REQUIREMENTS FOR A MOBILE INTERACTIVE WORKSPACE TO SUPPORT DESIGN DEVELOPMENT AND COORDINATION

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ABSTRACT

Building design is a complex multi-disciplinary process that requires extensive collaboration to develop a coordinated design that satisfies the functional, aesthetic, and economic requirements of the owner. Recently, 3D design tools are gaining acceptance and providing significant benefits to the design coordination process. However, it remains unclear as to how such tools can be incorporated effectively into fully digital interactive workspaces to support 3D design coordination. This paper describes an initial set of requirements for accomplishing design coordination tasks in a computer-supported interactive workspace. We developed these requirements through: (1) observations of design development meetings in paper-based workspaces, (2) observations of 3D design coordination meetings in current interactive workspaces, and (3) experiments conducted in a state-of-the-art interactive workspace. We describe the work practices of design teams in these different workspaces, the benefits of existing collaboration technologies, and the functionality required to support 3D design coordination.

KEY WORDS

Interactive workspace, design coordination, visualization, 3D modeling, computer-supported cooperative work.

INTRODUCTION

Building design is a complex process that requires the coordination of multi-disciplinary and multi-organizational teams working under intense schedule constraints. The building design process is iterative in nature and involves the exploration and analysis of a variety of alternatives until a satisfactory solution emerges. A building is considered successful when the different discipline-specific designs are integrated into a harmonious whole in a way that satisfies the functional, aesthetic, and economic requirements of the owner.

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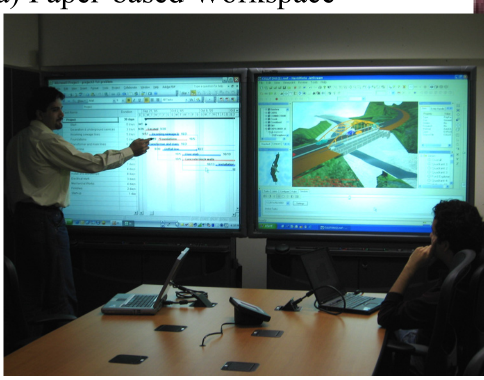
During the course of design, the different disciplines meet regularly to review the design of the various systems, and ensure that the team is making continuous progress towards a coordinated and conflict-free solution. Today, design meetings typically take place in physical workspaces, such as conference rooms, where all the relevant members of the team work together in the same place and time. Although most project information is generated electronically, teams primarily communicate and share information using paper-based representations (Figure 1a). Emerging technologies (e.g., touch-sensitive large-screen displays, table-top displays, laptops, and tablet PC's) offer great promise in enriching today's paper-based workspaces to create what are known as *interactive workspaces* (Figures 1b and c). Interactive workspaces are physical locations where people work, share, and use information together through electronic means. Research has shown that interactive workspaces improve the utility of project information and the quality of the decision-making process (e.g., Liston et al. 2000, Fox et al. 2000).

a) Paper-based Workspace

b) Current Interactive Workspace



c) State-of-the-art Interactive Workspace

Figure 1: Snapshots of Workspaces: a) Paper-based Workspace, b) Current Interactive Workspace (source: ENR.com), and c) State-of-the-art Interactive Workspace.

Recently, 3D computer-aided design (CAD) tools are gaining acceptance and providing significant benefits to the design coordination process (e.g., Staub-French and Fischer 2001, Khanzode et al. 2005, Kam et al. 2003). Using 3D design tools, design teams are able to integrate information electronically and identify potential design conflicts semi-automatically. Although the use of 3D CAD tools is well established, it remains unclear as to how such tools can be incorporated effectively into fully digital interactive workspaces where multiple groups of people work together to accomplish design development and coordination. There is a rapidly growing need to better understand these groups and their work practices for the purpose of developing better tools for collaborative interaction and visualization.

This paper describes an initial set of requirements for accomplishing design development and coordination tasks in a computer-supported interactive workspace. We developed these requirements through: (1) observations of design development meetings in paper-based workspaces (Figure 1a), (2) observations of 3D design coordination meetings in current interactive workspaces (Figure 1b), and (3) experiments conducted in a state-of-the-art interactive workspace in our visualization laboratory (Figure 1c). These requirements form the basis for a new Mobile Interactive Workspace (MIW) we are configuring for use during design development and construction coordination at project sites.

BACKGROUND ON INTERACTIVE WORKSPACES

Understanding group work inside interactive workspaces is already the focus of much study, particularly in the areas of human-computer interaction (HCI) and computer-supported cooperative work (CSCW). Olson and Olson (1997) and Dix et al. (2004) provide general reviews of the work in these areas. Classic work by McGrath (1984) provides a complete framework for understanding the kinds of tasks that take place in collaborative settings, most of which are relevant to interactive workspaces for building design and coordination. Many research examples of interactive workspace infrastructures designed to support group collaboration also exist, including the *ClearBoard* system by Ishii and Kobayashi (1992), the *Tivoli* system by Pedersen et al. (1993), the *GAZE* system by Vertegaal (1999), the *iWork* system by Johanson, Fox, and Winograd (2002) in Stanford's Centre for Integrated Facility Engineering (CIFE)'s *iRoom*, and the *Dynamo* system by Izadi et al. (2003). These systems collectively demonstrate there are tangible benefits to incorporating state-of-the-art technology and digital media into physical workspaces.

In the Architecture, Engineering, and Construction (AEC) domain, several research efforts are investigating the requirements of interactive workspaces (e.g., Liston et al. 2000, Christiansson et al. 2002, and Messner et al. 2005). In particular, Liston et al. (2000) has conducted a study to identify the requirements of interactive workspaces to support construction coordination with 4D (3D + time) models. They developed an initial set of requirements by studying paper-based workspaces, 4D workspaces, and a prototype interactive workspace. They concluded that interactive workspaces help construction teams to perform more meaningful tasks. This research provides a useful framework for our study of interactive workspaces to support design development and coordination.

STUDY OF PAPER-BASED WORKSPACES

We studied the design development meetings of the Center for Interactive Research on Sustainability (CIRS) project being constructed near downtown Vancouver, British Columbia. This is a joint project between the University of British Columbia, Simon Fraser University, the BC Institute of Technology, and the Emily Carr Institute of Art+Design. CIRS will be a 65,000 square foot facility that aims to be the most innovative and high performance building in North America, demonstrating leading edge research and sustainable design, products, systems and decision making.

Figure 2: 3D Rendering of the Center for Interactive Research on Sustainability Project (source: Busby Perkins + Will)

We observed eight design development meetings for the CIRS project (a total of 22 hours). These meetings took place in a paper-based physical workspace (Figure 1a). All meetings were recorded on video for later review. During seven of these meetings, consultants on the project met to discuss design alternatives and logistics of coordinating their work. The eighth meeting was dedicated to scheduling milestones for the design phase of the project. At least 3 authors were present at each meeting. One author was an active participant in some of the meetings; the others were passive observers who collected complete observational logs. These logs formed the basis of a qualitative analysis, as is often done to determine workspace requirements in the domains of information visualization and computer-supported cooperative work (CSCW). In our analysis, we systematically categorized interactions between meeting participants and the physical artifacts that were used in meeting activities (e.g. paper, notebooks, and mobile devices such as PDAs and cell phones). This formal "coding" of artifact interactions allowed us to understand the work practices of participants and the kinds of user interactions that need to be supported in an effective digital workspace environment. Based on our observations, several major design implications to facilitate interaction emerged:

1. Make shared information persistently accessible to all members of the group

Shared documents, such as architectural plans, were usually placed in the center of the table. When the diagrams were central to the discussion, people gathered around them and often pointed or gestured over the diagrams simultaneously. Moreover, when the discussion diverged from the documents to other topics, the documents were left in place, where they could still be seen by most participants. People then frequently referred back to the document content by simply pointing. These observations suggest that a tabletop display may be beneficial. Furthermore, if these documents had been closed or placed at a distance, we expect people would not have expended the effort to access them for such quick references. Thus, persistence should be maintained wherever possible to ensure that information will be used effectively during meetings (e.g., by turning off screen savers on shared displays).

2. Support erasable annotation via direct input

Pointing and gesturing towards shared documents was very common. People also made explicit drawing-like actions over diagrams, usually without actually making marks on the paper. In at least one instance, participants wrote on blank tracing paper placed over the diagram instead of on the diagram itself. We conjecture that annotating diagrams could be very useful if it could be done without permanently changing the master copy. Such annotation should be done through direct input (e.g. pen or finger interaction directly on the diagram) because direct interaction allows people to seamlessly switch between annotation, pointing, and gesturing. Direct input can also serve to attract attention and emphasize ideas in addition to creating the actual marks on the page. Technologies such as SMART Boards enable these interaction techniques.

3. Support individual activities without interfering with group activity

Individual activities were common and important during group meetings. Often individuals needed to view, manipulate, or annotate artifacts (e.g. paper or electronic documents) without distracting the rest of the group from their discussion. These artifacts sometimes belonged to the individual, but other times were artifacts shared by the group, which were not currently in use. For example, a person might take a document from the center of the table to take a closer look at an artifact that was previously discussed. People also manipulated shared documents in preparation for later use. For example, an architect might flip through a large collection of architectural drawings to display the one most relevant to the current discussion in case it was useful as a reference. Similarly, during the scheduling meeting, the moderator placed several milestones on a shared timeline while the discussion diverged to other topics in preparation of discussing those milestones later (Figure 3). We believe these types of activities need to be possible without distracting other members of the group because they were central to the workflow of the design meetings we observed. We also observed that simultaneous access to personal copies of the same information could be helpful. When photocopies of a document were handed out, people often browsed or annotated their personal copy during discussion. We believe that Tablet PCs with easy access to shared information could provide support for these individual activities

4. Support subgroup activities

Subgroup activities were just as important as individual activities during meetings. These included whispering to a neighbor, holding a side conversation with a few people, and sharing documents with a small group. The mobility of paper documents facilitated subgroup activities in these meetings. For example, paper documents frequently moved to the center of a group activity, allowing the document to be viewed by that group separately from other subgroups. In addition, pointing to a paper document or moving it toward someone could get their attention without distracting the group as a whole. These observations suggest that mobile computing technology (Tablet PCs, PDAs) might be useful in supporting subgroup activities in an interactive workspace.

5. Provide very simple means for transferring information to shared displays

Our observations suggest that moving information from personal devices to shared displays needs to be trivial (e.g., through removable USB drives or a common data repository accessible from all computers). For example, we found that some participants would prefer to share information on smaller displays instead of displaying them on a larger display because it did not break the flow of their current activity. In one meeting a participant turned his laptop around to share some information with the group even though there was a data projector plugged in at the other end of the table (Figure 3). This solution left some participants unable to see the screen. Furthermore, it was difficult for the owner to interact with his computer. In addition to requiring little effort on the part of participants, information transfer mechanisms need to be available to any participant on demand during the meeting. Participants often discussed topics that were not on the agenda, and therefore could not always predict prior to the meeting exactly what information would be needed.

Figure 3: Construction manager working with scheduling milestones (left), and participants turning laptops around to share information with the group (right).

6. Maintain support for traditional artifacts

Although we believe that computer support is valuable for many aspects of design coordination activities, we do not believe that traditional artifacts (e.g. paper and physical models) can be replaced entirely. Some tasks may be better done on paper because of its ability to support very flexible interactions. Given the nature of these meetings, it is reasonable to expect that meeting participants will continue to bring a wealth of information to the meetings. Some of this information may only be available, or may be more readily accessible, in non-digital form. A successful interactive workspace should provide physical space for traditional artifacts and should support their use in conjunction with digital media.

7. Make spatial relationships between different diagrams easy to see

With paper documents, meeting participants often spend time comparing two or more diagrams to understand how they were spatially related. We observed one instance where participants could not determine whether the two diagrams depicted the same building site because there was no explicit connection between the diagrams. Providing explicit cues to make spatial relationships clear (e.g., by automatically rotating diagrams of the same area to the same orientation and overlaying them) could reduce time spent on such comparisons and improve meeting productivity. Liston et al. (2000) also recognized the need to interact with and visually communicate critical relationships between project information.

8. Make properties of the building design clear and easily accessible

Design details such as 3D structures and material properties of objects are not clear from printouts of 2D design drawings. Our observations revealed that participants spent substantial time explaining the 3D nature of structures using hand gestures and clarifying other aspects of the design (e.g. that a particular wall was to be made of glass). Digital media, including 3D modeling and the use of color, can make such information more accessible. Liston et al. (2000) also cited the need to interact with different kinds of project information and make group appropriate views of project information available to all participants.

STUDY OF INTERACTIVE WORKSPACES

We studied the design coordination meetings of a Chemical and Biological Engineering Research project for the University of British Columbia (UBC) (Tabesh and Staub-French 2005), and a Bio-pharmaceutical Pilot Plant project for Sequus Pharmaceuticals (Staub-French and Fischer 2001). These projects were unique because they were designed and coordinated electronically using 3D CAD. The UBC research facility consists of teaching and research spaces for the study of biological, chemical, environmental and process engineering. The Sequus facility consists of office space, manufacturing space, and process development space. The building systems on these projects were complex and accounted for a large part of the total project cost, which made them ideal candidates for 3D modeling.

We observed approximately 12 design coordination meetings on these projects. We documented the 3D views utilized, the design conflicts identified, and the solutions proposed. Team members typically gathered around a conference table and viewed the integrated 3D models on a computer projection (Figure 1b). Interaction with the computer was typically through a keyboard and mouse controlled by one individual. Key project participants reviewed the integrated model to identify design conflicts, brainstormed possible solutions for resolving the conflicts, and documented the results which were reviewed at the next meeting. Typically, the activities for identifying and presenting design conflicts were accomplished electronically, while the brainstorming and documenting activities were performed using paper-based sketches and annotations.

We also conducted experiments in our state-of-the-art interactive workspace (Figure 1c) to simulate activities observed in 3D design coordination meetings. These experiments investigated the extent to which 3D design coordination could be supported by state-of-the-art collaboration technologies. Our state-of-the art interactive workspace at UBC consists of two SMART Board displays that are arranged in a conference room format. The SMART Boards are electronically connected to the conference table so that switching capability is built directly into the table. This configuration enables any team member to connect to the SMART Boards through the table and share their information with the team. The workspace is outfitted with a control device that controls how inputs are directed to the different displays. Participants can interact directly with the projected image via touch or pen input. This interaction changes the dynamics of work practice by allowing any individual to control input without passing a keyboard and mouse. Moreover, areas of conflict can be marked and design ideas can be sketched directly on top of the digital image. Thus, brainstorming and documentation activities can be done digitally, providing direct correspondence between annotations and the 3D model. These benefits address some of the limitations of interactive workspaces used in industry today. However, additional functionality is necessary to fully support the process of design development and coordination.

In addition to the integration, interactivity, and visualization requirements noted above, our studies of 3D design coordination suggest that the following functionality is required:

1. Identification and visualization of design conflicts

We investigated different 3D technologies that support automated conflict detection and found that most are capable of detecting physical interferences (also referred to as 'hard conflicts') between components of different systems. Figure 4 shows a hard conflict between conduit and ductwork that was automatically identified by Autodesk Building Systems™ (left) in 2D and Navisworks Clash Detective (right) in 3D. However, other type of interferences (i.e. 'soft conflicts') concerning issues like clearances (e.g. the cable tray requires clearance on the top for access), or functionality (e.g. a series of conduits blocking the air terminal and the air flow) are also critical in developing coordinated models. Navisworks Clash Detective provides support in identifying conflicts that occur in clearance spaces around objects (e.g., clearance spaces for access). However, to identify the majority of soft conflicts, we have found that the functional, performance, tolerance, safety, and installation requirements must also be explicitly considered (Tabesh and Staub-French 2005).

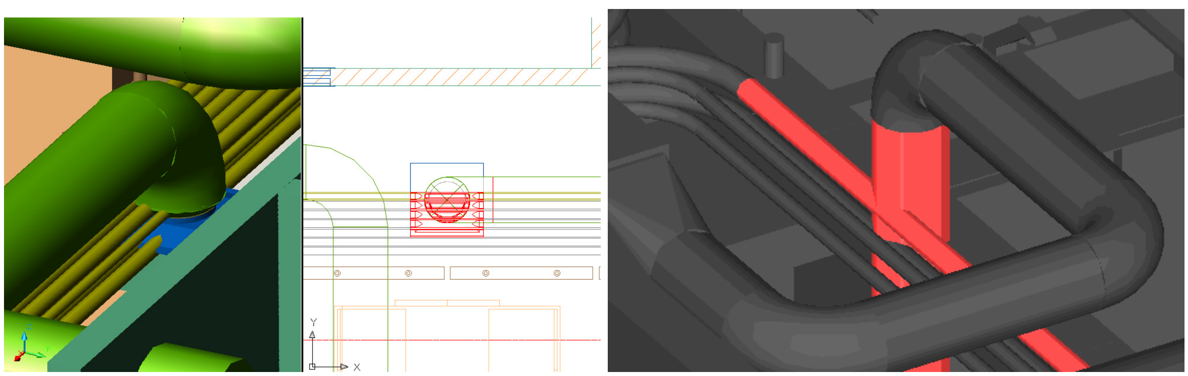


Figure 4: Hard conflict between conduit and ductwork identified in Autodesk Building Systems (left) and Navisworks Clash Detective (right).

2. Support brainstorming activities to investigate design alternatives

We observed that as project teams try to resolve design conflicts, they often explore a variety of alternatives that may address the problem. In these brainstorming activities, the project team explores a variety of 3D views to understand the nature of the problem. Then, the participants may use hand gestures over the 3D projection to communicate alternative routings and configurations, or they may sketch out their ideas on a 2D or 3D printout or on a blank piece of paper. With touch-sensitive SMART Board displays, participants can annotate directly on top of the 3D image using SMART Notebook or red-lining tools provided by the conflict detection software. However, current interactive technologies do not support sketching and annotating the models in 3D. For example, a participant can annotate an image of the conflict in 3D but if they then view the conflict from another perspective, the annotation is no longer evident. Additional functionality is necessary to enable project teams to brainstorm alternatives in 3D and link these alternatives to specific 3D views.

3. Support documentation of the meeting process

In 3D design coordination meetings, design conflicts are identified, alternatives are explored, and hopefully a solution is developed and agreed to by all parties. Typically, one person or organization is responsible for documenting the meeting and sharing the Meeting Minutes. Meeting Minutes, however, typically do not capture collaborative aspects of the discussion, nor do they capture the process for how a solution is developed. Navisworks Clash Detective provides clash reports that document conflicts including the type of conflict, the status of the conflict, the date, and user comments. We have found that SMART Boards facilitate this process through the annotation and screen-capture functions. However, we found that the interaction with multiple pieces of software was not smooth and as a result, the history of the meeting captured was limited. For example, participants in design coordination meetings often view information in Word documents to convey other aspects of the 3D design. To compile a history of the meeting, users would have to string together numerous images captured from the screen, which would be time-consuming and lose the intelligence of the original documents. Alternatively, users would have to manually integrate the annotations made in different software with different formats into a single cohesive story. A successful interactive workspace should provide support for documenting the entire meeting process and results in a framework that is easy to use and supports multiple pieces of software.

CONCLUSIONS AND FUTURE WORK

This paper describes an initial set of requirements for interactive workspaces to support 3D design development and coordination. We studied project teams in paper-based workspaces and current interactive workspaces. These studies increased our understanding of design teams and their work practices, and helped us to identify the requirements of effective digital workspace environments.

We are currently implementing a state-of-the-art *mobile interactive workspace* for use during detailed design and construction of the CIRS project discussed previously. This interactive workspace will first be installed at the architect's office where we will study the project team as they conduct 3D design coordination meetings. Then, we will outfit the interactive workspace in a construction trailer to study construction meetings at the project site. These studies will provide additional insights into the requirements for 3D design coordination, as well as the requirements for construction coordination with 3D models. We are also investigating the underlying data schemas required to provide an integrated project environment, and visualization techniques to support information visualization and interaction.

Interactive workspaces can provide significant benefits to project teams throughout the design and construction process. We believe that these workspaces will improve the utility of project information and the quality of the decision-making process.

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