ABSTRACT

Architectural design practice is a collective work of different levels of expertise. Collaborative design relies on seamless meshing of specialists with different levels of expertise, skills and views. Research on collaborative design suggests various methodologies for supporting synchronous or asynchronous communicative practices of designers in reviewing and analyzing design decisions at different stages of the design process. However, they do not address the provision of an action platform that would enable collaborative group decision making in architectural design. There are four requirements for this platform: 1) sharing of design decisions among designers, 2) sharing of design rationale among designers, 3) detecting conflicts among design decisions, and 4) sharing of designers responses to design decisions. This paper presents a conceptual model of an asynchronous collaborative design environment that implements methodologies for addressing these requirements.

1 INTRODUCTION

The increased complexity of technology, economics and society has replaced the traditional master architects and planners with today’s multitude of design experts - each involved in one or more phases of the design process. Architectural design is a collective work of design participants from many different disciplines with varying expertise, skills, design paradigms, and working platforms. Collective architectural design practice does not tolerate fragmentation and lack of communication among individual experts. It requires seamless meshing of specialists, and collaborative usage of their individual skills, knowledge and views in the design process.

Collaborating design experts declare a growing need to co-ordinate the efforts of design experts and to provide for timely information transfer among them. This need has given rise to experimental and quasi-experimental research studies conducted for understanding the nature of collaborative work in architectural design practice (Kalay 1997, Jabi 1996, Bhat et al 1993, van Bakergem and Obata 1993, Maher et al 1993). Literature consists of description of methodologies and prototypes developed for supporting computer mediated collaborative architectural design practice (Kalay 1997, McCall and Johnson 1996, Davidson and Campbell 1996, Knapp and McCall 1996, Jabi and Hall 1995, Fenves et al 1994).
Conceptual models and prototypes developed to enable computer mediated collaborative architectural design fall under two main general categories of collaboration: synchronous and asynchronous collaboration. The focus of this research is not one of the many studies that concentrate on the social, psychological or technical issues of synchronously shared physical or virtual workspaces. Rather, the focus of this study is on the distribution, organization, and management of design ideas and actions that originate in isolated workspaces of collaborating designers. This paper focuses on issues of development prevalent to group design support systems for asynchronous collaborative architectural design process. In this paper, the author makes an analysis of the currently developed and employed methodologies for supporting designers at different stages of the collaborative design. Methodologies are categorized according to their support to different requirements of the collaborative design process. In section 3, the author presents a conceptual model of an Asynchronous Collaborative Design Environment (ACDE) that would establish functionalities for supporting different requirements of collaborative designing.

2. RESEARCH ON COMPUTER SUPPORTED COLLABORATIVE DESIGNING

Research on collaborative design process indicates that designers perform collaborative design activity in different ways (Maher et al. 1998). Maher et al. (1998) categorizes three different types of collaborative design. The first type of collaborative designing is mutual collaboration in which designers work together by making negotiated decisions during the entire design session. The second is called exclusive collaboration, in which designers work on separate parts of the problem, negotiating occasionally by asking advice from other designers. The third type of collaboration is dictator collaboration. In dictator collaboration, design decisions are made by a dictating designer, and agreed upon by other designers.

Mutual, exclusive and dictator types of collaborative designing occur when designers work in same space-same time, different space-same time, same space-different time, and different space-different time. In same space-same time mutual designing, designers deal with the same design problems. They synchronously develop solutions in a shared physical workspace. In same space-same time exclusive designing, designers synchronously work on a shared physical workspace, but develop design solutions that address different design problems. In same space-same time dictator collaborative designing, a dictating designer develops design solutions at a shared workspace, and solutions are approved by other designers at this workspace. In different space-same time mutual collaboration, instead of a physical shared workspace, a virtually shared
workspace is used.

Research on collaborative decision making process has identified three major stages in collaborative design process: information space, situation space and action space (Wellens and Ergener, 1988). An information space contains data that impinge upon the group from multiple information sources (figure 1). Situation space presents the commonly held "big picture" that is formulated by the group after examining its information space. An action space represents the behavioral options available to the group regarding its ability to affect environmental events. When action is taken in action space, it impacts the current data and events in information space, and the big picture of the information space formulated in situation space. Modifications are fed back to the initial pool of data and reassessed to see if additional action is required (Wellens and Ergener, 1988).

Figure 1: Major components of a collaborative decision making (adapted from Wellens and Ergener, 1988)

In a collaborative environmental design practice, an information space is where a design team shares all the necessary information about a design problem. This information package is collected from multiple information sources. If the problem is to design a building, the information space mainly consists of information about the building location, surrounding environmental conditions, building regulations, architectural program, user and/or client requirements. After the examination of all the information, the design team formulates the "big picture" for the design project - its objectives and priorities. Design experts define which information and requirements are applicable to the design problem at hand. This stage of design is called the situation space. An action space in design practice is the place where decisions are made towards the achievement of the objectives and requirements formulated in the situation space. A drafting table, a
computer desktop, a meeting room are examples of an action space. Another space that exists and is not recognized by Wellens and Ergener (1988) is the *review space*. A review space is where members of the design team individually as well as, as a group identifies the performance of a design decision, and brings in arguments and comments towards the modification or acceptance of a design decision.

Developments in Computer-Aided Design (CAD), Computer-Aided Architectural Design (CAAD), Computer-Supported Collaborative Work (CSCW), Group Decision Support Systems (GDSS) and Distributed Artificial Intelligence (DAI) provide varying computer based methodologies for supporting different stages of collaborative design process. Current research on synchronous or asynchronous collaborative design process has succeeded in providing methodologies or prototypes for supporting different working spaces of collaborative design practice. A number of researchers have developed methodologies that enable either collection of design information or review of design rationales. These task-specific computer mediated support systems can be categorized into three in terms of their support to: (1) Information space, (2) Situation space, (3) Review space.

### 2.1 Support for Information Space

The first type of approach in developing computer based collaborative design environments focuses on *information space*. The research that fall under this category is identified with its objective to enable inter-disciplinary communication and collaboration in design via shared information space. Many researchers attempted to achieve this objective by enabling collection of all necessary information required for a design problem in centralized or distributed databases. In a shared information space, collaborating design participants are provided the capability to simultaneously retrieve all the information about a design project.

An example of a support to information spaces is ID'EST (Kim 1995). Integrated Design Environment using STEP methodology (ID'EST) is an object-oriented database, and is developed to support collaboration via shared information space. ID’EST is designed to enable communication of design expert via sharing unified data description and standardized data exchange format (STEP) and integrating CAAD tools that would manipulate and appraise certain aspects of a design decision (Kim 1995). ID’EST uses an abstract product modeling technique (PM) to ensure unified data description of the divergent design data that would be produced and shared among design experts.

Another technique employed for collaborating via shared database is based on document-based exchange of information (e.g. DWG, DXF) among remotely located design
participants. Week (1995) reports of such kind of CAD database developed on a Web site for the communication of designers working at remotely located architectural firms. This shared database conceptualized not only to contain, but also to manage control on hyperlinked CAD data. Utilization of such kind of a distributed database is anticipated to enable different designers to work on different parts of a design data at the same time: simultaneous co-authoring (Week 1995).

2.2. Support for Situation Space

The second type of approach observed in research on collaborative design process is to develop computer mediated techniques that establishes a situation space where the design team can formulate the nature of a design problem, define its objectives and requirements.

Multi-user version of PHIDIAS II introduces a mechanism that mediates a situation space that resides in asynchronous collaborative design practice. PHIDIAS II supports the actions taken in identifying the requirements, objectives and constraints of a design problem. It establishes a space in which design participants can formulate a big picture of the current design project. PHIDIAS II supports this functionality by establishing a mechanism that detects overlapping concerns of designers, and of the conflicts with the formulated big picture of the project. As described by McCall and Johnson (1996), these objectives are achieved mainly by argumentative components such as advocates, announcers and scouts. Argumentative components of PHIDIAS II detect, notify, document and enable the discussion of conflicts and overlaps of personal and professional viewpoints in design. Advocates of the system watch and detect the conflicts between design decisions and design principles. Announcers detect overlaps in the concerns of the subscribers of the system and notify subscribers of these overlapping concerns. They enable asynchronous communication of subscribers with overlapping concerns, by carrying out e-mail text messages presented in the context of relevant design decisions. Scouts facilitate text documentation of the arguments in group collaboration and notification of them to subscribers of the system (McCall and Johnson 1996).

2.3. Support for Review Space

The third type of approach observed in research on collaborative design process focuses on providing a shared space for expressing and reviewing design decisions – a review space. Some researchers found a way of achieving this objective by integrating virtual reality technology into the review space in collaborative designing. Representation of design ideas by constructing them in virtual environments and enabling designers to virtually exist and communicate in these environments established a synchronous architectural design review space. Research on virtual design environments provided insights on social, psychological and technical aspects of a virtual review space when
utilized in collaborative evaluation of architectural design decisions (Davidson and Campbell 1996). Researches on virtual reality technology, and Virtual Reality Modeling Language (VRML) applications on the WEB ([DIVE], [DIV], [SICS], [MERL], [NPS]) have provided valuable insights that are applicable in the development of virtual platforms for synchronous interactive design environments.

An example of a shared virtual environment as a tool for architectural design review is GreenSpace II. GreenSpace II is developed to construct a distributed virtual environment for reviewing architectural design projects by multiple participants (Davidson and Campbell 1996, Mandeville et al 1995). Developers of GreenSpace, conceptualized that a design review environment is not a place to create or construct any new design decisions, rather to communicate among each other the ideas that are part of a pre-existing design (Davidson and Campbell 1996). For that reason, GreenSpace II does not enable creation or construction of new design decisions, but provide support to sharing and refining of design data via synchronous collaboration of design team in a shared virtual environment.

Current telecommunication technology enables computerized techniques such as shared virtual environments, distributed electronic whiteboard, video conferencing, web conferencing that establish varying capabilities for virtually shared review spaces in cross-platforms. In architectural design education, Virtual Design Studios (VDS) make use of these techniques by conducting long-distance studio reviews across space and time. In VDS, multi-user review spaces are constructed using shared whiteboards (or pin-up boards) that are accessed through local area networks (LANs) or wide area network systems (WANs). Observations made in VDS delineate how review space is affected from the utilization of synchronously or asynchronously accessed whiteboards (Wojtowicz et al 1996, Wojtowicz 1995, Kvan 1994).

2.4 A Need for Group Support Systems for an Action Space

Computer-based collaboration tools were developed mostly for supporting synchronous and asynchronous communication of teams working in information space, situation space and review space. There is no single system tested and verified to date that satisfactorily supports the needs and requirements of every design participant, as well as the collaborating team to jointly engage in cross-space and cross-time environmental design practice. Little consideration is given to the development of virtual or physical action spaces that will enable mutual or exclusive creation, modification, and discussion of design decisions. However, with foreseeable improvements in computer technology, and research on collaborative design work, it is conceivable to begin thinking about a virtual collaborative design environment. This paper attempts to help the establishment of such a
design platform by developing a conceptual model of an asynchronous design environment, and by developing methodologies for its implementation.

3. CONCEPTUAL MODEL OF AN ASYNCHRONOUS COLLABORATIVE DESIGN ENVIRONMENT

Design work conducted in same space-different time and different space-different time are types of asynchronous collaborative design practice. Asynchronous collaborative design activity is a collective work of two or more designers, who work on same design problem in isolated workspaces. Work conducted in isolated workspaces is involved in the creation or modification of design ideas that address similar or different aspects of the design problem. Asynchronous collaborative design environment is a shared distributed space that mediates mutual, exclusive and dictating manner of collaborative designing. There are mainly four requirements of an asynchronous collaborative design process.

1. Sharing of design decisions among designers,
2. Sharing of design rational among designers,
3. Detecting conflicts among design decisions,
4. Sharing of designers responses to design decisions

Figure 2: *Four main requirements of asynchronous collaborative designing*

3.1 Sharing of Design Ideas among Designers

Empirical evidence suggests that systems which provide access to shared information, at
any time and place and using minimal technical infrastructure, are the main requirements of groups collaborating in a decentralized working environment (Bentley et al 1997, Gorton, Hawryszkiewycz and Fung 1996). The methodologies prevalent in the proposed conceptual model suggest an asynchronous collaborative design environment that is accessed by one or more designers from a variety of computer platforms distributed over remote locations (figure 3). In the proposed model of asynchronous collaborative design environment (ACDE), designers asynchronously employ actions prevalent to a design problem. These actions take place in a designer’s isolated personal workspace. The work done in isolated workspaces, at remote locations and at different times are shared asynchronously among other designers in a shared workspace. This is accomplished by representing and routing contents, artifacts and rational of isolated design works into a shared workspace.

Figure 3: Conceptual model of asynchronous collaborative design environment

In ACDE, sharing of design ideas among designers is established by collecting digitized design documentation in a shared multimedia database. An access to this database is
provided to registered designers. Any registered designers can check-in and out information about a design decision from the shared database at any time. This database consists of records of design documents. Records are organized according to fields that provide information on design documents. Information on design documents contains when, who and what is been developed and shared with other members of the collaborating team. Profile cards are created for every collected design document. A profile card contains information about the author, document meta-data (date, size, document type), the contents of a document, check-in (load into database), check-out (load from database) actions performed on a document and reviews prevalent to that design document.

Collaborating designers search and retrieve representation of design decisions via indexed profile cards. A profile card is a pointer to a design decision object. Design decision objects contains hierarchically organized data, analysis and review objects (figure 3). A data object consists of design documents and supporting reference documents. An analysis object contains analysis information that includes meta-data and contents data. Design participants may respond to the provisions or requirements of any design decision at any stage of the design process. Reviews of any specific design decision are gathered and organized by review objects. Designers interact with information contained within data, analysis and review object by performing specific operations. They can check-in (load) and check-out (retrieve) data objects, search and view analysis data, create and view review objects. The system keeps track of these actions, and enables designers to inquiry about the time, performer, and outcome of these operations.

3.2 Sharing of Design Rational among Designers

Sharing of design rationale is required among groups collaborating in decentralized working environments because of the need to understand and evaluate design decisions. Understanding of design decisions are not based merely upon the implications of a design documentation, but also on the reasons, concepts and ideas that are not communicated or well communicated in a design documentation.

Research on design rational (DR) indicates that recording of design rationale mostly occurs during the creation process, and not all designers are reluctant to engage in the recording of the design rationale rather than the design ideas (McCall and Johnson 1996). In the documentation of design ideas, the design rationale is not always documented. Designing and design considerations take precedence in collaborative design process. Designers and design team spends less time documenting why they made certain decisions than on making those decisions. To over come these problems the proposed model of asynchronous collaborative design environment provides a mechanism which
enables designers to share their already recorded design rationale, or record their design rationale after the creation process is over. This functionality enables importing of redlined CAD data, and other forms of digitized multimedia data during the checking-in of a document (figure 4). A designer can attach an additional reference document to further support or describe decision made in a design document.

Figure 4: An interface to sharable documents sorted by check-in date.
When design rationale is documented, it is communicated by a medium such as text, symbols or graphics. Observations made on the externalization of design rationale indicated that design rationale is not always well-communicated. The medium used for the recording of design rationale also contributes to poor communication of the design rationale. For example, in the description of design rationale via symbols and graphics, not all symbols are familiar to other designers, or are interpreted in the same way. To eliminate fortuitous misinterpretations that might occur in graphics or symbols interpretations, ACDE provides a functionality by which additional text-based descriptions is attached to the graphical documentation. During check-in (figure 4), the designer is provided a text-based medium where s/he can further elaborate the reasons why certain actions need to be taken. Checking-in form enables a designer to attach additional reference documents, and to type in additional information that would further elaborate a design rationale.

3.3. Detecting Conflicts among Design Ideas

Collaborating designers produce design ideas that may strongly or weakly conflict with each other. Detection and elimination of conflicts in a design project is crucial, because the later the conflicts are discovered, the more costly and impractical it is to improve the quality of the project (McCall and Johnson 1996). In synchronous collaborative designing designers themselves discover conflicting ideas and relationships between their own work and the work of the others. The conflicts are detected when ideas become explicit to others during the same space-same time communication (face-to-face interaction), or during the different space-same time communication (video or web conferencing). In asynchronous collaborative designing, detection of conflict is dependent on how well the design ideas are communicated and shared over the same space-different time and the different space-different time communication.

The proposed model of asynchronous collaborative design environment provides a functionality that helps detect conflicts among shared design ideas and notifies designers about the detected conflicts. For the elimination of conflicts among proposed design ideas, two types of conflict detection techniques are provided. The first is a designer-reconciled detecting in which a designer himself or herself examines a set of documents and detects the conflicts. In system-reconciled detecting, the designer executes a set of conflict-detecting routines that compare documents according to some predefined criteria. The techniques developed for achieving this objective make use of routines that start with an examination and analysis of design documents, and then compare analyzed documents with each other. Analysis of documents is done by extracting documents meta-data and contents data. The meta-data consists of information about the document name, date,
format, and size. It is extracted by merely looking at the document itself. The information about the contents of a document is gained by explicitly requiring the designer to select among a general category of design contents information that best describes the contents of a document.

Once the document is analyzed according to meta-data and contents data, the documents are categorized according to document author, document name, date of check-in, and general category of document contents (figure 5). The conflict detection routines compare all documents or a set of documents, according to the category extracted from the analysis of a document. In the comparison phase, the conflict detecting routines can be configured to compare all documents that belong a project, or sets of the documents that are selected according to some criteria such as document author, date of creation, general category of document content.

Figure 5: An interface to check-in documents
3.3.1 System-Reconciled Conflict Detecting Routines

A system-reconciled detecting routine works in the following manner. The designer defines a set of criteria that the conflict detecting routines will work with. A designer can define the criteria by filling out a detect-conflict form (figure 6). In this form, the designer identifies which types of documents should be compared, and also identifies according to which criteria the comparison should be made. The conflicts are detected among documents that have similar document author, name, format, size, date, and category. The conflicts are detected among these documents by comparing document name, author, format, size, date, and category. Designers may want to detect design conflicts in different ways by choosing different combination of criteria. For example, a designer may seek to detect conflicts among documents which are of the same file format (e.g. AutoCAD’s DWG file format) and which fall into same category (e.g. Floor Plan). From this set of documents, the designer may require the system to find documents that have been created by different designers. The algorithm works as follows:
**Constants:** Different File Author  Same Category  =  Floor Plan

**Differences:** Same File Format  =  dwg

Assume that the database consists of documents as such:

<table>
<thead>
<tr>
<th>Author</th>
<th>Name</th>
<th>Date</th>
<th>Size</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>atuzmen</td>
<td>Current.dwg</td>
<td>1/3/98 12:01 PM</td>
<td>2KB</td>
<td>Site Plan</td>
</tr>
<tr>
<td>atuzmen</td>
<td>A1_plan.dwg</td>
<td>1/5/98 1:55 PM</td>
<td>12KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>yildirim</td>
<td>Current.dwg</td>
<td>1/5/98 3:34 PM</td>
<td>5KB</td>
<td>3D Model</td>
</tr>
<tr>
<td>yildirim</td>
<td>A1_plan.dwg</td>
<td>1/6/98 3:34 PM</td>
<td>23KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>yildirim</td>
<td>SW_section.gif</td>
<td>1/6/98 3:34 PM</td>
<td>5KB</td>
<td>Section</td>
</tr>
<tr>
<td>yildirim</td>
<td>B5_plan.gif</td>
<td>1/6/98 3:34 PM</td>
<td>23KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>atuzmen</td>
<td>A1_plan.dwg</td>
<td>1/7/98 1:55 PM</td>
<td>18KB</td>
<td>Floor Plan</td>
</tr>
</tbody>
</table>

The AND Boolean operation on (same category and same file format) gives:

<table>
<thead>
<tr>
<th>Author</th>
<th>Name</th>
<th>Date</th>
<th>Size</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>atuzmen</td>
<td>A1_plan.dwg</td>
<td>1/5/98 1:55 PM</td>
<td>12KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>yildirim</td>
<td>A1_plan.dwg</td>
<td>1/6/98 3:34 PM</td>
<td>23KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>atuzmen</td>
<td>A1_plan.dwg</td>
<td>1/7/98 1:55 PM</td>
<td>18KB</td>
<td>Floor Plan</td>
</tr>
</tbody>
</table>

The AND Boolean operation on (same category and same file format) and (different file author) gives:

<table>
<thead>
<tr>
<th>Author</th>
<th>Name</th>
<th>Date</th>
<th>Size</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>atuzmen</td>
<td>A1_plan.dwg</td>
<td>1/7/98 1:55 PM</td>
<td>18KB</td>
<td>Floor Plan</td>
</tr>
<tr>
<td>yildirim</td>
<td>A1_plan.dwg</td>
<td>1/6/98 3:34 PM</td>
<td>23KB</td>
<td>Floor Plan</td>
</tr>
</tbody>
</table>

3.4 **Sharing of Designers Responses to Design Ideas**

In collaborative design, designers do not merely exchange design ideas, design rationale and detect conflicts among design ideas, but they also deal with negotiations and mutual agreements. Collaborating designers negotiate and come to mutual agreements by communicating their responses to proposed design ideas. In this looping feedback mechanism, there are mainly three types of responses (Wade 1977). The first is the response of the designer to his or her own design ideas, to see whether it has taken the form s/he has intended. The second response type is the responses of other design
participants to the proposed design idea. The third is the response of the designer to others’ responses.

In collaborating design environments, the design participants are concerned with the sharing of the last two types of responses – sharing of other designers’ responses to a design decision and the author’s response to others’ responses. The proposed model of asynchronous collaborative design environment (ACDE) is designed to enable argumentative discourse among designers by providing support to these two types of responses. This objective is achieved by enabling the broadcasting or routing of comments, questions, and instructions to any design participant at any time. Comments, questions and instructions are expressed and shared via any digitized multimedia format including text, audio, video, image, and graphics. In order to enable the occurrence of argumentative discourse in asynchronous collaborative designing, the system provides a functionality that enables recording of responses via a response form (figure 7). A response form consists of fields which provide information about the responder, what the response is about, what design document it is addressed to, who it is addressed to, level of urgency, and expected actions in respect to this response. By using the response form, responses can be described in text-based format and be supported with additional multimedia document attachments.

Figure 7: Response form
Once a new response is created, the response is recorded in a shared review space where the system collects and organizes responses in the context of relevant design decision. Responses to any design ideas are viewed whenever the designer wishes to view or deal with. Responses can be viewed by sorting them according to author, date, level of urgency, subject, and expected actions. However, a designer may also ask to be notified immediately whenever there is a new response in the area that the designer had chosen to be notified. The registered designer may choose to be immediately notified when the response fall into any category of design subject (e.g. conceptual design), urgency level (e.g. both high and medium urgency level), responder (e.g. only responses coming from project manager), or expected actions (e.g. approval). Designers with matching notification criteria receive an e-mail message that informs them about the newly created design response.

4. FUTURE DEVELOPMENTS

Methodologies for establishing an asynchronous collaborative design environment are developed in the conceptual model of ACDE. According to this model ACDE provides functionalities that mediate four main requirements of a collaborative design environment: (1) sharing of design decisions among designers, 2) sharing of design rationale among designers, 3) detecting conflicts among design decisions, and 4) sharing of designers responses to design decisions. The objectives of the proposed conceptual model requires the consideration of currently introduced telecommunication and programming paradigms that would enable implementation of a shared workspace that works effectively cross-platforms. Explosive developments in the Internet and WEB standards (such as HTTP, SGML), client-server architecture, document markup language (HTML), and platform independent sequential and object-oriented programming languages (such as VRML, JAVA, JavaScript, CGI, Perl) suggested elaborate techniques that would enable the implementation of ACDE.

The methodologies employed in the conceptual model of ACDE are partially implemented with a client-server architecture. The server side is implemented on a WEB server with a Common Gateway Interface (CGI), and client side implemented in HTML, JAVA and CGI scripts. The WEB server extended with CGI presents a series of HTML pages and dispatch user response to these pages by embedded CGI scripts. The development of ACDE is proceeding through development of user interfaces, control and routing algorithm that implement functionalities of ACDE. Domain and case analyses are being developed to delineate the operations, attributes, aggregation and associations
required for the implementation of ACDE. The primary goal now is to conduct further studies in the implementation, testing and evaluation of ACDE. In going through these stages, the author seeks to incorporate new research findings about asynchronous collaborative design, and insights gained from the evaluation of the prototypes of ACDE.

6 REFERENCES


