Expert and Situated Actions in Collaborative Design

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Abstract: This paper considers one of the fundamental questions behind research and implementation into collaborative design systems for architectural design: To what extent is design situated and to what extent is it expert behaviour? Extending from this question arises implementation questions for CSCW systems for architectural design. The authors propose a cognitive model of design and tested the model experimentally. From the results of the experiments, a discussion is presented of the expert and situated facets of the design process which have been manifested.

Keywords: collaboration, CSCW, group work, design

I. Collaborative Architectural Design

Research into the role and application of computers to communication and collaboration to support work done in groups (see Holtham,1994 for a historical overview) provides a background to the work described here. While it is not necessary here to review the various directions and conclusions of the great wealth of research which exists, it is useful to note that computer mediation has been found to impact the collaborative process in significant ways:

- Process structure benefits (Nunamaker, Briggs & Mittleman 1995)
- Greater participation (Kiesler & Sproull 1992).
- Better results: (Kraemer & Pinsonneault 1990)

Design activities pose an interesting environment in which to examine these claims. Some researchers have suggested that social processes should play a critical role, thus distinguishing design as a different activity and one that therefore requires different types of interface support. In particular, we are interested in the need for the communications medium to permit participants to achieve sufficient social process communication. It is postulated by some that these social communications are fundamental to achieving necessary social communication. For example, Harrison and Minneman (1995) argue that Xerox PARC research on collaborative work reaches a common conclusion:

"that social processes are crucial; that these social factors are significantly affected by being physically distributed; and that design participant’s social actions are altered by the technologies that connect remote locations.” (p. 687)

We question the extent to which design is a situated event and suggest that it exhibits interesting characteristics of both expert and situated behaviours. Thus, similar to Harrison and Minneman we examined the process of collaborative architectural design but reached very different conclusions. If our findings are correct, then computer support for these tasks needs to be re-thought.

II. Architectural Collaboration: A Cognitive Perspective

Our approach to understanding the collaborative process is founded on the assumption that two experts collaborating to solve a problem will look very similar to one expert solving a problem. We therefore based our predictions regarding collaboration on a fairly traditional cognitive model of expert problem solving. Each participant is considered as an individual agent working largely in parallel with other agents to achieve a common goal. Given that the subjects used in this experiment were experts in the task domain, the hypothesised model of collaboration was constructed following previous research on expert problem-solving patterns.

Experienced architectural designers working collaboratively on a problem should behave like typical experts in any other area of expertise. They should have larger chunks of knowledge which they can apply quickly and in a fairly error free way. They should also be able to work forward from the initial state of the problem (novices tend to use strategies such as working backwards from the goal). Furthermore, they should be able to reason by analogy from a large base of well cross-referenced knowledge about the field. Experts also plan better and monitor their progress more carefully (see Bedard and Chi, 1992, for an extensive account of expert/novice differences).

Experts demonstrate very consistent patterns of processing demonstrated on well-learned tasks. This allows prediction of the problem-solving process with a significant degree of detail. As stated, the central hypothesis of this
research is that collaborative work by experts will look very much like individual expert work. There are additional processes, those we have labelled as meta-planning, negotiation, and evaluation, but even these might be construed as interactive extensions of processes that individual expert problem solvers carry out.

According to our model, the first step of the collaborative problem-solving process is meta-planning, where the collaborative agents create a top-down control structure to co-ordinate their activities. That the best architectural practitioners place great emphasis on the initiation of design exercises has also been documented in earlier work on the process of design (e.g., Coxe, 1989; Cuff, 1991). Once a meta-plan has been agreed upon, the participants set to work on the problem. Each participant receives certain tasks to do, works on them, passes on the results, and proceeds to the next task. Ideally, the first meta-plan results in a solution to the problem but there are three other possibilities: 1) the system produces no answer, 2) the system produces a wrong answer, and 3) the system encounters a stopping problem. Case 1 would occur when the meta-plan was set up only to meet an intermediate goal while case 2 would occur when the meta-plan was inadequate to meet either an intermediate goal or the final goal. In either case the participants would need to re-negotiate the control structure. The stopping problem is similar but more complicated. The stopping problem occurs when it is unclear if a problem space will result in a solution or will lead to endless calculation. The dilemma is whether to stop or wait for a solution. If a participant determines that a procedure is taking too long he could decide to stop and re-negotiate the control structure. This is essentially a process of independent task planning that is executed separately by each collaborator.

In addition to the problem-solving process, collaboration will involves many other elements including personality, emotion, culture, and many other social / psychological factors. The approach we are taking here argues that these do not have a significant impact on the measurable outcome of the collaboration or on the process of expert problem-solving. We argue that this is primarily shaped by the skills and expertise of the participants - i.e., the knowledge component of the collaboration rather than social or situational ones. Contrary to Harrison and Minneman (1995) we therefore argue context effects, socio-cultural variables, and other non-knowledge level individual differences may very well influence many aspects of collaboration but they do not alter the participant’s knowledge level, which is the primary determinant of the collaborations outcome. Such may affect things like the degree to which the collaboration is enjoyed, but the real result of the collaboration, in this case, an architectural design, will be unaffected by them. A great deal of research in cognitive science supports this view (see Newell & Simon, 1972, for an account of this perspective), and it is the goal of our research to test this hypothesis empirically in the context of collaborative architectural design.

The general model of collaboration proposed here which will be evaluated in these studies is shown in Figure 1. The first step involves a process of planning how to execute the task in a co-ordinated way. It is a "meta" planning process in the sense that it is about how to break down the problem into individually manageable units as well as about how and when the collaborators should come together to integrate their individual efforts. This process is followed by another co-operative step - negotiation regarding specific aspects of the design problem. Following an initial negotiation, each expert participant separately engages in well-learned routine problem-solving guided by the meta-plan that was agreed upon and constrained by the jointly-made, task-specific negotiated decisions.

Participants interactively evaluate the outcome after they have completed their agreed upon components and are then either finished or they iterate through the steps again. The process may begin again following further task-specific negotiation or more general meta-planning. If the proposed model is correct then the tools used to support collaborative work should be aimed at facilitating the meta-planning, negotiation and evaluation components of the process. Aside from this, the tools need not be any different than those used for individual work, except for requiring a means to share the results.

The participants combined performance was measured in terms of degree of completion of the design and as well as its quality. We predicted that more restricted channels of communication would require more meta-planning in order to better utilise the available band-width. In this paper we examined video conferencing (high

![Figure 1](image-url)
The results were very clear. Subjects made no attempt to construct explicit plans for structuring the collaboration or the task, either in the video conferencing condition or in the chat line condition. Instead, subjects simply began work and dealt with issues, such as the division of labour and the design process, in an ad hoc manner. However, despite not having a formal agreement on how to proceed, subjects seemed to flow naturally from one task to the next. Not once did our subjects reach an impasse in deciding the direction of the design. Disagreements were extremely minor and quickly resolved.

In order to more empirically ascertain the nature of this interaction we looked across subjects at the order in which tasks were completed. What we found was a strong tendency for different pairs of subjects to approach the problem in the same way, indicating an implicit agreement across subjects as to how to proceed. For example, all subject pairs first went over the design specifications and then began with the parking lot. Following this they proceeded to sketch in either the circulation (e.g., paths and roads) or the locations for the other structures (e.g., the playground). The landscape details (e.g., gardens, ponds, trees) always received the lowest priority. As it turns out this way of dividing up the tasks represents formal units of architectural analysis that our subjects would have learned. The order too, working from the largest and most constrained elements (i.e., the parking lot) down to the most flexible elements (i.e., trees and flowers), is the general approach that these students were most familiar with. In addition there were differences between the landscape architects and the architects. Specifically, the landscape architects always gave a high priority to zoning the structures, completing this task first and working in the circulation after. In contrast, the architecture students focused on the circulation as a design element (i.e., they used the circulation to create patterns) and tended to work in the structures around it. Checking with their instructors we learned that this observed difference reflected a real difference in their training. Specifically, the landscape architects were explicitly taught to do the zoning first, while the architects were taught to focus on design themes, for which the circulation provided them with a means to "tie" the design together.

In order to evaluate the quality of the finished product we had the results independently graded by two lecturers from the University of Hong Kong Architecture Department. Agreement between the two markers was quite high (80% overlap in the rank order of the grades). The disagreements were minor and were resolved through discussion. Subjects were graded according to the percentage of the required design tasks they completed, the degree to which they satisfied the technical requirements of the tasks that they did complete, and the overall quality of their design. A reliability analysis revealed an Alpha coefficient of 0.877 indicating that all three measures were tapping the same construct, which we assumed to be a general competency for the task. Taking an average of the three measures to create an overall score, the two groups (video conference versus chat line) showed no difference, both producing a mean overall score of 6 out of 10. Although the number of subject pairs was too low to rule out any effect for the conferencing technology we could rule out the existence of any large systematic effects. This, despite the very real limitations imposed by the bandwidth in the chat-line condition (i.e., in the video conferencing subjects could talk and draw at the same time whereas in the chat-line condition they could only do one at a time).

The protocols were encoded according to two schemas. One followed the collaboration model described above, identifying the communication exchanges that fell into the metaplaning, negotiating and evaluation steps. It was observed that individual work continued throughout the working period so this was not encoded discreetly. The results of this encoding showed that the participants engaged in the same amount of metaplaning, negotiating and evaluation regardless of the bandwidth available. In both chat line and video/audio communication, the participants exhibited these three exchanges in the same ratio of 1:5:2. Thus, we can conclude that the collaborative model was followed in the same way regardless of the bandwidth available.

III. Experimental Test and Results

An architectural design problem was devised to test the hypothesis in a collaborative setting. Two rooms were each equipped with Pentium computers. The computers were wired for video conferencing and were connected by a local area network. We used Microsoft's NetMeeting has provided a shared electronic white board and which supports remote audio, video as well as a chat line. For the audio we used headsets with a connected microphone so that subject's hands would be free. For the video we used Connectrix's Color QuickCam for Windows. All connections passed through the wall so that, with the door between the rooms shut, subjects were cut off from any direct communication.

The participants were given a written problem definition and a site plan. Details of the design problem and the resulting protocols can be found in Kvan, West & Vera, 1997. It is sufficient to note here that the problem required the participants to design a small park on a sloping site squeezed between building in an urban setting, using architectural or landscape elements to solve problems of parking and circulation.

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We then encoded the protocols according to the level of design content embedded in the exchange. We identified four types of communication occurring:

- high-level design communication, which encompassed strategic and significant decisions
- low-level design communication, such as the colour of a line or placement of a detailed item (such as a bench)
- task-oriented exchanges, such as reading instructions
- interface-oriented exchanges such as “speak up please”

When the protocols were encoded in this way, we found that the participants accommodated for the lack of bandwidth by dropping most of the low-level design communications as well as the task-oriented and interface-oriented communications, reserving the bandwidth for high-level exchanges. High-level exchanges rose from comprising only 22% of the video/audio communication to being 50% of the chat line communication.

Finally, it should be noted that there was, in addition to the regularities described above, considerable variability in the final design products and the ways in which they were created. For example, some subject pairs worked together on each design element while others worked in parallel on different elements. Also, some subject pairs worked in a very egalitarian, democratic manner while other pairs were dominated by a single authoritarian subject. However, despite the variability in the way that subject pairs organised themselves, the behaviour of the subject pairs towards the task was predictably based on expert knowledge. This pattern of work methods has been noted in other design observations (Maher, Cicognani & Simoff, 1997).

IV. Discussion

In a classic experiment studying expert-novice differences in reconstruction of chess boards, Simon & Chase (1973) found that experts recall a larger number of meaningful chess patterns than novice subjects. Simon & Chase argued that the apparent superior skills of chess experts are attributable to the large number of memory “chunks” stored within long term memory. From this finding, qualitative and quantitative accumulation of knowledge/schemata and their organisation have been seen generally as critical in explaining expertise. Internal knowledge is therefore the differentiating characteristic of an expert and studies of expert problem solving behaviours focus on this.

Our initial model for design sprung from this assumption and predicted that collaborators would generate a task meta-plan to guide them through the process of solving the design problem. This meta-plan would be based on chunks of expertise they have accumulated to guide them efficiently to a good design result. This turned out to be wrong — no evidence was found of varying levels of meta-planning when the channels changed. Meta-planning did not seem to guide govern the way the subjects handled the different bandwidths available. In fact, the protocols indicate just the opposite: a dynamically created flow of joint problem-solving that looks very situated. If our analysis of the collaboration were to stop here, we might conclude that collaboration needs to be understood as emergent distributed cognition, a process which is not capturable at the level of an individual's knowledge and processing. However, if one looks at the protocols across all the subjects there was a remarkable consistency in the way the problem was approached and solved. Subjects filtered out the less important communication and used available bandwidth effectively, apparently without any conscious effort or co-ordination to do so.

The research described here flies in the face of assumptions made by several others that have worked in the field of computer-mediated collaborative design. Typically other research is driven by the need to recreate a “design space” in all its properties, without critically evaluating the contribution of these properties to design outcomes. An example of such work is that found in Tang (1991). Here, the author identifies actions of “writing, freehand drawing and gesturing activities that occur when three or four people work around whiteboards or large sheets of paper,” noting that

“collaborative drawing tools should not be based only on what features computer technology offers...the design of collaborative technology needs to be guided by an understanding of how collaborative work is accomplished. By understanding what resources the collaborators use and what hindrances they encounter in their work, tools can be designed to augment resources while removing obstacles.” (p. 143)

While we agree with this point that the design of tools for collaboration should be based on a good understanding of the process, the author goes on to conclude that gestures are as important as any other communication and that

“...design of tools to support collaborative drawing activity should consider:
- conveying gestures, maintaining their relationship to the drawing space;
- conveying the process of creating and using drawings, with minimal time delay;
- providing concurrent access to the drawing space;
- allowing intermixing among drawing space actions and functions; and
- enabling all participants to share a common view of the drawing space.” (p. 156)

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Our findings also point out some of the important problems with the standard model of expert behaviours when applied to the design process, pointing up a useful opportunity to examine the extent to which design is situated or not. While it cannot be denied that the context within which an activity is carried out will affect the outcome, it is clear that we are, as humans, adaptive to our environment (we learn to shut out the noises which interrupt us as we design) and adaptive of it (we find that shutting a window helps to control the noise). Although we exist in an environment with infinite levels of complexity, we solve each problem and make each decision in a much more restricted informational context (Simon, 1957). So it is in any collaborative communication - we adapt to it and we adapt it to our needs. Since our individual cognitive systems are not built to cope with the full complexity of the environment at any one time, we pick out what is relevant and necessary and proceed.

The pattern of problem-solving found in this study reflected the knowledge the subjects had (from their architecture classes) regarding how to solve this kind of problem. So, although the collaboration looks very situated, it is, in reality shaped and guided by the collaborators' individual knowledge of the task. This fact becomes observable in this study because we controlled the knowledge background of our participants.

In some ways, the results presented here seem very obvious: Experts in a particular area of knowledge solve problems in consistent and regular ways. However, much has been said recently about the special nature of collaborative work, especially on open-ended, creative problem-solving tasks such as architectural design (notably from researchers associated with Xerox PARC, e.g., Tang, 1991; Harrison and Minneman, 1995). Following this argument, it has been proposed that systems to support collaborative design must be high bandwidth tools which communicate a very substantial volume of information on the context of the process - facial inflections, vocal expressions and gestures in addition to the immediate product of design such as drawings, texts and models.

Designers do receive feedback from the process, the actions, the materials and the exchanges of design itself. Indeed, designers will talk about the importance of drawing and how the act of drawing is a conversation with oneself as much as a communication to others. It is through the drawings that designers identify, examine and solve problems. In a collaborative effort, these communications do assume an important communicative role as well as the discursive role they already hold in a singular process. Yet how important are the particulars of the feedback and to what extent does design still occur effectively without such a rich and broad context?

Zhang & Norman (1994) have observed that the expert behaviour model of cognition fails to accommodate these external representations, including physical symbols, external rules and constraints embedded in the physical settings. Similarly Hutchins (1995 & 1996) suggests that we should extend our cognitive model to include a larger extent of the world and that this external world acts to store and represent our knowledge. This interpretation gives the situated context of design a clearer meaning and explains the behaviours of the designers during collaborative exchanges better than does the explanation that design is deeply situated and depends upon a gestalt of the context.

The expert behaviour model also suggests that designers follow scripts (equivalent to moves in chess) which have proven to be effective in earlier situations. Clearly this cannot explain what we observed as the participants invented approaches and methods for solving the problem. Designers do apparently manifest a process that fails to be categorised sufficiently by the expert model. Nevertheless, we find that, through the messy protocol data as well as the varied social and communicative conditions, emerges the classic pattern of expert problem solving behaviour. The situated model is insufficient to support the design process in itself. What we have seen is a hybrid process in which the participants respond the situation in which they are working and both exploits its particulars and are influenced by its peculiarities. Our observations on the use of video, audio or text communications reinforce the findings. This suggests that collaborative design can occur without high bandwidth communication between the participants, even though the design process itself is influenced by the setting. Our findings suggest that design is substantially an expert activity in which the context of design provides stimulus and feedback but that the context is not a controlling feature of the process. Thus, a design support system can be effective if it facilitates the execution of the expert behaviour without fully rendering the collaborative context transparent. Indeed, much of what is taken as necessary situated behaviour and communication was removed by the participants themselves when the bandwidth was restricted, but their design products were indistinguishable from that produced in a more ‘situated’ setting.

References


Kvan T., R. L. West and A. H. Vera (1997): Tools and Channels of Communication, in Preprints of the Third International IFIP WG5.2 Workshop on Formal Design Methods for CAD University of Sydney, Sydney


