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STUDYING COLLABORATIVE DESIGN IN HIGH BANDWIDTH VIRTUAL ENVIRONMENTS

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ABSTRACT

In today's global design world, architectural and other related design firms design across time zones and geographically distant locations. High bandwidth virtual environments have the potential to make a major impact on these global design teams. However, there is insufficient evidence about the way designers collaborate in their normal working environments using traditional and/or digital media. This paper presents a method to study the impact of communication and information technologies on collaborative design practice by comparing design tasks done in a normal working environment with design tasks done in a virtual environment.

Before introducing high bandwidth collaboration technology to the work environment, a baseline study is conducted to observe and analyze the existing collaborative process. Designers currently rely on phone, fax, email, and image files for communication and collaboration. Describing the current context is important for comparison with the following phases. We developed the coding scheme that will be used in analyzing three stages of the collaborative design activity.

The results will establish the basis for measures of collaborative design activity when a new technology is introduced later to the same work environment – for example, designers using electronic whiteboards, 3D virtual worlds, webcams, and internet phone. The results of this work will form the basis of guidelines for the introduction of technology into global design offices.

Keywords: Collaboration, Architectural Design, Communication Technology

1. INTRODUCTION

Recent developments in networked 3D virtual worlds and the proliferation of high bandwidth communications technology have the potential to transform the nature of collaboration in professional design. There have been numerous studies of collaboration in Europe and the USA that have resulted in system architectures to support data transfer and information sharing. However, the impetus for these initiatives has been mainly system-driven as distinct from user-driven. Whilst these initiatives have undoubtedly led to important advances in the enabling technologies required to support changes in global economic practices, the lack of attention to the way people actually work together leaves a large gap in understanding their needs.

This is not a new problem but has persisted whenever new technologies are proposed as solutions to market driven changes without first trying to understand the problem that needs to be solved. In the architecture and construction industries, there is insufficient evidence about the way designers collaborate in their normal working environments using both traditional and digital media. It is this gap that our research addresses. This project focuses on collaboration among designers in the early stages of design in which conceptual, and then more detailed, models for a project are being developed.

There are two basic research objectives: one is to obtain evidence about design practice that will inform the architecture and construction industries about the impact and potential benefit of using digital collaboration technologies; the second is to add to long term research knowledge of human cognitive and behavioural processes based on real world data. In order to achieve this, the research methods must be able to acquire a rich and heterogeneous set of data from design activities as they are carried out in the normal working environment. This places different demands upon the data collection and analysis methods to those of laboratory studies where controlled conditions are required. In order to address this, the research approach that has been adopted is ethnographic in nature and case-study-based. A series of in-depth studies are carried out in order to provide baseline results for future research across a wider community of user groups. An important objective has been to develop a methodology that will produce valid, significant and transferable results.

The research will contribute to knowledge about how architectural design and the construction industry may benefit from the introduction of leading edge collaboration technologies. The outcomes will provide a sound foundation for the production of guidelines for the assessment of high bandwidth tools and their future deployment. The knowledge will form the basis for the specification of future collaboration products and collaboration processes.

2. STUDYING THE IMPACT OF HIGH BANDWIDTH VIRTUAL ENVIRONMENTS ON COLLABORATIVE DESIGN

In order to understand the potential impact of high bandwidth environments on collaborative design, we first need to have data that characterises collaborative design activity without the high bandwidth environment. In this research we undertake a series of studies into how designers work collaboratively using both traditional and digital media. The research involves the observation and

analysis of designers working remotely on commercial projects in their normal environment, an architectural design office. There are three separate phases to this study in which the designers and the design offices are the same, but the collaborative technologies change. The change in collaborative technologies is incremental, moving from the technology already in use to the use of a high bandwidth virtual environment. The data collected in these phases will be coded and analyzed, and then compared to determine the impact of the change in collaborative technology.

The three phases are:
1. A collaborative design process in which designers work with their current design and communication tools.
2. A collaborative design process in which we introduce a shared drawing system with synchronous voice and video in addition to the currently used design and communication tools.
3. A collaborative design process in which we introduce a 3D virtual system in addition to the current design and communication tools.

2.1. SET-UP FOR FIRST PHASE: USE OF CURRENTLY AVAILABLE DESIGN AND COMMUNICATION TECHNOLOGY

The first study is an investigation into the existing practices for early stage collaborative design in a specific architectural firm when designers in different offices are collaborating. The main aim is to establish a baseline for comparing conceptual design processes before we introduce new collaborative technologies. Processes to be examined include communicating and designing from different locations considering duration of tasks, and use of design tools and channels of communication.

For this baseline study, the research process includes:

- Preparation of the study context: identifying participants, physical locations.
- Selection of data gathering methods: audio-video recording devices, field diaries.
- Collection and collation of data: logistics, checklists, storage, security.
- Analysis of data and reports of the results: viewing, coding, documentation

The setting for the study has been established in two geographically distant locations, one office in Sydney and the other office in Melbourne. The project study area is as near as possible to the normal space the designers work in, and is one where they have all the facilities they would typically expect to have on hand. The work area includes such things as a large desk or table where large drawings can be laid out, a large wall to pin-up images, posters and other material, and sufficient space around to freely move about. These requirements were met by a space called ‘library’ in the Sydney office (see Figure 1) and a similar space in the Melbourne office of Woods Bagot Pty Ltd.

2.2. SET-UP FOR SECOND PHASE: INTRODUCTION OF SHARED DRAWING WITH AUDIO AND VIDEO COMMUNICATION

The second phase is an investigation and comparison of designers using a shared drawing board with audio and video conferencing. The purpose of this

study is to introduce collaborative technology that facilitates communication without altering the current sketching and drawing processes used in current practice. Figure 3 shows a snapshot of the plasma screen with pen interface that we are using for this phase. The plasma screen allows the participants to draw on the shared whiteboard without the shadow cast by a front projection system. Our initial trials do not use the video conference image because the participants thought it uses bandwidth unnecessarily, but the participants do have audio contact.

Figure 1. Designing space in Sydney office

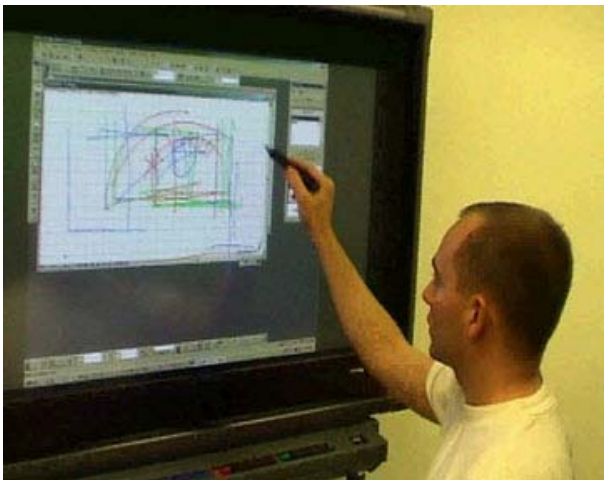
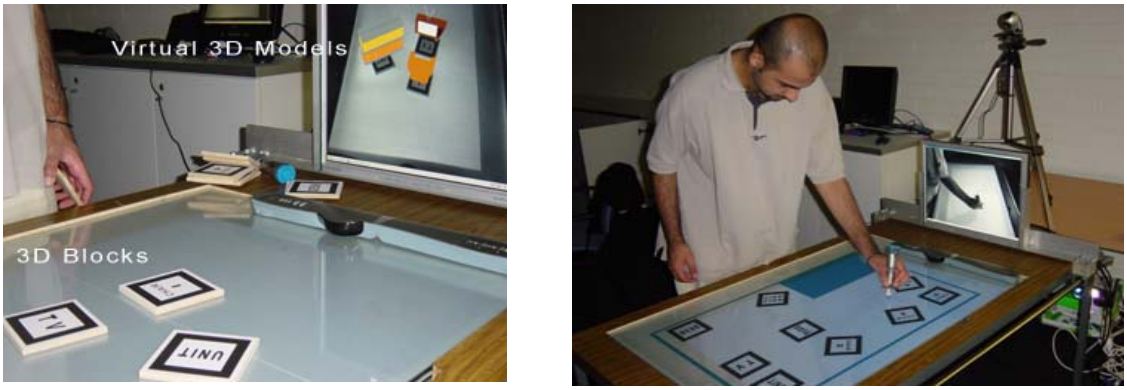


Figure 2. 2D Shared White board

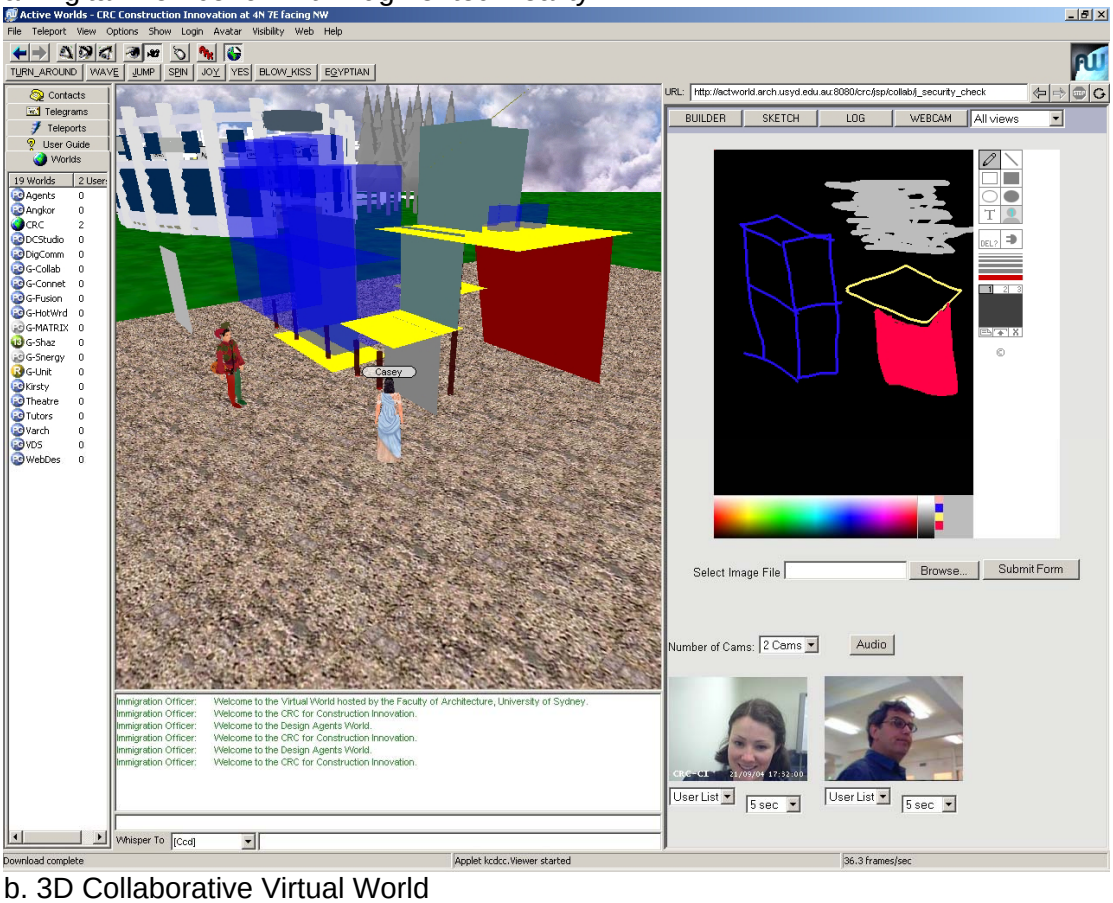
2.3. SET-UP FOR THIRD PHASE: INTRODUCTION OF 3D VIRTUAL ENVIRONMENT

The third phase is an investigation and comparison of the same designers in the same offices, using a high bandwidth environment in which 3D models are built, discussed, and modified. We will consider two approaches to introducing high bandwidth 3D modeling: a workbench, which moves the design drawings and models back to a horizontal surface, with 3D augmented reality; and an immersive 3D virtual world in which the designers are represented as avatars within the design model. The purpose of this study is to introduce technology

that significantly alters current practice. Figure 4a and 4b illustrates the two approaches for this phase.



a. Digital Workbench with Augmented Reality



b. 3D Collaborative Virtual World

Figure 3. 3D Virtual Environment

3. OBSERVING AND ANALYSING COLLABORATIVE DESIGN ACTIVITY

Collaboration is an essential part of human activity and a dominant mode of work activity. Computer support for such activity is a relatively recent development in design and other related domains. Essentially, the development of effective collaborative systems has to be based on analysis and evaluation techniques that deal effectively with collaborative activity. Although there is now

a large body of empirical work on the human-computer interaction (HCI) domain, little progress has been made with determining factors that influence the organization or design of collaborative work with the use of techniques or methods that provide for systematic analyses.

Communication has a central role in many human activities, even for tasks and technologies that are strictly individual (Suchman, 1987; Heath, 2000). Consequently, interpersonal communication is the basis for collaborative design and for innovation, since these interactions provide for the creation of shared understanding (Saad and Maher, 1996). Thus, it is critical to first examine the social and interactional dimensions of work, in order to make suggestions about the design of computer support and high band-width support for collaborative design. The understanding derived from observations of design practice can then be used to inform the design of appropriate technology. We took the approach of analyzing human behavior and intentions in collaborative activity, considering that a static and inflexible conception of collaborative activity has prevented the evolution of useful environments where people can work and socialize with each other in a socially natural way (Heath et al. 1995). Typically collaborative design in architecture is a common occurrence with architects communicating their ideas to their peers in the form of verbal representations voiced or typed and graphical representations (Gabriel and Maher, 2002).

Protocol analysis has been accepted as a prevailing research technique allowing elucidation of design processes in designing. And whilst the earlier studies dealt mainly with protocols' verbal aspects, later studies acknowledge the importance of design drawing, associating it with design thinking which can be interpreted through verbal descriptions.

The protocol analysis technique has been adopted to understand the interactions of design teams (Cross and Cross 1996; Mazijoglou et al 1996; Stempfle and Schaub 2002) and design behaviour of teams (Goldschmidt 1996; Günter et al. 1996; Valkenburg and Dorst 1998). Protocol studies of collaborative industrial/architectural design concern the understanding of team collaboration, in terms of use of communication channels and design behaviour variables (Mazijoglou et al. 1996; Vera et al. 1998; Kvan and Candy 2000; Gabriel and Maher 2002). On the other hand, protocol studies in the engineering design domain focus on the work environment context and the social interaction discourse as well as design behaviour and communication (Badke-Schaub 2003; Glock 2003). The emphasis becomes the analysis of conversation patterns, to gather information about the team dynamics, individual motivations, social interpretations etc.

Protocol studies of architectural design in practice have rarely been done because of the difficulties in collecting protocols - architectural design often being an individual practice. Nowadays, with the globalisation of design offices, architects have to collaborate with each other as well as with professionals from other disciplines. As a result of this change, design process increasingly occurs as a social process through "communication of ideas" and "communication with drawings". Thus it is possible to collect a reasonable amount of rich protocol data form a team of architects in real work environments.

A Methodology Combining Ethnography, Context Analysis and Protocol Studies

We have combined context analysis and protocol study methodologies for the collection and analysis of data about collaborative design as it takes place in a natural environment. The context analysis continues over the research timeline, and the protocol analysis occurs during the intensive period where the video recording is employed, as illustrated in figure 5.

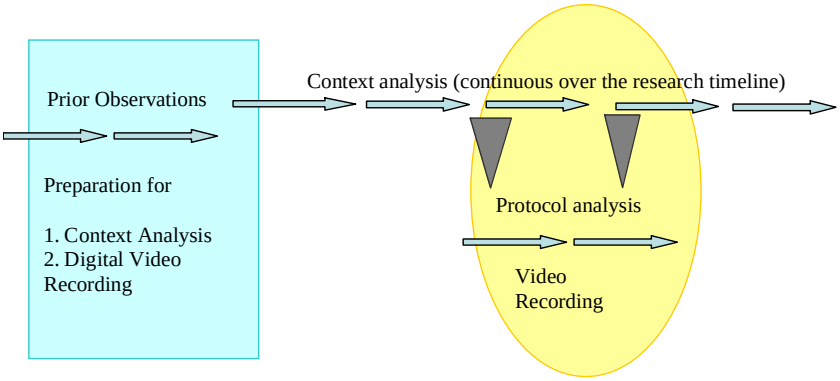


Figure 4. Context and protocol analysis

Context analysis is the end product of a continuous direct observation in workplace studies. Direct observation is the data collection technique whereby researchers are present at the scene and record the events that take place in field diaries sometimes supplemented by audio tape recording. Such observation is usually undertaken in as unobtrusive a manner as can be achieved. And to that end, the researchers become part of the normal working environment by taking up residence sometime before the actual observation work takes place. In this case, the researcher was resident in the company for two days per week and was a familiar figure to the designers taking part in the study. In this way, he was able to familiarize himself with the general working practices of the design office and to see how the subjects worked with their colleagues at a general level. The researcher observed interactions, listened to conversations in situ, had informal talks with the site staff and collected material on how the tools, instruments or technology was used.

The study employs a second observation method - using multiple video cameras to monitor and record activities of designers. Video recording sessions had to be done in a common meeting space in the company office since the set-up has been fixed in that area. Video recordings were limited to specific design sessions where the architects meet to review and resolve problems of the design project at hand. The advantage of these recordings is that a lateral in-depth analysis of the protocols can be done with a formal approach. Other than the times captured by video, designers exchange information and ideas continuously in the office within smaller time intervals. Thus, the limitation of video recording is that it is harder to get an insight about the complete picture of the work practice. However sufficient data about the work practice has been collected (using the informal context analysis approach) in order to describe architectural context in the present study.

4.1. PROTOCOL ANALYSIS

By recording and measuring the design tasks, we can look for differences and correlations between design activities and communication channels using different technologies.

4.1.1. Experimental Set-up

The method to collect protocol data is to monitor and record using multiple video cameras. The data captured enables precise inspection of the events and actions by rewinding and forwarding the video thus helping the researcher to fill in the gaps in direct observation records and to focus on specific aspects of the process. Our aim is to record the designers' activities and verbal exchanges when they are engaged in a collaborative design activity at a distance.

The placement of the cameras is an important issue, since all participant movement, verbalizations, gestures and the drawing actions and outcomes must be recorded. Camera 2 and 3 in both study settings capture the gestures, general actions (such as walking, looking at, moving to the side etc) while camera one has to capture the drawing process in detail (see Figure 5). Camera one is mounted on the ceiling, while the other two cameras stand on tripods.

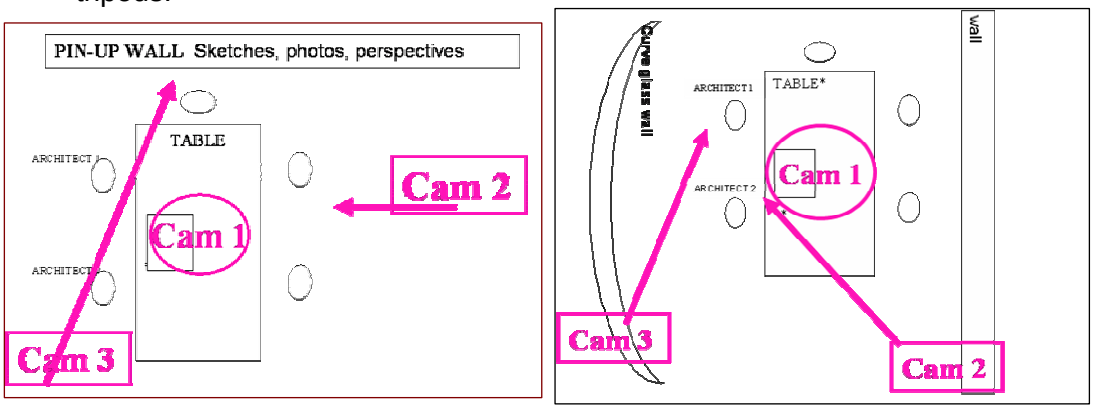


Figure 5. Camera positions (Left: Sydney office, Right: Melbourne office)

4.1.2. Segmentation

The data collected is a continuous stream of voice and video. In order to analyse the data, it needs to be segmented. The smallest segmentation definition is an event. An event is an optimal definition in behavioural research because happenings are arbitrary and actions change in relatively small and unpredictable time intervals. Typically in collaborative design, actions and intentions change arbitrarily because architects draw and communicate interactively. Thus the events should reflect WHO is doing WHAT in a collaborative environment. When WHO or WHAT items change, this starts a new event. This segmentation provides the elements of the data that are associated with a code for analyzing the entire recorded activity.

4.1.3. Development of the coding scheme

The basis for the development of a coding scheme is a consideration of the expected results of the study. We expect that the communication channels will have an impact on the design process, so we need to measure the changes in the use of communication channels and the amount of time spent in different design activities. In reflecting on this, we have identified three categories of

information we want to record and measure: “who” is present during the collaborative activity, “how” they are communicating, and “what” they are doing.

“Who” is involved in the collaboration at any given time is coded as the participants. Further, the coding should allow the analyst to understand how and in what way each person in the team joins in the collaborative activity. Thus every action is coded associatively with each team member.

“How” they are communicating is coded as the medium of communication, such as:

face to face
telephone
fax
email
messenger
shared or single person drawing
shared or single person modeling
video conference

These channels give us information about whether the current collaboration type in the activity is synchronous or asynchronous. In terms of content, this may be design-related or design-free communication. We refer to design-free conversations as an interruption to communication, because of our interest in analyzing design-related conversations which affect collaboration. Another interruption type is defined as the breakdown of communication because of a technical problem.

The “What” category refers to what the designers are doing . Our classification of tasks is into three categories: “Design Process” which reflects the content of the designing process, “Access Information” which reflects the referred domain knowledge, and “Team Communication” which reflects the conversation patterns in a group.

Analysis of the designing process is based on theories which consider design as a problem solving process that is ill-structured and opportunistic in nature. In order to analyze the designing process we adopted codes from a process-oriented coding scheme (Gero and McNeill, 1998). The scheme is based on problem understanding and solving strategies, and it involves categories of analysing a problem, evaluating a problem, proposing solutions, as well as the knowledge types referred to. The coding scheme was used to analyse individual designers as well as team work (Purcell et al., 1996). In addition to the selected codes two more actions are added: analysing/ understanding representations and evaluating/ reworking the representations. The reason for additional codes is to better represent the nature of the architectural design activity. It was observed that the architects were either trying to understand the previously produced representations, discussing how to represent design elements, or whether the drawing needs specific lines or shadows etc. Thus analysing or evaluating representations was an important part of the process, as well as analysing or evaluating the design solutions or concepts. Design process and information accessing codes are listed below:
Design Process:

- propose a new idea/concept/ design solution
- clarify meaning or a design solution, expand on a concept

- analyse a proposed design solution
- analyse/understand a design representation
- re-work/elaborate/ evaluate a design representation (propose or negotiate modifications on a representation, or add to a previous version)
- analyse/understand one's view/concept/idea or a problem
- identify or describe constraints/ violations
- integrate/combine ideas in the team or adapt existing solutions to meet new constraints and objectives

Access Information:

- consult external information (request/search for information about a previously-introduced concept/idea/design solution. Ask for a partner's idea/view/decision)
- Refer to design brief/client requirements

Another category in "what" designers are doing relates to decomposing the team's communication. We borrowed the category codes from Milne and Leifer (2000) in which the authors named this category as "navigation" - it refers to handling and exploring the issues in a design team discussion. Codes like intervene, manage, coordinate, reflect, rationalize, reflect the conversation patterns in a team. The breakdown of the "team communication" codes is as below:

- reflect: Comment on group process, assess progress, measure against previously developed goals, review path of discussion
- coordinate: solicit feedback, check for consensus from the group (or the other participant)
- intervene: Redirect the focus of discussion, propose a new area/ category for discussion/exploration, look ahead to possible new goals for the group discussion
- manage: model activity, delegate/assign tasks, cause others to modify actions, guide group in its mode of activity through reiterating goals, including level on which to hold discussion
- affirm: provide positive feedback, express assent or agreement, agree on an idea/concept/ solution
- orient: Introduce personal background, express personal perspective not tied to a piece of information, only reflecting on personal experience
- rationalize: Provide justification background for suggesting a course of navigation

4.1.4. Software support

A software application is needed to manage the audio-video recorded data as well as to capture actions and verbalizations with precise timing. Reviewing the software alternatives, and considering the coding process, we decided that multiple tasks such as managing the codes, accessing the multimedia stream, and seeing the coding scheme, as well as presentation and management of the data should preferably be done in one interface. For these reasons we chose to work with INTERACT. Additionally the software enables watching multiple video streams simultaneously, within one single coding session. So that It is possible to analyse several videos at the same time that were recorded from different camera views of the same scene. The interface for the INTERACT software is shown in Figure 6. In the analysis shown we had only one video camera on the

designer being studied. The interface shows how we can move through the video and attach a code to segments of the video.

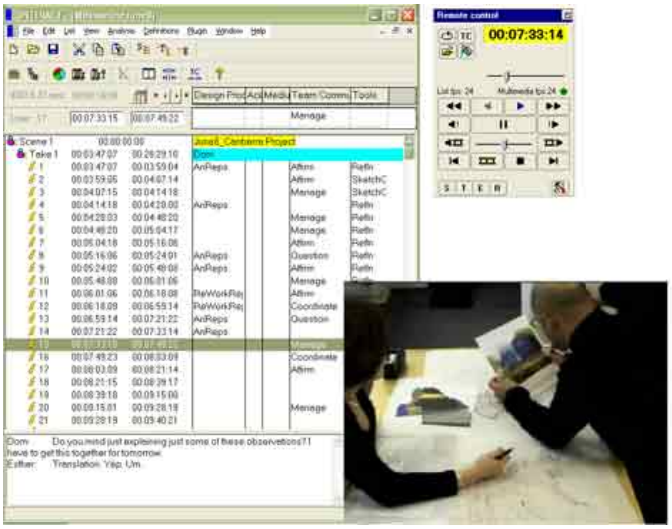


Figure 6. INTERACT interface

5. SUMMARY

The research approach and the coding scheme described here present an analytical framework that can be applied to characterize the activity of design teams. This paper presents a structured approach for detailed analysis of design team activity that distinguishes between factors of collaboration (who, communication channels, tools), designing activity, and communication in the team. There are two outcomes from the research so far. One outcome is the definition of the phases of the study which allows a comparison to be made and the impact of high bandwidth virtual environments to be measured and described. The second is the methodology and coding scheme that defines how the data is collected and analysed. We propose that the developed coding scheme can support qualitative and quantitative analysis of design team activity that more precisely reveals the nature of team processes than unstructured video analysis methods. The first outcome is transferable to other research projects by using the same incremental phases approach and varying the discipline and/or the technology being studied. The second outcome is transferable to the study of any collaborative process.

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