrams

We have used the Electronic Cocktail Napkin to build a query-by-diagram retrieval scheme for databases of designs, and we have used the scheme to index case bases of architectural post-occupancy evaluation studies [10], and on-line libraries of technical data about heating, ventilating, and air-conditioning (HVAC) [5]. For data in which spatial relations or physical form is salient, designers may prefer to construct queries by drawing diagrams, rather than constructing a textual query from key words. Our scheme employs simple visual bookmarking: A designer first draws diagrams to index items in the case library. Later, those cases may be retrieved by drawing similar diagrams.

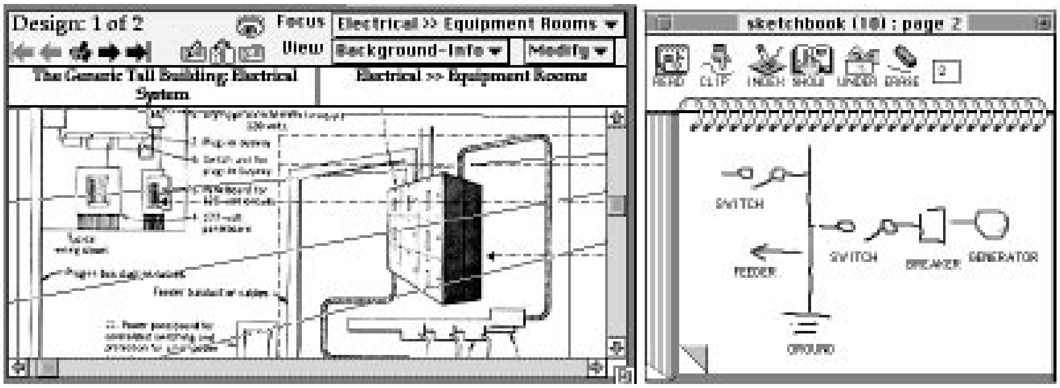
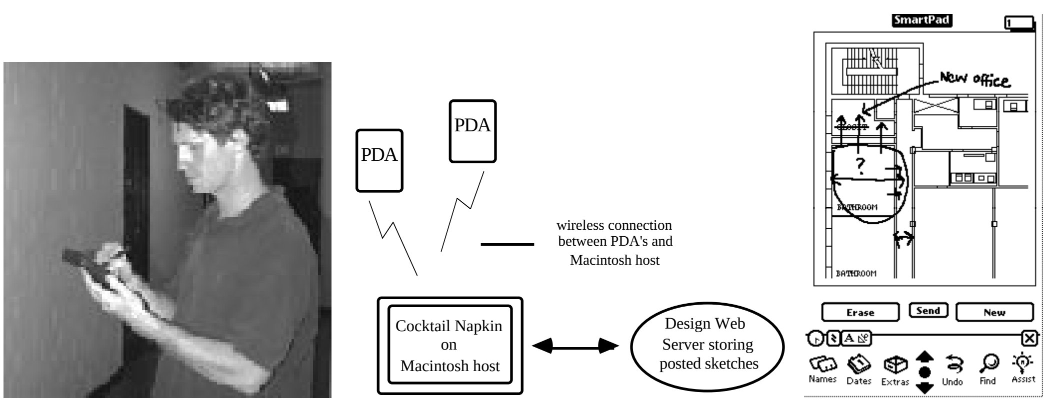


Figure 6. In Retrieving Cases with Diagrams, sketches and diagrams are used to index relevant information from on-line design databases.

In a large collaborative design database, sketches, diagrams, drawings, and photographs will comprise a significant fraction of the data. We can apply the visual bookmarking scheme we developed for querying case libraries to design databases that are constructed collaboratively by a design team. We see query by sketch as a valuable addition to text based search and retrieval for designers participating in a large collaborative project to find and retrieve design information that others have stored in the database.

Digital Design Sketchbooks and mobile, wireless, graphical communication

We have experimented with a wireless mobile sketchpad communicating with a wired host computer to support a team of distributed, collaborating designers [2, 3]. Each design team member works with a Digital Design Sketchbook, a handheld Personal Digital Assistant (PDA). We are currently using the Apple Newton Message Pad 130 with a PCMCIA wireless modem. The Newton and a Macintosh running the Cocktail Napkin program communicate using a wireless (radio frequency) modem connection speaking Appletalk. A web site for the design team serves as a shared repository and design history for drawings, written comments, and photographs, contributed by each design team member. Drawings and text from the web site can be downloaded to the PDA, annotated locally, and the designer's marked-up version uploaded to the web site for others to consider.



(a) (b) (c)

Figure 7. (a) using the digital sketchbook to document on-site conditions; (b) web server for the design team stores drawings, comments, and other data provided by the PDA's; (c) designer's marked-up drawing on the PDA, uploaded to the server.

In our prototype, the mobile PDA's running our SmartPad program communicate with the Electronic Cocktail Napkin software running on a "host" Macintosh. When the Napkin program receives a drawing from one of the mobile PDA's, it saves the drawing as a GIF file, and copies the file to a special directory on the web server. A CGI on the web server polls this directory and whenever a new file appears it adds the file to the design team's web page. A simple web browser running on the PDA would enable a user to retrieve any drawings, photographs, or text that other team members have posted; the present version can only return drawings originally made on the PDA or the Napkin. In a future version, we plan to replace the generic web serving software with a PHIDIAS-like server that can help structure the emerging design as the team works.

Summary

We have outlined three approaches to computer support for collaborative design that we are exploring—shared drawing , an archive of rationale, and coordination of decision-making. Correspondingly we believe—drawing is a primary medium in many design domains, design tools should support not only construction of the artifact but also the argument about the artifact, and that computer tools should help design teams manage and work within explicit agreements about the design. The interplay between these three approaches, and their execution with various hardware and software technologies—mobile sketchpads, Java clients and back-end servers, promise a fascinating, if fast-changing, research program in collaborative CAD.

Acknowledgments

We gratefully acknowledge the following support for the projects described in this report:
• A grant, DMII 93-1316, from the NSF: "Avoiding interference conflicts in architectural subsystem layout - a constraint based approach" • a NASA SBIR contract with Johnson Engineering, Boulder: "Using hypermedia and the information superhighway to Improve design of spacecraft interiors" • a grant from the Colorado Advanced Software Institute and USWest Advanced Technologies, "PDA-Based architectures for graphical interchange" • A University of Colorado President's Educational Technology Grant, "Toolkit for Technology Enhanced Education".

References

1. S. Bly, S. Harrison, S. Irwin., "Media Spaces: Bringing People Together in a Video, Audio, and Computing Environment" Communications of the ACM, Vol. 36, No. 1, 1993, pp. 26-45.

2. W.V. Citrin, M.D. Gross, "Distributed Architectures for Pen-Based Input and Diagram Recognition", ACM Conference on Advanced Visual Interfaces, ACM, Gubbio, Italy, 1996, pp. 132-140.

3. W.V. Citrin, M.D. Gross., "PDA-based Graphical Interchange for Field Service and Repair Workers" Computers & Graphics, Vol. 20, No. 5, 1996, pp 641-650.

4. J. Conklin, M. Begeman. "gIBIS: a hypertext tool for exploratory policy discussion", Conference on Computer-Supported Cooperative Work, Association for Computing Machinery, 1988, pp. 140-152.

5. E.Y.-L. Do, M.D. Gross. "Reasoning about Cases with Diagrams", Third Congress on Computing in Civil Engineering, American Society of Civil Engineers, 1996, pp 314-320.

6. S. Greenberg, S. Hayne, R. Rada, Groupware for Real-Time Drawing, McGraw Hill, London, 1995.

7. Gross., "Avoiding Conflicts in Architectural Subsystem Layout" Concurrent Engineering: Research and Applications, Vol. No. 2, 1994, pp. 163-171.

8. M.D. Gross., "The Electronic Cocktail Napkin - working with diagrams" Design Studies, Vol. 17, No. 1, 1996, pp. 53-70.

9. M.D. Gross., "Why Can't CAD be More Like Lego?" Automation in Construction, (in press).

10. M.D. Gross, C. Zimring, E. Do, "Using Diagrams to Access a Case Base of Architectural Designs", Artificial Intelligence in Design '94, Edited by J. Gero, Kluwer, Lausanne, 1994, pp. 129-144.

11. S. Harrison., "Computing and the Social Nature of Design" ACADIA Quarterly, Vol. 12, No. 1, 1993, pp. 10-18.

12. H. Ishii, M. Kobayashi, J. Grudin, "Integration of interpersonal space and shared workspace: Clearboard design and experiments", Groupware for Real-Time Drawing, Edited by S. Greenberg, S. Hayne, R. Rada, McGraw Hill, London, 1995, pp. 96-125.

13. J. Lee. "SYBL: A Tool for Managing Group Decision Rationale", Conference on Computer-Supported Cooperative Work, ACM, 1990, pp. 79-92.

14. R. McCall. "PHIBIS: procedurally hierarchical issue based information systems", Proceedings, International Congress on Planning and Design Theory, American Society of Mechanical Engineers, 1987.

15. R. McCall, P. Bennett, P. d'Oronzio, J. Ostwald, F. Shipman, N. Wallace. "PHIDIAS: A PHI-based design environment intgrating CAD graphics into dynamic hypertext", European Conference on Hypertext, 1990.

16. R.J. McCall, P. Bennett, E. Johnson. "An Overview of the Phidias II HyperCAD System", ACADIA (Association for Computer AIded Design in Architecture), Edited by A. Harfmann, M. Fraser, ACADIA, pp. 63-74.

17. S.L. Minneman, S.A. Bly, "Managing à trois: a study of a multi-user drawing tool in distributed design work", Conference on Human Factors in Computing Systems (CHI '91), ACM Press / Addison Wesley, New Orleans, LA, 1991, pp. 217 - 224.

18. W.J. Mitchell, "The Future of the Virtual Design Studio", Virtual Design Studio, Edited by J. Wojtowicz, Hong Kong University Press, Hong Kong, 1995, pp. 51-59.

19. W. Rittel, W. Kunz. "Issues as elements of information systems", Working Paper 131, Center for Planning and Development Research, University of California, Berkeley, 1970.

20. S.A.R. Scrivener, D. Harris, S.M. Clark, T. Rockoff, M. Smyth, "Designing at a distance via real-time designer-to-desgner interaction", Groupware for Real-Time Drawing, Edited by S. Greenberg, S. Hayne, R. Rada, McGraw Hill, London, 1995, pp. 5-23.

21. J. Wojtowicz, ed. Virtual Design Studio. Hong Kong: Hong Kong University Press, 1995.