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An Outline of the Requirements for a Computer-Supported Collaborative Design System

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ABSTRACT

Computer-Aided Architectural Design (CAAD) systems have adequately satisfied several needs so far. They have dramatically improved the accuracy and consistency of working drawings, enabled designers to visualize their design ideas in three-dimensions, allowed the analysis of designs through data exchange and integrated databases, and even allowed the designers to evaluate (and in some cases generate) designs based on comparisons to previous cases and/or the formalization of grammars. Yet, there is a consensus that CAAD systems have not yet achieved their full potential. First, most systems employ a single-user approach to solving architectural problems which fails to grapple with the fact that most design work is done through teamwork. Second, current systems still can not support early design stages which involve client briefing, data collection, building program formulation, and schematic design generation. This paper seeks to study remedies to both of the afore-mentioned limitations through focusing on the fundamental dialectic and collaborative nature of what is called *designing*: a concerned social activity that proceeds by creating architectural elements to address a set of requirements and their re-thinking as a result of architectural conjecture. To investigate this relationship, it is proposed to build a computer-supported collaborative design environment using the tools of conceptual modeling, object-oriented algorithms, and distributed agents. Based on findings regarding the role of artifacts in collaborative design and a literature survey, this paper concludes with an outline of the requirements for the above system.

1 INTRODUCTION

In 1963, Steven Coons authored a visionary paper titled "An Outline of The Requirements for a Computer-Aided Design System" which set the research agenda in Computer-Aided Design for the next three decades (Coons 1963). In his paper, Coons predicted many of the capabilities that CAAD systems have now achieved as well as research issues that are still being pursued. "A computer system," he wrote, "to work in partnership with a designer, must have several clearly definable capabilities. It must be able to accept, interpret, and remember shape descriptive information introduced graphically." Furthermore, Coons predicted the need for computer-supported collaborative design:

> The Computer-Aided Design System should be capable of carrying on conversations with, and performing computations for several designers at several consoles substantially all at once. In this way each designer can be immediately aware of what the other designers are doing, and thus avoid one of the truly severe problems of intercommunication that designers face today.

Thus, instead of being the result of a recent realization that design proceeds by teamwork, the focus on collaboration is due to recent technological advances, both on the hardware and software sides, which, coupled with a maturity in the knowledge-base of group behavior and dynamics, have made it possible to support and enhance collaborative processes through technological interventions. With these developments in mind, and as indicated by its title, this paper was composed to reflect on the original work of Coons, but also to extend it to the researchable issues of the present.

Beginning with a re-investigation and critique of various views of the design process, the following section attempts to establish insights into its fundamental nature as a social phenomenon. The particularity of this social activity, however, can not be exclusively established through abstract theories. Therefore, in section three, a case study is presented that analyzes the *everydayness* of designers in the professional workplace by placing emphasis on the role of its most apparent and persistent manifestations: the design-related artifacts. Insights into how people co-operate and the role of technology in facilitating this process can also be gained by studying the body of knowledge created in other disciplines. One of the most relevant disciplines to the topic of this paper is that of Computer-Supported Co-operative Work (CSCW) which constitutes the focus of section four. In particular, this section will survey work discussing such issues related to design as the use of drawing surfaces, artifacts, and gestures. Based on a distilling of knowledge gained from theories of architectural design, phenomenological observations and a review of relevant literature in other disciplines, an outline of the requirements for a computer-supported collaborative design system and a discussion of future directions concludes this paper.

2 THE DESIGN PROCESS REVISITED

Many design methodologists, over the years, have described design as a process consisting of definite steps or stages. The goal behind such descriptions is to draw a picture of design as a rational, systematic and deterministic process in an attempt first to externalize the methods and rationale used by designers in order to emulate or enhance them and second to define a *science of design* (Markus 1969), (Simon 1981). Most of these methods divide the design process into three stages: analysis, synthesis and evaluation. The weaknesses of this abstraction are then counter-acted by an extensive use of return loops to preceding steps which is due to a realization that the design process is not as linear or simple as first thought. It, thus, becomes apparent that the degree of insight into the design process provided by the above rationalistic approach is rather questionable. As Lawson has argued, a plausible reason for the inherent weakness of these design process charts is that they "... seem to have been derived more by thinking about design than by experimentally observing it, and characteristically they are logical and systematic" (Lawson 1990). Such objections to a systematic approach to design, however, had begun to appear even before the adoption of the Kuhnian paradigm shift in scientific inquiry (Kuhn 1970). As Broadbent notes, "Systematic design methods, so far, have tended to complexity and abstraction to such an extent that few practicing architects believe that they have much validity in the 'real' world." The reason for such rejection, he continues, is that "... up to now, there has been a tendency in developing 'systematic' design methods, to take techniques which happen to be available, and to force these onto design, without questioning their actual relevance" (Broadbent 1969).

Although the description of architectural design as a sequence of steps still re-emerges, slightly modified, in recently published papers (Carrara et al. 1990), this rationalistic model is now regarded as a misguided approach to understanding design (Coyne and Snodgrass 1991). Researchers such as Coyne and Snodgrass, Schön, Habraken and Gross, for instance, argue for alternative design theories and methods in which the understanding of design's nature stems from the return to the everydayness of the designer. By utilizing the hermeneutics of Gadamer and Heidegger and the pragmatism of Dewey, Coyne and Snodgrass have argued for a method that "represents a paring away of esoteric and abstract theories and models used to explain everyday phenomena, such as language and thought." According to this approach design is viewed as a phenomenon of human praxis that can be explicated through interpretation: "The approach adopted in unfolding this argument is to follow the hermeneutic account of how understanding in any area of endeavour is acquired" (Coyne and Snodgrass 1991). Schön's research could be viewed as an instance of such a phenomenological account. In agreement with Coyne and Snodgrass, Schön has argued that the patterns of reasoning employed by designers while designing do not "significantly differ from reasoning in everyday life" (Schön 1988). Yet, through his introduction of the triad of rules, types and design worlds, he provides further insight into "the designer's ways of knowing" by focusing on the dialectic relationship between the objective and subjective aspects of design.

Another attempt to explicate the complexity of design, has been made by Habraken and Gross. By employing games as metaphors to designing, Habraken and Gross seek to provide a more profound understanding of design, but due to their methodology, they are also able to introduce the issue of collaboration into their inquiry (Habraken and Gross 1988):

> When designing involves the interaction of many actors, all involved with transforming an artifact, we see similarities with board games ... One of the most difficult aspects of

> understanding designing has always been that too many divergent acts occur simultaneously, defying simple description. We found it useful to develop a set of games that each isolates and focuses a single aspect, each giving a clearer picture of what just some of designing is about.

According to the above views, then, descriptions of design as a sequence of steps does not offer sufficient insight into the complexity of the social interactions that take place in its development. Thus, instead of attempting to examine it as a linear process, design should be approached as a collaborative activity taking place in various settings. As Schön has noted, design should be treated "not primarily as a form of 'problem solving', 'information processing', or 'search', but as a kind of making" (Schön 1988). Yet, a more profound understanding of this notion of design as making could be reached through further exploration of the context in which it occurs, that is the design settings. As the primary environments in which designers bring to bear their private and shared design worlds, design settings not only enable communication, but also promote the co-operative resolution of a design situation. As it will be shown below, on the other hand, due to their focal and prominent position within design settings, a study of the physical and virtual artifacts could provide considerable insights into one of the most fundamental aspects of design.

3 THE ROLE OF ARTIFACTS IN COLLABORATIVE DESIGN

Rather than constituting mere information holders, whose importance has been acknowledged, but also underestimated, artifacts are at the heart of designing. Ömer Akin, for instance, views architecture as a direct effect of a dialogue between representation and the idea (Akin 1982). He writes:

> Architecture, then, rises from a representation of an architectural idea that in turn results from the very special and painstaking interaction between representations of the designer's mind and representations on paper, in books, in computers, and/or in physical models. Representation allows thought and design to take place.

If Akin's comments are extended to include collaboration, one can discern the fundamental dialectic and collaborative nature of what is called *designing*: a concerned social activity that proceeds by creating architectural elements to address a set of requirements and their re-thinking as a result of architectural conjecture.

When viewed in relation to collaborative design, artifacts acquire an additional role. Since they constitute the embodiment (representation) of design ideas and actions, they become a major means through which communication is achieved. In order to get at their specific roles in collaboration, a case study was conducted in which designers at the professional workplace were observed utilizing a phenomenological methodology which focused on participation in the everydayness of the designer as well as casual discussions, collection of artifacts, note-taking, and detailed descriptions of insightful events. Due to space constraints, only a summary of the results can be included in this paper.

3.1 A Case Study

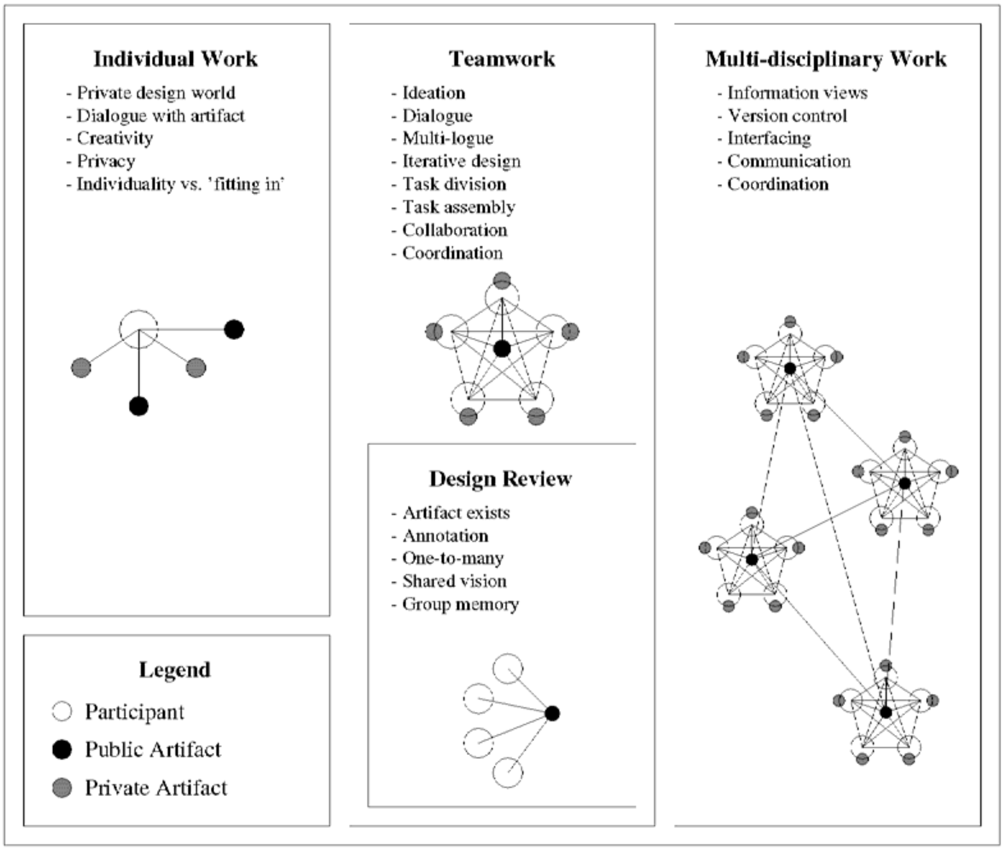
Focusing on the actions of designers as they unfold in their natural setting, the architectural office, allowed for a kind of knowing that is not available otherwise. This knowledge, as Schön writes, can be derived not through technical rationality, but through observations of the actions of the designer: “It seems right to say that our knowing is *in* our action. And similarly, the workday life of the professional practitioner reveals, in its recognitions, judgments and skills a pattern of tacit knowing-in-action” (Schön 1985). Through the case study, several observations were made regarding the role of artifacts in collaborative design. When visiting the architectural office, one is struck by the large number of artifacts that surround the designers (see figure 1-a and 1-b). This seems to confirm Schön's notion of designers being *immersed* in design worlds (Schön 1988). One can also discern the degree to which teamwork and hierarchical social structures are present in the office through a study of the layout of the spaces. In the aforementioned case study, the studio space was partitioned into four areas (each having four workstations) separated by modular low partitions (see figure 2). Each of the quadrants served as a 'project room' where a design team was assembled to collaborate on the same project. Hierarchy was also evident in the delineation of a main studio space, secretarial pool, offices for senior architects, accountants, marketing, partners and offices for the president and his partner.

The case study reached a conceptual framework for design activity according to which, design work can be divided into three categories: Individual work, teamwork and multi-disciplinary work (see figure 3). This framework was used as a beginning point for the exploration of the different design settings in relation to the artifacts and interactions taking place within them. The figure below illustrates the relationship between the designer and the artifact and delineates the issues and activities associated with them. Due to their relevance to the scope of this project and their availability for observation, only two of the three categories were addressed in the case study.

Figure 1: **(a) Material Samples in Library and (b) Archived Projects.**

Figure 2: **General View of the Office Showing Two of the Four Project Spaces.**

Figure 3: **A Conceptual Framework for Design Work.**



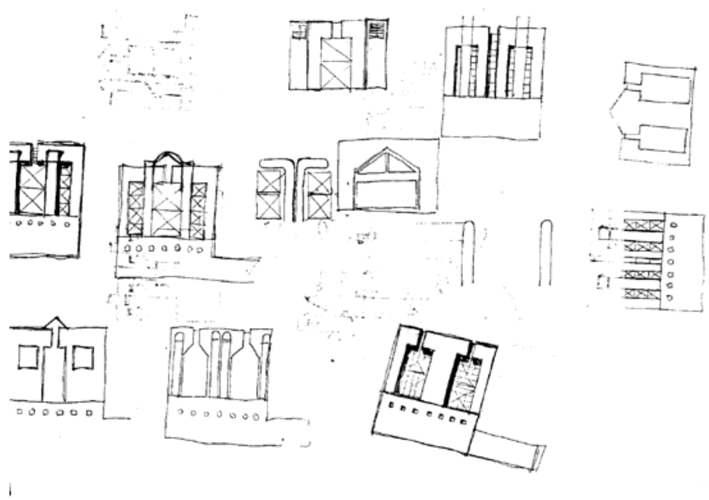
3.1.1 Individual Work

Even though this paper focuses on collaboration, processes that are carried-on individually should not be ignored because they form the building blocks of any collaborative process. Schön describes individual design as a dialogue, mediated by an artifact, between the designer and the design situation (Schön 1983). He describes this dialogue as a reflective situation in which back-talk between the designer the designed occurs.

Artifacts produced in an individual design setting can be viewed as sharing two dichotomous characteristics: divergence and convergence. While providing divergence by broadening the design space under exploration, the depiction of multiple alternatives, also leads to the elimination of undesirable solutions and, through progressive refinement, to convergence on satisfactory ones. The sheet depicted in figure 4, which was created during an individual and private process for the purpose of exploring facade alternatives, serves as an illustrative example. The large number of small-scale drawings include in it is indicative of the designer's effort to explore a multitude of design solutions. On the other hand, the increasing detail that is incorporated (e.g. shadow rendering, fenestration patterns) in some of the sketches is characteristic of the occurence of a synchronous process of convergence.

Another characteristic of individual work is that it can also be conducted within a group setting. During one meeting, a designer withdrew from active participation in the meeting in order to draw some sketches on the side (see figure 5). He later re-joined the discussion and used the sketches he had created as supports for his argument. This seems to corroborate a similar experience reported in (Tang and Leifer 1988):

Figure 4: **Divergence and Convergence While Exploring Alternatives.**



> For example, in Session A, one participant began to sketch a drawing in a private area of the workspace, demonstrating apparent loss of interest in the discussion and sustaining his own interest by doodling. The others eventually directed their attention to his drawing, and yielded a turn to him, asking him to explain it.

Artifacts created within an individual setting vary in roughness, completeness and clarity. These attributes depend on the creator's preferences, the mode of creation and intended mode of use. One can almost derive the purpose and mode of creation of an artifact from its inherent attributes (see figure 6). If an artifact is created at a meeting, it will most likely be rough and incomplete because it is drawn fast. Speed is also the reason certain types of artifacts are *not* chosen as vehicles to discuss ideas. For example, it is rare to see three-dimensional models being patiently constructed during design discussions.

Figure 5: **Individual Sketching Within a Group Setting.**

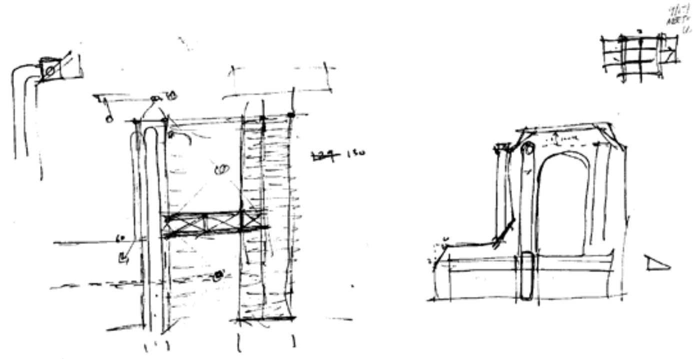
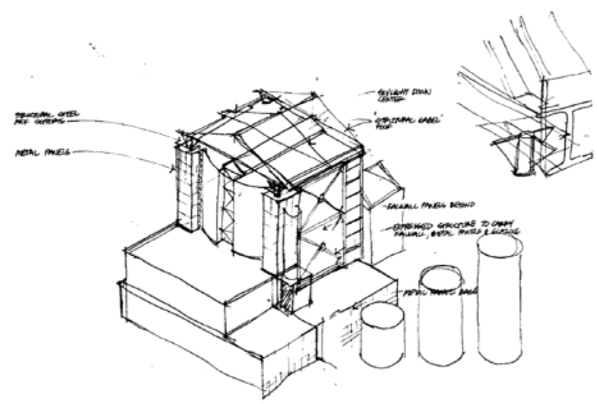


Figure 6: **Artifact Generated to Support a Design Discussion.**



3.1.2 Team Work

In the case study, teamwork was studied within two settings: the formal and informal. However, due to space limitations, only the latter will be discussed here. Teamwork in the informal mode is ubiquitous, but, nevertheless, inconspicuous. During the course of a typical day, the designers in a team interact in a complex and continuous way with a range of interactions covering simple requests, spontaneous gatherings, handing a memo, illustration of a concept, discussion during lunch break and many more. These interactions are said to be inconspicuous because they are so much immersed in the day-to-day habits and practices that one usually tends to overlook them. The general impression, of the studio space is that designers seem to be working individually without much interaction. Yet, when observed for longer periods of time, it becomes evident that they continuously interact, sometimes in parallel with performing their individual tasks.

For example, one observation was of a designer who casually stopped by the desk of a fellow team member to request information (see figure 7). The latter responded, again casually, neither lifting his sight from the drawing he is working on, nor halting his work. This implies that designers carry on collaborative tasks transparently as part of their everydayness.

Other observations support the notion that artifacts are the primary vehicles through which design progresses. During one of the informal meetings, a senior level architect was explaining a design idea to another junior-level architect (see figure 8-a). Throughout this meeting, the senior architect was expressing himself mainly through drawing actions. At a certain point, the two architects were joined by a third (see figure 8-b) who initially observed the discussion, but did not participate. A few minutes later, the third participant left the meeting momentarily (see figure 8-c) and returned with a document (a specification catalog) containing information pertinent to the discussion. Furthermore, during the whole span of the meeting, at least one participant was looking at the artifacts being discussed rather than at the other two participants (see figure 8-b). These observations indicate that artifacts endow the discussion with a sense of reality and allow the designers to "project" the ideas onto the discussion. This notion of projection is articulated by (Coyne and Snodgrass 1991) as follows:

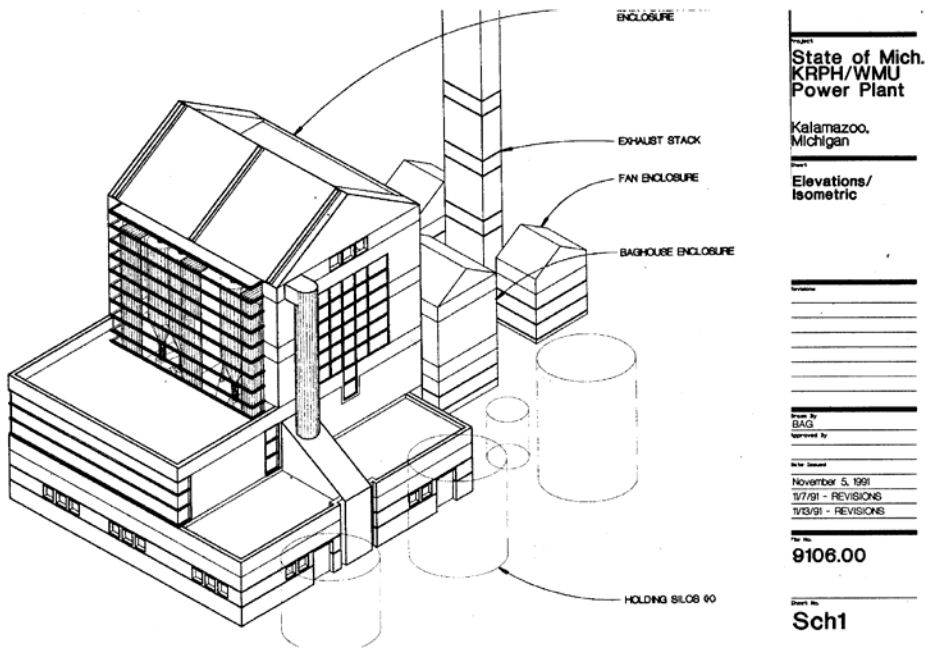
Figure 7: **Casual Interactions .**

> The act of designing involves the projection of a partial design onto a particular design situation. The match or otherwise between this projection and the situation as it presents itself brings objects to light and changes the game.

Finally, it is interesting to note that the attention and care by which artifacts are annotated, categorized and stored has other significations and purposes than clear unambiguous communication to others. Finished drawings usually contain a "title block" that clearly identifies the number of the project, the title, and scale at which the drawing is depicted, but it also notes the name of the person who created it and the name of the person responsible for it (see figure 9). The reason behind such care and accuracy is that these drawings are in many cases legal documents and the firm can be held responsible for any errors they might contain.

Figure 8: **Informal Design Discussions in the Studio Space.**

Figure 9: **Annotation of Finalized Artifacts.**



4 COMPUTER-SUPPORTED CO-OPERATIVE WORK

Having gained an insight into collaborative design through a theoretical discourse as well as an empirical one in the previous sections, the focus will now turn to a review of research work conducted within the field of Computer-Supported Co-operative Work (CSCW) which relates directly to the topic at hand and contains valuable information and knowledge of how technology can facilitate the ways in which people co-operate. CSCW is a multi-disciplinary field of research that is defined according to (Greenberg 1991) as: "... the study and theory of how people work together, and how computer and related technologies affect group behaviour." One of the topics researched within CSCW, and of interest here, is that of collaborative design.

A number of researchers have emphasized the sharing of drawing surfaces as an essential feature of collaborative design. Bly's paper "A Use of Drawing Surfaces in Different Collaborative Settings," clearly makes this point, but also suggests that activities other than drawing are equally significant: "[The] drawing activities (the actions and their uses) might be as important to collaborative design work as the resulting artifacts (the marks on paper comprising drawing clusters)" (Bly 1988). Attempting a more specific description of the activities that fundamentally influence the process of designing, Minneman and Bly have noted that "... participants regularly combine marking activities with talk, that they rapidly move among drawing, writing, and gesturing, that they interact on the same drawing marks, and that they use marks and gestures to illustrate and reference ideas" (Minneman and Bly 1991). It is important here to point to the direct correspondence between the above view and that of Schön which specifically refers to architectural design: "Drawing and talking," he writes, "are parallel ways of designing, and together make up what I call the *language of designing*" (Schön 1983).

While the above research examples focus on the issue of sharing drawing surfaces as a means of promoting collaboration, Tang and Leifer have attempted to view it as a means of enhancing the creative process itself: "In addition to helping store information and convey ideas, the workspace also plays an active role in the process of developing ideas" (Tang and Leifer 1988). Due to their observations on the limited ability of conventional CAD tools to adequately serve the creative aspects of collaborative work, Tang and Leifer's account acquires even more relevance to the objectives of this paper. On the other hand, the two key features that they propose for the facilitation of the collaborative development of ideas could be viewed as initial steps toward the development of future computer systems. These features consist of:

> a) being able to readily try out representations of ideas in the public workspace, and b) having those representations gradually evolve into distinct artifacts, often through other participants building on and modifying them.

Focusing on topics more pertinent to the available computer technology, Olson and Bly have introduced into the discourse the issues of space and time distribution. Through an in-depth analysis of *communication* and *interaction* in the design process, Olson and Bly have arrived at the conclusion that supporting the more focused and task-oriented processes is more critical and effective than supporting open-ended and informal ones (Olson and Bly 1991). This focused process, according to them, posses the following list of characteristics:

- It is highly interactive, requiring dialog in real time;
- It generally requires a shared workspace as the focus of that interaction, to create a visual record or representation of the interactions;
- It often requires additional reference material—notes, documents, manuals, etc.;
- It requires some record of past interaction, even though it may be highly informal—memory of work group members (e.g. "Do you remember why we came up with that solution?").

Due to the nature of architectural design as an essentially mission-critical, concerned and collaborative activity, Olson and Bly's findings could directly inform the process of building future computer systems.

5 CONCLUSION

This paper was authored in order to ground a research agenda on collaborative design in the theoretical, empirical, and inter-disciplinary work that has been generated so far. Given this baseline of knowledge, it is hoped that researchers and designers of future systems will be able to extract useful guidelines and avoid some of the pitfalls they might otherwise face. Yet, it also serves as the theoretical underpinning for a proposal to construct an environment for computer-supported collaborative design. Thus, beginning with a brief discussion of a theoretical and methodological approach to the task of creating such a computer system, this section will conclude with a reference to a series of associated requirements and guidelines.

This paper began by advocating a *hybrid* approach to addressing the issues of computer-supported collaborative design. As indicated in the previous sections, theories of design and group dynamics, phenomenological observations, empirical data, and knowledge generated in disciplines outside architecture can combine to fully inform efforts to construct supports for collaborative design. By adopting varied perspectives and methodologies, it is hoped that relevant critical issues will present themselves in ways otherwise not available.

Design is complex. Thus, rather than engaging in the futile effort of depicting it with simple and linear processes, one should embrace its subtleties, serendipities, and complexities and use them to one's advantage by designing for breakdown and the unexpected (Winograd and Flores 1987), (Ehn 1988). Furthermore, *design is collaborative*. Traditional views of the architect as lone hero and primary creator of a work of architecture have been replaced, due to a paradigm shift, with a recognition of collaboration not only as a means to respond to the increasing complexity of architectural tasks, but also as a means to enhance the discipline as a whole. It, then, becomes apparent that future CAD systems must be able to address various issues of collaboration because the inclusion of various agents (client, contractor, consultant, user, ...) into the process as well as such capabilities as computerization, standardization, and integration is not simply a practical solution, but a way of assuring architectural quality.

Design is making and as such requires special emphasis on the action of making as well as the thing being made, i.e. the artifact. Computerized tasks should fall from the reflective world of present-at-hand to an unreasoned and spontaneous readiness-to-hand. As a prerequisite, however, these tasks should be absorbed into the background of and become indistinguishable from the designer's everydayness, tradition and praxis. Virtual artifacts, on the other hand, need to be brought closer to the designer's world of concerns so that they are endowed with such attributes as objectiveness and identity not dissimilar to those found in physical artifacts. That is, there exists a need to maintain a seamless continuity in the representation and treatment of the physical and the virtual. An ability for un-impeded capture and incorporation of physical design sketches into the set of private and shared virtual artifacts, is certainly one way CAD systems could achieve the afore-mentioned goals.

Metaphors of design, and especially those of design worlds and settings, are essential for the development of shared virtual workspaces and drawing surfaces. While these would serve as the holding environments for design artifacts and histories, they can play an even more important role as centers of gathering and interaction, thus fostering communication and collaboration. For that to happen, these virtual settings should be able to convey different modes of communication, such as talking, drawing, gesturing, writing, and model building. By being linked to worldwide multi-media information networks, they could provide access to a wealth of ideas and resources that will considerably broaden the designer's horizon.

A computer system, to ultimately benefit the design enterprise, must be deployed judiciously, put to use at the earliest possible stages of the process, and be able to follow its developments. Thus, beginning from technology support for client briefing, computer systems should be able to assist designers in creating, representing, modifying and reasoning about one of the first, but most basic documents associated with a particular project: the building program.

Though often characterized by complexity and dynamic relationships and requirements, a building program also represents the most specific and precise aspect of an architectural project. It is due to the later attributes that building programs constitute prime candidates for computerization. Once a building program exists within the realm of the computer, opportunities for collaborative manipulation of its elements become available. Based on a mapping of the representations in the building program, computer systems could support a collaborative process during which designers, clients, project managers, consultants and others engage in the creation, manipulation and refinement of its graphical, textual, and organizational entities. Yet, given the dynamic and social nature of collaborative design, computer systems should also posses a temporal awareness by employing timelines, design histories and other version control mechanisms as well as ways of defining social and hierarchical roles. Current efforts in conceptual modeling of buildings, reasoning about user intent and the use of object-oriented approaches and distributed artificial agents will greatly facilitate this process.

As indicated in earlier sections, the developments of architectural ideas, which designers often view as the essence of architectural creation, significantly depend on the production of multiple, ambiguous, incomplete and abstracted graphic representations. Computer systems should take advantage of the virtual artifacts' unique ability to dynamically represent themselves in different ways by customizing the amount and resolution of information they present to the user. Such mechanisms, however, should avoid the brittleness usually associated with current systems by allowing for a variation in the granularity of control and the implemented protocols of interaction. Brittleness should also be avoided by ensuring a degree of tolerance for incomplete or inaccurate data. Ideally, if a computer system's performance is to degrade it should do so gracefully – that is, at a rate proportional to the amount of missing or erroneous data.

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