CRC Construction Innovation
BUILDING OUR FUTURE

Experimental Methodology Report

Research Project No: 2002-024-B-02

The research described in this report was carried out by:

Project Leader	Mary Lou Maher	
Researchers	Robin Drogemuller	Zafer Bilda
	Kirsty Beilharz	Linda Candy
	Andy Dong	Mijeong Kim
	John Gero	Tony Shi
	Mike Rosenman	Ji Soo Yoon
	Thomas Bellamy	Figen Gul
	Rod Gameson	Yinghsiu Huang
	Willy Sher	Sue Sherratt
	Tony Williams	Adel Ahmed
	Stephen Egan	Owen Macindoe
	Kathryn Merrick	Robert Shen
Project Affiliates	David Marchant	
	Carolyn Mitchell	
	Kanyarat Nemprempree	
	John Crawford	
	Lan Ding	
	Melissa James	
	Richard Hough	
	Steve Pennell	

Research Program: B
Sustainable Built Assets

Project: 2002-024-B
Supply Chain Sustainability

Date: December 2003

Distribution List

Cooperative Research Centre for Construction Innovation
Authors

Disclaimer

The Client makes use of this Report or any information provided by the Cooperative Research Centre for Construction Innovation in relation to the Consultancy Services at its own risk. Construction Innovation will not be responsible for the results of any actions taken by the Client or third parties on the basis of the information in this Report or other information provided by Construction Innovation nor for any errors or omissions that may be contained in this Report. Construction Innovation expressly disclaims any liability or responsibility to any person in respect of any thing done or omitted to be done by any person in reliance on this Report or any information provided.

Please direct all enquiries to:

Chief Executive Officer
Cooperative Research Centre for Construction Innovation
9th Floor, L Block, QUT, 2 George St
Brisbane Qld 4000
AUSTRALIA
T: 61 7 3138 9291
F: 61 7 3138 9151
E: enquiries@construction-innovation.info
W: www.construction-innovation.info

Table of Contents

1. PREFACE

This report presents the experimental methodology for the research investigations of the CRC project "Team Collaboration in High Bandwidth Virtual Environments". A series of studies of design practice will be carried out in the Sydney and Melbourne offices of an international architectural design company. The main aim is to determine how process improvement may be achieved using high bandwidth collaboration technologies. The research design was developed by the University of Sydney with the co-operation of industry partners, Woods Bagot Pty Ltd and Ove Arup Pty Ltd, and the CSIRO, Melbourne. The project as a whole is addressing several research areas including the emerging area of multi-user design modelling, a topic that is at the leading edge of high bandwidth virtual environments research.

2. EXECUTIVE SUMMARY

In architectural design and the construction industry, there is insufficient evidence about the way designers collaborate in their normal working environments using both traditional and digital media. It is this gap in empirical evidence that the CRC project, "Team Collaboration in High Bandwidth Virtual Environments" addresses. The project is primarily, but not exclusively, concerned with the conceptual stages of design carried out by professional designers working in different offices. The aim is to increase opportunities for communication and interaction between people in geographically distant locations in order to improve the quality of collaboration.

In order to understand the practical implications of introducing new digital tools on working practices, research into how designers work collaboratively using both traditional and digital media is being undertaken. This will involve a series of empirical studies in the work places of the industry partners in the project. The studies of collaboration processes will provide empirical results that will lead to more effective use of virtual environments in design and construction processes.

The report describes the research approach, the industry study, the methods for data collection and analysis and the foundation research methodologies. A distinctive aspect is that the research has been devised to enable field studies to be undertaken in a live industrial environment where the participant designers carry out real projects alongside their colleagues and in familiar locations.

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. The plan is to carry out a series of in-depth studies 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. This project directly addresses the industry-identified focus on cultural change, image, e-project management, and innovative methods.

3. 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 and to offer significant process improvement. There have been numerous studies of collaboration in Europe and the USA that have resulted in system architectures to support information sharing. Whilst these initiatives have undoubtedly led to important advances in the enabling technologies required to support changes in global economic practices, there remains a gap in our understanding of the impact of the technologies on the working practices of the people who are the primary users of such systems.

This report describes the research approach and methods that will be used to carry out a series of empirical studies of design practice in an architectural design company. The studies will focus on the collaboration processes adopted by designers working on the same projects but in different locations. The aim is to provide empirical results that will support organizations in the drive towards more effective use of virtual environments. The results will provide the foundations of further work which will be disseminated to the design and construction industries through workshops, guidelines and recommendations. The research findings will contribute to a growing corpus of evidence about the emerging area of collaborative virtual environments for design including their contribution to process improvement and impact on communication and behavioural patterns.

The document can be read selectively according to the reader's interests. Those in haste are directed to sections 1 to 4 for a quick overview. The industry research study is described in section 4. Those readers who would like to know more about the research methodologies that underpin the adopted approach should turn to section 5. For the serious student of design research, the reference list is a valuable source of additional information.

3.1 Project Scope

The CRC Project 2002-024-B "Team Collaboration in High Band Width Virtual Environments" is concerned with collaborative design using high bandwidth communication technology and leading edge design tools.
The aim is to increase opportunities for communication and interaction between people in geographically distant locations in order to improve the quality of collaboration. The studies of collaboration processes will provide empirical results that will lead to more effective use of virtual environments in professional design and construction processes.

The specific objectives of the project are to:

- (i) Develop guidelines for the assessment of high bandwidth tools amongst members of a design team from the same organization in virtual environments
- (ii) Analyse and document experience with different forms of collaboration amongst members of a design team from different organizations in virtual environments
- (iii) Report on possible futures for collaboration in high bandwidth virtual environments

The project is intended to benefit the industry partners in Australia by proposing more effective communication and collaboration in a global construction context. It will introduce leading edge technology to the Australian construction industry. The experience and knowledge about collaboration in a high bandwidth environment is particularly important for design teams that are not co-located, as is generally the case. The knowledge derived from collaboration in design teams is transferable to teams across the entire spectrum of the design and construction process. The knowledge will form the basis for the specification of future collaboration products and collaboration processes. High bandwidth collaboration provides the opportunity for Australian organizations to become globally competitive because it reduces the reliance on geography and removes the "tyranny of distance". This project directly addresses the industry-identified focus on cultural change, image, e-project management, and innovative methods.

The project will contribute to knowledge about how architectural design and the construction industry may benefit from the introduction of leading edge collaboration technologies. In order to understand the practical implications of introducing new digital tools on working practices, research into how designers work collaboratively using both traditional and digital media is being undertaken. This will involve a series of empirical studies in the work places of the collaborating partners in the project.

3.2 Human Ethics

A pre-requisite for the commencement of the study is the written consent for human ethic approval from the University of Sydney Human Ethics Committee and the CSIRO, Melbourne.

Ethical Considerations include:

- Nature of Research
- Risks and Benefits
- Participants and Recruitment
- Participant Information and Consent
- Privacy and Publication of Results
- Direct observation and audio-video monitoring with minimum intrusion
- Data to be archived and secured with full confidentiality
- Complete anonymity to all direct participants

For Human Ethics approval, the following are needed:

- Participant information statement which is a brief introduction to the aims of the research, the methods to be used and the use and distribution of research material.
- Participant consent form to be signed by the participants, an agreement on anonymity, and the use of research material.
- Partner agreement in the form of written approval by the company for employee participation.

See Appendix 1 for the ethics approval application details.

4. STUDYING COLLABORATIVE DESIGN

Research into the characteristics of collaborative work can assist in our understanding of how the collaborative design process can be supported and how new technologies can be introduced into the workplace. An understanding of collaborative design includes such factors as the role that communication media play, the use of physical materials, and computer tools and the way people communicate verbally and non verbally. Only by gathering information about the rich and complex picture of collaborative design can we understand the characteristics and needs of the practitioners involved as well as those factors which contribute to their professional effectiveness.

4.1 Research Studies

The project will undertake a series of research studies into how designers work collaboratively using both traditional and digital media. The research will involve detailed investigation of designers working on commercial projects in their normal environment, an architectural design office. The studies will take place in three phases:

1. A design process in which designers work with their current design and communication tools.
2. A design process in which designers use a shared drawing system with synchronous voice and video.
3. A design process in which a 3D virtual system is used in addition to design and communication tools.

The first phase study will be carried out using an open ended exploratory approach into gathering data about all aspects of existing design practice using traditional media, tools and communication devices. The second phase will investigate the impact of the use of collaborative technologies in the same environment: in particular, the effect of different technologies applied to the same tasks will be studied. The third phase involves studies of the effect of different ways of using the same technology.

4.1.1 Research Questions

In the first phase of the investigations, the aim will be to understand the nature of the collaboration process as it takes place using traditional methods and without digital systems for designing and communicating.

The primary aim of the investigations is to understand the nature of the collaborative design process and the significant factors that affect professional effectiveness. In the first phase, the design activities using current methods will be investigated and the outcomes will provide a baseline study of the main characteristics of such work. In phases two and three, design activities using different digital systems for designing and communicating and the changes that take place as a result of using the technology, will be examined. Thus, the impact of collaborative design technology on the design process will be determined by addressing such questions as:

- What are the key factors that determine the way that collaborative design takes place?
- What is the effect of working in remote locations on task effectiveness and efficiency?
- How are the materials and tools used to exchange ideas and designs in a collaborative process?
- What are the obstacles to effective and efficient collaboration?
- What factors affect the success or failure of a given design project?

The project will use the answers to these questions to identify how design process improvement can be achieved employing collaboration support technologies. The first step towards addressing these questions will be to investigate the current practice of the designers using traditional working methods and materials. The study will be undertaken in the design offices of a multi-national architectural design firm and will operate within the context of a design competition, typically confined to a two-week period. The design process is intense and needs to be completed within that short time frame. The first study will focus on a design team of two designers; one located in the Sydney office and one located in the Melbourne office of the company, Woods Bagot Pty Ltd. Because the project will be based on competitions that arise from the industrial world, the content will be different for each study. However the designers, their locations, the type of data collected, and the analysis tools will be kept the same.

4.2.2 Research Methods

Research methods for the collection and analysis of data about collaborative design as it takes place in a natural environment have been identified. There are two approaches: Context Analysis (including prior observations) and Protocol Analysis. The Context Analysis continues over the research timeline, and the Protocol Analysis occurs during the intensive period where the video recording is employed. Further information about Context Analysis and Protocol Analysis may be found in section 5 below.

Figure 1 illustrates the chronology of the methods involved.

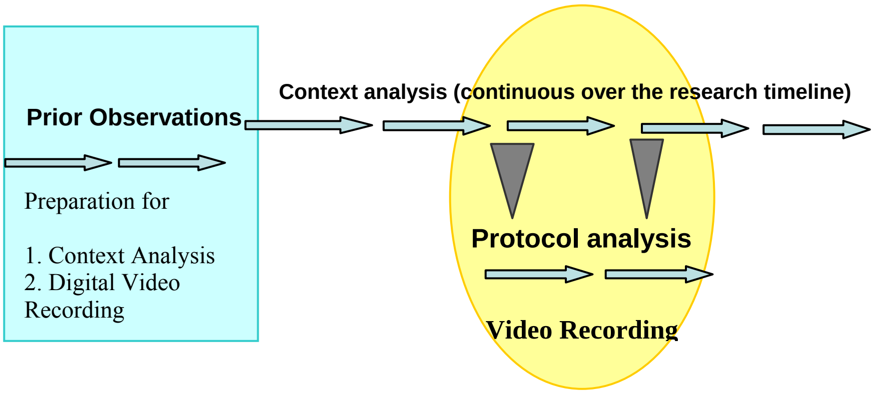


Figure 1 Context and protocol analysis

Data collection requires *direct and lateral* observation techniques. Direct observation is the data collection technique for context analysis, where the researcher records the events in his/her field diary. Monitoring and recording methods will be required for lateral observation of the data from the design process. Lateral observation is done by watching the recorded videos. It allows precise inspection of the events and actions and helps the researcher to fill in the gaps in direct observation records and also to focus on specific aspects of the process. The steps for the data collection can be summarized as follows:

- Step 1 Preparation: what is to be recorded? Agreement on definitions of events, actions etc. between researchers. Technical preparation for digital monitoring and recording of design process.
- Step 2 Prior observations: direct observation of *events*, keeping field diaries, record comments, use of audiotape as a memory aid. Prior observations help identifying the study setting, and enhancing what is to be recorded in the field diaries.
- Step 3 Design Studies: direct observation + video-audio recording are used to gather data.

There are three main topics to be studied: collaboration, design process and design methods.

1. Collaboration: effort and effectiveness, communication and behavioural patterns.
2. Design Process: origin and development of ideas, conflicts and resolutions, outcomes achieved.
3. Design Methods: the use of materials and tools, number and type of sketches, models etc.

The research requires effective organization of the collected data since different data sets are collected. There are four categories of data to be collated:

- Direct observation data: field diary comments, facts, interpretation
- Video recorded data: digital storage and *labelled* for ease of access
- Verbal transcriptions: for text analysis
- Visual data; sketches, drawings, photographs that may be associated with verbal reports.

4.2 Phase 1 Study

The first study will involve an investigation into the existing practices of architectural designers. The main aim is to establish a baseline for comparing an existing conceptual design process with one in which on-line collaborative technology has been introduced. Factors to be examined include the effect of working in remote locations on communication and task effectiveness and efficiency and the way materials and tools for exchanging ideas and designs are used.

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 methods for collecting data will be by direct observation and audio video monitoring in the environment. The aim is to monitor events in such a manner as to impose minimum intrusion upon the participants. The location and position of cameras and related equipment is agreed with the partner companies. Data will be stored and a back up version archived in a secure place.

By its very nature, the kind of research to be undertaken is participative and, hence, involves close consultation with the company personnel involved. Before any study is carried out, important preparatory activities are needed, in particular:

- Consultation with the intended participants about the requirements of the research
- Identification of suitable physical space
- Acquisition and testing of data collection equipment

The industry partners have been closely involved in the preparatory work for the studies. It is important to involve all personnel in the company whose time and effort are needed in order that they are aware of the issues implied by doing such work on site. In addition, there are implications about the use of the workspaces which require consultation with office managers and other relevant people. The actual physical location where the project and the recording are to take place needs to be agreed with the designers who are to participate in the studies and whose work will be closely monitored.

4.2.1 Study Settings

The setting for the study will be in two geographically distant locations, one office in Sydney and the other office in Melbourne. The project study area should be as near as possible to the normal space the designers work in and be one where they have all the facilities they would typically expect to be on hand. Requirements were acquired from the participating designers such things as for a large desk or table where large drawings could 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 2) and a similar space in the Melbourne office of Woods Bagot Pty Ltd.

The criteria used to assess the study setting are summarized below:

- The space is large enough to locate cameras that do not interfere with movements in the area.
- The space has power points and internet connections on the floor or on the walls
- The space has a large table and a pin-up wall/board.
- One camera will be mounted on the wall or the ceiling in order to view the table from above.
- The space does not have to hold all the video equipment permanently. The library space is used for other purposes during the day, so equipment will be removed and locked away.
- The video system should be portable and easy to set up for those purposes.

Figure 2. Study setting (Left: Sydney office, Right: Melbourne office)

The placing of the cameras is an important issue, since we want to monitor all participant movement, verbalizations, gestures and the drawing actions and outcomes. 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 3). Camera one is mounted on the ceilings while the other two cameras stand on tripods.

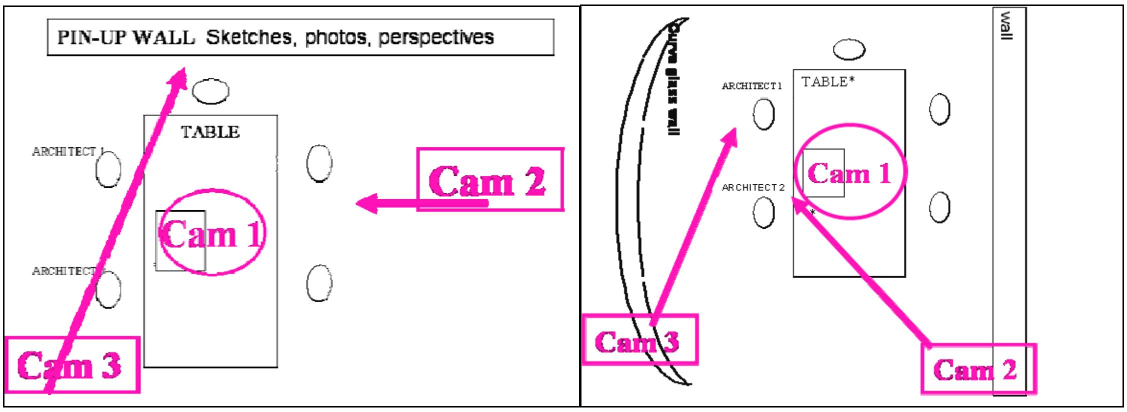


Figure 3. Camera positions (Left: Sydney office, Right: Melbourne office)

4.2.2 Video Recording

In order to gather live data about the design process activities, recording methods have been identified and acquired. Preparation issues include the installation and testing of the video recording system as well as the storage, handling and security of the recorded data. The acquisition of audio-video recording equipment requires an assessment of the capability of the equipment itself and of the location into which it will be placed. The data collection will yield many hours of design protocols. The protocols have to be transcribed and analysed using the video recordings. The requirements for the video recording system are:

1. Ease of locating the precise times (time stamp) of spoken comments, drawing marks etc.
2. Ease of capturing verbalizations and synchronously associating them with drawings on paper and images on video.
3. Ease of reaching specific incidents, actions, speech in the lengthy recorded design sessions.
4. Support for analysis of multi-modal conversations, i.e. two (or more) designers drawing, two (or more) designers talking.
5. Support for observations of both drawings and speech in the same digital media.

To record the designers' activities and verbal exchanges for the complete length of time the design project takes place, the video recording system must be located in a suitable area throughout that time. The requirements of this system are such that it supports the collection of data in the working environment in a way that has minimal intrusion on the work in progress. In summary, the features of the video recording system consist of:

- Three cameras to record activity from different viewpoints.
- Quick and easy access to events and scenes.
- Mountable and portable computer system with software installed.
- Sufficient disk space for storing16 frames per second video over eight hours per day for two weeks
- Digital archiving and backup facilities.

4.2.3 Methods for Study Phases

The data collection methods for each of the three phases of the studies will be as follows:

Phase 1: The base study of current collaborative design process and methods

The methods are:

- Direct observations recorded on a field diary
- Monitoring of events (digital video recordings)
- Interviews

Phase 2: The trial use of selected collaboration technologies based on Phase 1 scenario.

This will be achieved by studying the effect of different design and collaboration technologies applied to the same task as in phase 1.

The methods are:

- Continuing direct observations recorded in field diaries
- Monitoring of events via digital video recordings
- Conduct protocol analysis trials with a developed coding scheme.

Phase 3: The trial use of virtual systems in addition to the phase 2 technologies.

This will be achieved by studying the effect of different ways of using the same technology.

The methods are:

- Continuing direct observations recorded on diaries
- Monitoring of events via digital video recordings
- Protocol analysis
- Diary analysis, cross comparisons of field diaries
- Data flow analysis.

5. RESEARCH METHODOLOGIES

This section provides an overview of research approaches and methods that have been identified as relevant and useful for use in this project. Ethnography is a generic term that is used to characterise research into human activity in the natural environment as distinct from laboratory-based studies where controlled conditions apply. The approach has been extended into those fields concerned with designing and developing interactive technology, a process that requires detailed attention to the full spectrum of human characteristics and behavioural patterns. Experience has suggested that if interactive systems are to be acceptable to users and effective in enhancing their work and personal activities, it is essential that the context of use is understood and taken account of in interactive technology system design. In order to do that, methods and techniques for gathering field data have been developed. Two methods for collecting and analysing heterogeneous data are available to this form of field research: context analysis and protocol analysis. Context analysis provides information about the overall situation in which the design process is taking place. Protocol analysis refers to the detailed examination of the ways in which representations are produced within the particular conditions of the activities that are provided by the context analysis. The methodology for this project brings together ethnographic, context and protocol studies.

5.1 Ethnographic Studies

Ethnography is an approach to social inquiry provides an informal mode of description and analysis. Ethnographic studies in design have been used for the purpose of making designers sensitive to the sociality of work and identify broader issues for an effective design. Some practical strategies have been defined for the use ethnography in design: for example, so called ‘Quick and dirty’ ethnographic studies, used to provide a broad understanding of the work domain (division of labour, work activities etc.) in a relatively short period of time, concurrent ethnography a parallel process in which investigation of work and systems design proceed at the same time and evaluative ethnography, a more focused version of quick and dirty ethnography to provide a ‘sanity check’ of design proposals or an existing prototype (Crabtree, 2003).

The ethnographer is required to bring awareness to the co-operative aspects of work revealing how work is organized by parties to the work, and whether those parties be co-located or distributed across space and time. As Saphiro (1993) puts it, “ethnographic work analyst should identify particular aspects of ‘what is really going on’ in a given field of work and ‘what is really the problem’ that people encounter doing it”. Ethnography’s role is thus defined as to ‘impart knowledge’ as to the cooperative work of intended users, not to ‘give form’ to potential design solutions supporting that work (Plowman,1995).

Ethnographic research begins with *exploration* and *inspection* driven by the work under study. Exploration involves developing a familiarity with the cooperative work. The researcher might engage direct observation of the work or might be rather remote, observing interactions on video or listen to talk on audiotapes. Other methods includes informal interviews with staff, group discussions conducted, work diaries and records be consulted. Thus exploration aims at gaining first hand knowledge of the work of the site. Over the course of the exploration, certain activities and work practices become more pronounced, and some analytic themes begin to emerge and the researcher tries to analyse those emergent categories (Crabtree, 2003).

In a design context, ethnographic work is often characterized by gathering of the worksite materials; sketches, diagrams, and photographs of spaces/places, arrangement of tools/instruments/technologies and videotapes of the site’s staff in action. In addition to collecting worksite material, the flow of conversation and workplace chat should be recorded and transcribed at a later stage, forming an important part of ethnographic record. Video recordings of the work environment in combination with textual descriptions could portray the sense of the real-time organization of the work, which is an essential source of data for the researcher. The analysis stage involves the production of data and extraction of findings from the records. A classification scheme is often used for interpreting the data. Classification schemes are provided by the categories that make up analytic generic formats. These categories are then used to *code* the data. This method of analysis has a long history in anthropology and social science research.

The following sections provide information about the origins and use of context analysis and protocol analysis both of which have been devised to meet the requirements of data collection and analysis in ethnographic style research.

5.2 Context Analysis

Context Analysis establishes the scope and the context of the domain. The purpose of domain analysis is usually to identify the situations that represent the case study as a whole. Context analysis has been used in a large range of domains such as management, education, social psychology, engineering design, software design, human computer interaction, usability etc. Thus the term “context” could have various definitions depending on the scope of the domain.

Context analysis establishes the basis of ethnographical research. It is an informal mode of description and analysis where the researcher becomes familiar with the worksite in order to acquire a concrete understanding of the work taking place. Typically, in the architectural design domain, the researcher gathers data about the context of the study, which includes an acquaintance with design practice and the physical environment that is used. Context analysis also provides an opportunity to establish a relationship with the study participants, with other members of the design environment, social interactions through an extended period without the pressure of the formal data collection task. These observations undertaken prior to the main study include the topics of conversations, noting and recording the sketches, drawings and diagrams used and how communication takes place.

5.2.1 Context Analysis and Software Usability Studies

Context analysis has been developed and applied in the field of Human Computer Interaction, in particular, in the area of usability studies. Usability Context Analysis (Thomas and Bevan,1995) is defined as a structured method for eliciting detailed information about a software product and how it will be used, and for deriving a plan for a user based evaluation of a product. Within this definition the ‘context’ refers to the product features and the user evaluation.

In usability studies, to obtain information on the context of use, a detailed checklist is used. Then the output is a description of the context of use, derived from the completed checklist. The initial context analysis may identify gaps that could be later filled by user observation, interviews, survey questionnaires, or user participation in context of use analysis, focus groups or brainstorming (Usability guide, www.usabilitynet.org).

An example of user participation in context analysis can be found in the Esprit project (Candy and Rousseau, 1995), a field study which included a context analysis exercise with the team members. One of the aims of that context analysis exercise was to enable the team involved to develop a document which addressed the issues associated with product usability and thus achieve a shared view. The exercise also served as a data collection tool for gathering necessary information about users, tasks, and environments prior to detailed analysis (Candy et al, 1995).

Context Analysis provides a baseline for measuring performance of designers and systems in use; in other words performance metrics may be derived from the Context Analysis. Performance of a collaborative team refers to measures about the task performed. The questions of what should be measured and how to measure it, in order to be able to calculate the metrics, needs to be determined in a principled way by the project team. The performance measures could be related to analysis of task output such as quantity (how much?) or quality (how good?). The task time (how long is task completion?) is another performance measure, and further one can determine productive versus unproductive time spent during task completion. Performance measures provide a quantitative approach to the process of events and actions rather than their content and intentions. However in the design context, we are also interested in the content of the tasks and the goals and intentions components of the tasks. The number of sketches produced, or the time spent on goals which contributes to the completion of the design task, could be meaningful data, albeit incomplete, when we look at a design environment. Similarly looking at only the quality or representational types of the design output may not be sufficient to represent what has been going on during the task. As a performance measure, unproductive time refers to the time spent on actions that did not contribute to the task, however, in the design context, those actions might contribute to the quality or continuity of the task in hand.

5.2.3 Context Analysis Applied to Collaborative Design

All these factors point to the fact that we need to look at the process of designing in terms of the strategies, goals or intentions involved during the process, in order to have a complete picture of the term "context". Prior observations involve investigating and understanding the nature of current design practice in the work environment before setting up any video monitoring. During this stage the researcher is introduced to the context with informal and prior observations. The researcher directly observes the *events*, and records them into the field diary. Use of audio tape as a memory aid is recommended. Prior observations help in identifying the study setting, and enhancing what is to be recorded in the field diaries.

The benefits are summarized below:

- The purpose of prior observations is to gather information about key themes in the conversations, general actions/tasks of individuals, and the worksite material produced.
- It is an opportunity to establish acquaintances with architects, with office hierarchy, social interactions through an extended period without the pressure of the formal data collection task.
- Researcher constructs a preview of the context to decide on what events should be collected during the later collection of data video recording.

There are two major outcomes from this stage of the study:

- Development of themes, define designer's actions and design events
- Decisions on study setting, location of recording equipment, and the specifications of the recording equipment to use

Context Analysis involves observing interactions and conversations between people in the situation to be studied. This is done by direct observation and the observed events, actions, or content of conversations are recorded in a field diary in a structured way. During this period the researcher might need to interview or informally talk with the site staff to fill in the gaps in his/her conception of the context. Some important issues to consider include: determining the parties involved in the work, understanding how the work is organized, how the work place is used and how the tools, instruments and technology are used. The researcher produces a comprehensive and structured documentation of the collected data so that it can be shared with and used by other researchers in the field.

Photographs of the materials about the tasks are taken throughout for the inspection of work content in-situ. The materials could be drawings, sketches, documented brainstorming information, magazine pages, photographs of buildings, environments, 3D models, printouts of computer models etc. Continuous inspection of the design representations is an effective way of capturing the possible changes that take place as the design project evolves.

Context Analysis involves forming a complete picture of the worksite and the design tasks involved. Direct observation, interviews and the collection of produced material provides a comprehensive framework of what is going on. Context Analysis requires focusing on this framework to develop emergent categories and define actions and events based on reliable information about the situation as it develops.

The outcomes from this stage of the study include: category development (including emergent categories during the protocol analysis) plus new action and event definitions.

5.3 Protocol Analysis

Protocol Analysis is a technique first used by Newell (1968) in studying information processing systems. Attempts to understand 'how designers design' first started with introspective methods and then using protocol analysis techniques (Newell and Simon, 1972). The question of 'how designers think' was not separable from the former question, and many aspects of both questions were explored by using the design protocols (Eastman, 1970; Akin, 1986; Schon, 1987, Goldschmidt, 1991, 1995). The analysis of design protocols formalized the intuitive aspects of design and has been the basis of design cognition studies, revealing important insights on design problem solving and sketching in the architectural context.

Akin (1986), influenced by the information processing tradition, investigated design protocols with a different approach that extracted information from the content. Schön (1987) took a similar approach to analysing protocols of practising architects to illustrate the idea of "reflection-in-action". Goldschmidt (1991) emphasized that the design protocol should include both verbalizations and drawing. Similarly, Akin and Lin (1995) argued that it was important to investigate the drawing process as part of design protocols. The ROCOCO project studying protocols of collaborative design presents one of the early approaches to detailed analysis of drawings together with analysis of verbalizations (Scrivener et al., 1992 cited in Mazijoglou et al, 1996). Subsequently, recent design protocol studies focused upon the analysis of actions such as drawing, the movement of hands (hand gestures in sketching) and also seeing and looking which provided a comprehensive picture of physical actions involved during design (Suwa et al, 1998,1999, Kavakli and Gero, 2002).

There are five steps to protocol analysis:

1. Conducting constrained studies to collect protocols.
2. Transcribing protocols.
3. Parsing segments.
4. Encoding raw protocols using one of the coding schemes.
5. Analysing encoded protocols.

Among the above steps, segmentation and coding schemes play essential roles in manipulating protocols. Intrinsically, they are established to support and substantiate research assumptions and hypotheses.

Until relatively recently, most protocol studies have been using concurrent protocols where the subjects would attempt to verbalise their inner thoughts while trying to solve various design problems (Ericsson and Simon, 1993; Van Someren *et al*, 1994).

5.3.1 Concurrent versus Retrospective Reports

Protocols are the major source of data for protocol analysis. A protocol is defined as the recorded behaviour of the problem solver, usually in the form of sketches, notes, video or audio recordings (Akin, 1986). Two types of protocol reporting that have been developed in design research are named as 'concurrent' and 'retrospective'. In order to obtain concurrent protocols, the subjects are required to design and verbalize their thoughts simultaneously, while in retrospective protocols subjects are asked to design first and then retrospectively report what they do with or without the videotaped design process as a visual aid. Most protocol studies have been using concurrent protocols where the subjects would attempt verbalizing their inner thoughts while reasoning and sketching trying to solve various design problems (see Ericsson and Simon, 1993; Van Sommeren et al, 1994 for the details of the method). The subjects would work on a real or simulated problem situation being encouraged to "think aloud." They are asked not to rationalize or justify their decisions but to directly report their actual moves (or strategies and goals) when attempting to solve the problems, thus revealing details of the information processing sequence using their short-term memory. Recently, some researchers have began to apply retrospective protocols both to avoid the dangers of concurrent protocols and to understand perceptual aspects of designing (Suwa & Tversky, 1997; Suwa *et al*, 1998; Suwa *et al*, 1999), which are believed to be non-accessible to concurrent protocols. In retrospective protocols subjects attempt recollecting the preceding cognitive processes retrieving information stored mainly in long-term and partially short-term memory. To assist subjects with fuller and perhaps more reliable recall of their thinking processes Suwa and Tversky (1997) conducted a research aided by video recordings of the preceding design session. This led to some insightful results in the area of design cognition.

Apart from the above division into retrospective and concurrent, protocol studies can be distinguished as being process- or content- oriented (Dorst & Dijkhuis, 1995). Generally, studies employing concurrent protocols focus on process-oriented aspects of designing, being largely based on the information processing view of design activity. The main focus is put on design problems, design strategies, and various issues deriving from the design process (Eastman, 1970; Chan, 1990; Gero & Mc Neill, 1998). On the opposite, studies utilising retrospective protocols are aimed at cognitive aspects of designing, being based on the idea of reflection-in-action introduced by Schön (1983). They focus on 'internal' cognitive processes to provide a better understanding of designer's drawing, seeing, and other issues deriving from the design content (Suwa & Tversky, 1997; Suwa, Purcell, & Gero, 1998; Suwa, Gero, & Purcell, 1999).

Generally, views on the use of protocol studies range from identifying different modes in the design activity, to how knowledge and actions are embedded in design. Regardless of the difference in approaches, the protocol analysis has been accepted as a prevailing research technique elucidating design processes in designing. And while the earlier studies dealt mainly with protocols' verbal aspects, the later studies acknowledge the importance of design drawing associating it with design thinking which can be interpreted through verbal descriptions. A method of protocol analysis, though generally useful and credible, is not, however, devoid of a number of limitations.

Difficulties with the technique do exist, however, and many researchers have revealed the controversial aspects of the method. Two major issues have been raised about using protocol analysis to understand a design problem. First, a design protocol can only reflect part of the real design process; it cannot capture everything. Ericsson and Simon pointed out that the accuracy of the verbalisation in a protocol might be task–specific (Ericsson & Simon, 1984). If the task were responsive, involving only short-term memory, the verbal report would be closer to the real mental process. On the contrary, if a task is more retrospective, involving the use of long-term memory, then wrong or missing data might occur. A de-briefing interview or post-protocol questionnaire can be constructed after the protocol to reduce erroneous readings.

A second concern about protocol analysis is that the think-aloud protocol might distort the real design process. As Lloyd, Lawson and Scott pointed out, the methods of protocol analysis might interfere with the act of designing (Lloyd, Lawson & Scott, 1995). Recent research by Gero and Tang (2001), however, presents an argument that there is no associated interference with the ongoing design process when using concurrent protocols for exploring the process-oriented aspects of designing. In addition, real design is usually "thought over," designers have time to digest the design brief or architectural program. Designers would not normally be forced to work out a design in the artificially short period set up by a protocol analysis section. A real design process would be in a real setting (e.g., in a studio, using a drafting table) instead of in isolation in a laboratory. An alternative to protocol analysis is "discourse analysis," which suggests using transcripts of actual interactions involving domain experts and their clients in a real setting (Belkin, Brooks & Daniels, 1987).

Akin (1986) summarizes the limitations of using protocol analysis in experimental work as follows:

1. Since subjects are asked to verbalize their behaviours during protocol experiments, there is room for erroneous introspection.
2. Due to the extent of the analysis required to interpret the data and the quantity of the data itself, only small numbers of subjects can be used in each experiment. This is contrary to good experimental practice.
3. The thought process, being much faster than motor behaviour, cannot be fully reflected through the motor responses of subjects.
4. There are usually gaps or periods of silence found in most protocols, which obviously does not correspond to lack of cognitive activity (p. 181).

The recent availability of a relatively inexpensive means of communicating internationally and the expansion of international design practices have initiated considerable interest in studying collaboration at a distance both within the same discipline (e.g. architecture) and across disciplines (e.g. structural engineering, environmental engineering). Design work has been characterised as a social process in itself, rather than as a design process influenced by social factors (Suchman and Trigg, 1991). Consequently the design process is conceived as conversational and interaction based instead of as an information process inside the individual mind. It has become necessary to define design processes in terms of interaction with elements in the world.

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 (Schaub, 2003; Glock, 2001). The emphasis here is the analysis of conversation patterns, information about team dynamics, individual motivation and social interpretations.

Protocol studies of architectural design in practice have rarely been done because of the difficulties in collecting protocols. Architects used to be more involved in individual work which meant that the verbalisations and communications were kept to a minimum in the process. However, the protocols of a team of architects may be collected in the real working environment since the progress of design nowadays occurs through the communication of ideas and communication via drawings.

5.3.2 Protocol Analysis Applied to Collaborative Design

The protocol analysis method has been extended by the KCDCC group at the University of Sydney for studying designers. The analysis of design protocols is based on both drawing actions and verbalizations of the designer. The protocol coding stage is usually done manually and at least twice by one coder with a minimum of two weeks between the first and second coding. Following this, an arbitration coding is carried out using the two coded versions. All of these factors make the process time-consuming.

Another issue concerning the protocol analysis is to achieve a robust and consistent coding which needs many trials and testing of the coding scheme. The coding scheme has to have open ended and meaningful action codes, which should represent many aspects of the cognitive processes involved. For this purpose a psychological model is usually used which would provide the action categories in the coding scheme. The difficulty in the collaborative environments is that more than one participant's cognitive processes are involved. Thus the model not only should involve cognitive processes but should include the modes of interactions, communications between the designers and the work environment. Action theory provides a comprehensive framework to model those interactions. We also use the emergent categories determined from the context analysis to develop a coding scheme for in depth analysis of the parts of collaborative design process. This means that protocol analysis is used for the deeper analysis of certain aspects of the whole process while context analysis is used continuously over the research timeline (see Figure 1 above).

5.4 Data Analysis

The data collected using the methods described in the previous section, is of its very nature heterogeneous and qualitative. This provides a large and rich source of information on which to perform various forms of analysis. The aim of the analysis is to provide insight and understanding of the key characteristics of such issues as:

1. Collaboration: effort and effectiveness, communication and behavioural patterns.
2. Design Process: origin and development of ideas, conflicts and resolutions, outcomes achieved.
3. Design Methods: the use of materials and tools, number and type of sketches, models etc.

5.1 Analysing Communication

One focus is to categorise the communication activities between the participating designers including the tools and devices that are used to enable such exchanges. Communication activities may be characterised in terms of the number, type and mode of interactions.

Inspection and analysis of communication content and the structure of the conversation are the basic items to examine. Content-based analysis requires a text medium and hence, the verbalizations have to be transcribed. The text data should preferably be associated with the video data, since analysis of design protocols is based on inspection of communication and drawing behaviours interactively. The communication content is represented with specified codes of which there are numerous examples in the literature. We will start with a set of micro strategies as proposed by Gero and McNeil,1998. (see Table 1).

Table 1 Micro Strategies

Code	Description	Example
Ap	Analysing the problem	"What is the system going to need to do…"
Cp	Consulting info about the problem	"The brief says it has to be light and…"
Ps	Proposing a solution	"The way to solve that is…"
Cl	Clarifying a solution	"I will do that a bit neater"
Ep	Evaluating the problem	"That is an important requirement"

Dd	Making a design decision	"Ok. We'll go for that one"

The activity modes and activity codes that are used in behaviour observation will be applied to the analysis of the communication patterns together with behaviour analysis. Unexpected aspects of the behaviour analysis might emerge which will require further investigation that is when we analyse the verbalization, thus the communication content. Hence protocol analysis is not limited to the above codes. It is an elaboration of behaviour analysis.

5.2 Analysing Design Process

In order to understand what is needed to be able to improve a design process, information is required about the effort needed to achieve tasks and the effectiveness of the different aspects of the process in the current collaborative design process: for example, where the aim is to demonstrate the cost and effort benefit of using a particular technology system in comparison with existing non-digital mechanisms (Edmonds et al, 2001). Exchanges between designers involve many informal interactions and where a new system is introduced this adds effort to the process. By quantifying such exchanges, this can provide information for quality measurement, such as the existence of misunderstandings and errors and the recovery processes employed by the team members.

As an example, timed data was gathered from a set of observation records of the use of a new system for exchanging design data. (Candy and Harris, 2001). An analysis of the observation data suggested that the design process could be broken down into a set of identifiable sub-tasks. The amount of time the user/engineer was engaged in each of these sub-tasks could then be extracted, providing a more meaningful description of the process. Additionally the total time spent carrying out actions relating to each observation category could be extracted for each sub-task. Data about time estimates demonstrated that the one part of the design process, the transfer of a design from one tool to another was considerably faster compared to manual design transfers. The observation evidence suggested that this task was particularly significant in time terms in relation to the whole design process. A significant time saving was demonstrated and the projected effort saved of using the new tool-to-tool interface was significant.

A need was identified for a system to enable such information to be explored by all partners. Such a system must provide project wide access to the evaluation database and promote a sense of joint ownership of data. For that purpose, a distributed web-based method for the sharing of the information and the provision of exploration capabilities to all team members was developed. Because the understandings of the informal exchanges are distributed amongst the teams, the exploration and analysis of these data must itself be a collaborative process. The method gives all project team members remote access to a central data repository, and allows users to search and explore the data without the need for specialist tools and skills. (Britton et al, 2001)

5.3 Analysing Behaviour

Systematic observation is a common approach to behavioural research and an essential component of a wide range of fundamental and applied disciplines. The basic technique used in observational studies consists of recording who does what, and when. The record could also include where this behaviour occurred and with whom. Systematic behaviour observation has the potential to reveal the behaviour patterns during the activity of a design team. The researcher has to record the events with a time log, continuously to obtain the events and behaviours over the time period of design activity. Field diary notes provide us with the basis for inductive analysis of behaviour (see Appendix 4 Notes from a field diary).

The use of software support may be beneficial for the collection, analysis, presentation and management of observational data (see Appendix 3 for review of some available software packages). The software provides an interface that shows audio, video and text data of the sessions together. During an observation session, key presses are used to log events and the time at which they occur. A mouse or a computer pen could also be used as the input device. Then the software time-stamps each entry to record activities, postures, movements, positions, facial expressions, social interactions or any other aspect of a behaviour. Figure 4 shows an example of the recorded behaviours and how they are represented in one of the commercial software packages.

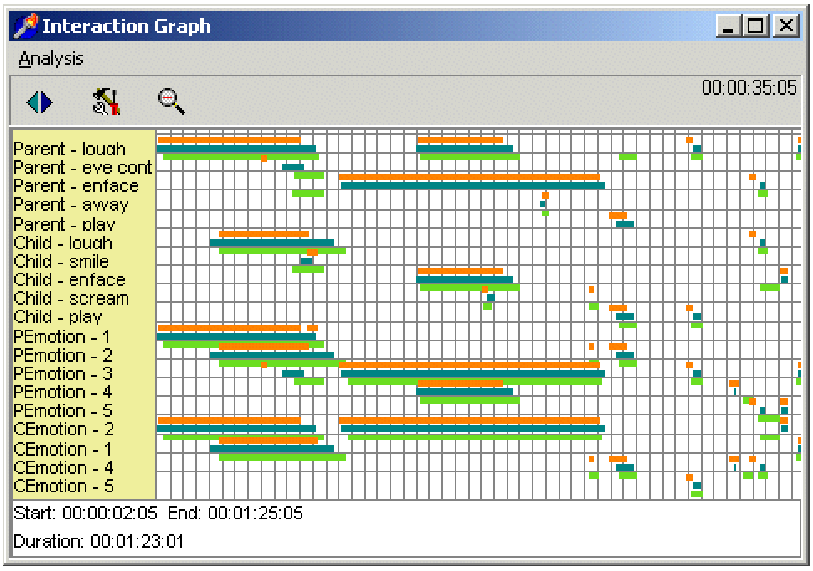
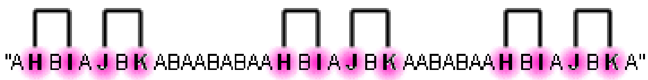
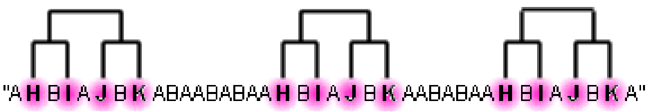


Figure 4 Example of recorded behaviours

In Figure 4, each colour line illustrates a different participant's behaviour, while the left-hand side column describes the content of the behaviour. The software makes it possible and easy to inspect behaviour patterns graphically over the time period. Further some software packages integrate algorithms which are able to discover and quantify behavioural patterns inside the observational data taking several parameters into account, such as order, duration and relative position of behavioural events.

The following example is cited from the website of a software company (www.mangald.de):

> "Person A is talking while person B is not listening and person C is arguing against person B". This combination of single behavioural codes ('A talking', 'B listening', 'C arguing', etc.) now forms a complex new behaviour of the whole group of observed people. This is being a simple example; consequently other code combinations would arise in the results which have to be interpreted. Two patterns of equal 'quality' can be found:
>
> 
>
>
> Also a hidden top ordered pattern can be found:
>
> 
>

The behaviour data for the proposed research studies are collected during architectural design and therefore, communication and sketching activities are both involved. This makes the itemized behaviours more complex and already in interaction with each other. One focus for the analysis is to determine the amount of time spent of various aspects of interest.

The following is a list of categories for which we will collect time-stamped behaviour data:

- Producing sketches-drawings (individual)
- Verbal communication
- Communication by drawing (two or more architects working on the same representation)
- Use of a particular technology (telephone, fax, email, collaboration software, CAD software etc.)

- Being away, not involved in design activity.

A second focus for the analysis is to categorise according to the communication medium:

- Verbal communication (decision patterns, discussion structure, determine individual roles in the team, is he initiator-analyser-summariser-decision maker etc.)
- Drawing communication (discuss the drawings, make changes on the drawings sketches and communicate the changes (verbal or visual), is interactive drawing process present?, how do they communicate via drawings)

Decomposing the above categories we have developed some initial behavioural codes:

- Drawing layout
- Drawing perspective
- Showing, referring to things on the working sketch
- Showing, referring to things in previous sketches
- Showing, referring to visual material (photos, pictures etc)
- Drawing-Drawing (two architects in contact sketching)
- Drawing-Looking (draw and then look at photos, perspectives-interactive)
- Looking at the pictures, photos, search magazines
- Looking at previous sketches
- Looking at the primary sketch in progress
- Using gestures to define something
- Verbal communication about
    - Working sketches
    - Past cases, visual precedents
    - Personal, design-free subjects

A number of other aspects of the data collection will be analysed. Appendix 5 provides examples of the approaches that can be used.

6. CONCLUSIONS

In conclusion, this project will study current design practice in order to understand the implications and potential benefits of bringing new collaboration technologies into the commercial design office. To achieve this, it is necessary to acquire data that accurately reflects the true nature of collaborative design. Methods for gathering and analysing the data, such as context and protocol analysis, have been assessed as suitable vehicles for this kind of research. The selected methods meet the particular demands of conducting empirical research investigations in a real world industry context. The requirements of the data collection and analysis methods are different to those of laboratory studies where controlled conditions are required. The research involves three phases of in-depth studies of a small number of designers carrying out real design projects in their normal environment. The aim is to provide baseline results for subsequent studies. The research will contribute to understanding of the impact of introducing collaboration technologies for design on the users of such systems and more generally, knowledge about human cognitive and behavioural processes. The outcomes will provide a sound foundation for guidance to industry about the future deployment of high bandwidth collaboration technologies.

7. REFERENCES

Akin, O. (1986) Psychology of Architectural Design, Pion, London.

Akin, O. and Lin, C.C. (1995) Design protocol data and novel design decision, Design Studies, **16**: 221-236.

Andriessen, E. J.H. (2003). Working with Groupware: Understanding and Evaluating Collaboration Technology. Springer-Verlag, London Ltd.

Belkin N.J., Brooks, H.M., Daniels, P.J. (1987), Knowledge elicitation using discourse analysis, International Journal of Man-Machine Studies **27**(2): 127-144.

Bevan, N (Ed.) (1997) Usability Context Analysis:A Practical Guide, NPL Usability Services, Teddington, UK.

Britton, J.H. Candy, L. and Edmonds, E.A. (2001) A Method for Sharing Information for Quality Measurement in Multi-Site Team Development, Pathways to Software Quality: Proceedings BCS conference on Software Quality Management IX, edited by Dawson, R. King, G. Ross, M and Staples, G. 19-29.

Candy, L., Edmonds, E.A., Heggie, S.P., Murray, B.S. and Rousseau, N.P. (1995). A Strategy and Technology for Front End System Development. Proceedings HCI International '95 Yokohama, Elsevier Science B.V. July: 103-108.

Candy, L. and Harris, D. (2001) Evaluating Model Data Exchange between System Engineering Tools. Journal of Systems Engineering, **4**, (1):13-23.

Chan, C. (1990). Cognitive processes in architectural design problem solving, Design Studies, **11**: 60-80.

Crabtree, A. (2003) Designing Collaborative Systems: A Practical Guide to Ethnography, Springer-Verlag, London Ltd.

Cross, N., Christiaans, H. and Dorst, K.(eds.) (1996) Analysing Design Activity. John Wiley and Sons, Chichester, West Sussex.

Dorst, K and Dijkhuis, J. (1995) Comparing paradigms for describing design activity. Design Studies,**16** (2): 261–274.

Eastman, C. M. (1970), On the Analysis of Intuitive Design Processes, in G. Moore (ed), Emerging Methods in Environmental Design and Planning, Cambridge, The MIT Press, Cambridge, Massachusetts:21-37.

Edmonds, E.A., Candy, L., and Britton, J.H. (2001). Sharing Strategic Knowledge; Evaluating B2B Transactions in Systems Engineering Design, Preprints of the Third International Workshop on Strategic Knowledge and Concept Formation, J.S. Gero and Hori, K. (eds). University of Sydney 17-18 December: 145-161.

Ericsson, K.A. and Simon, H.A. (1993) Protocol Analysis: Verbal Reports as Data, MIT Press, Cambridge, MA, Revised Edition.

Gabriel G. C., Maher M. L. (2002) Coding and modelling communication in architectural collaborative design, Automation in Construction **11**: 199–211.

Galle, P. and Kovacs, L. B. (1992). Introspective observations of sketch design, Design Studies, **13**: 229-272.

Gero, J. and Mc Neill, T. M. (1998). An approach to the analysis of design protocols, Design Studies, **19**: 21-61.

Gero, JS and Tang, M (2001) Differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process, Design Studies 21(3): 283-295.

Goldschmidt, G. (1991). The dialectics of sketching, Creativity Research Journal, **4**(2), 123-143.

Goldschmidt, G. (1995) Visual displays for design: Imagery, analogy and databases of visual images. In A. Koutamanis, H. Timmermans, I. Vermeulen (Eds.). Visual Databases in Architecture. Avebury:Aldershot: 53-74.

Goldschmidt, G. (1996) The designer as a team of one, in N Cross, H Christiaans, and K Doorst (Eds) Analysing Design Activity, John Wiley and Sons, Chicester, West Sussex.

Kavakli, M., Gero, J.S. (2002) The structure of concurrent cognitive actions: A case study on novice and expert designers, Design Studies, 23(1), 25-40.

Kvan, T. and Candy, L (2000). Designing collaborative environments for strategic knowledge in design, Knowledge-Based Systems **13**: 429-438.

Lloyd, P., Lawson, B. and Scott, P. (1995). Can concurrent verbalization reveal design cognition?, Design Studies, **16**: 237-259.

Mazijoglou, M., Scrivener, S. and Clark, S. (1996) Representing design workspace activity. In N. Cross, H. Christiaans, and K.Dorst (eds.) Analysing Design Activity, John Wiley and Sons, Chichester, West Sussex.

Munkvold, B.E. (2003) Implementing Collaboration Technologies in Industry: Case Examples and Lessons Learned. Springer-Verlag, London.

Newell, A. (1968). In the analysis of human problem solving protocols, Calcul et formalization dans les sciences de Lomme.

Newell, A and Simon, H.A. (1972) Human Problem Solving, Prentice Hall, New Jersey.

Plowman, L., Rogers, Y., and Ramage, M. (1995) What are workplace studies for?, Proceedings of the 4th European Confererence on Computer Supported Cooperative Work, Kluwer, Stockholm, Sweden: 309-324.

QSR (1997) NUD*IST User Guide, 2nd Edition, Scolari Sage Publications, London: http://www.sagepub.co.uk.

Saphiro, D. (1993) Interdisciplinary design: some future possibilities, Proceedings of IRIS 16, Universtiy of Copenhagen, Department of Computer Science: 15-27.

Schon, D. A. (1983). The Reflective Practitioner, Harper Collins, New York.

Schon, D. A. (1987). Educating the reflective practitioner. London: Temple Smith.

Stempfle, J. and Badke-Schaub P (2002) Thinking in design teams – an analysis of team communication, Design Studies 23, pp. 473–496.

Suchman, L. A. (1987) Plans and situated action: The problem of human-machine communication. Cambridge University Press, New York.

Suchman L. and Trigg R. (1991) Understanding practice: Video as a medium for reflection and design, in J. Greenbaum and M. Kyng (eds) Design at Work: Cooperative Design of Computer Systems, Erlbaum, Hillsdale, N.J.: 65-90.

Suwa, M. and Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis. Design Studies 18(4), 385-403.

Suwa, M., Purcell, T. and Gero, J.S. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. Design Studies **19**(4), 455-483.

Suwa, M., Gero, J. S. and Purcell, T. (1999) Unexpected discoveries and s-inventions of design requirements: A key to creative designs, In J. S. Gero and M. L. Maher (eds), Computational Models of Creative Design IV, Key Centre of Design Computing and Cognition, University of Sydney, Sydney, Australia: 297-320.

Thomas, C. and Bevan, N. (1995). Usability Context Analysis: A Practical Guide and Performance Measurement Handbook EC Project Versions. National Physical Laboratory, Teddington, Crown Copyright.

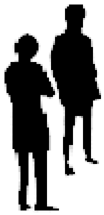
Valkenburg R. and Dorst K. (1998) The reflective practice of design teams, Design Studies, 19(3), pp. 249-271.

Van Someren, M. W., Barnard, Y. F. and Sandberh, J. A. C. (1994). The Think Aloud Method: A practical Guide to Modelling Cognitive Processes, Academic Press, London.

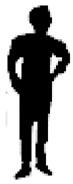
Vera, A.H., Kvan, T., West, R.L., and Lai, S. (1998). Expertise, collaboration and band with, retrieved from the WWW (http://arch.hku.hk/~tkvan/chi98/chi98.pdf)

8. APPENDICES

Appendix 1 Human Ethics Application



ETHICS APPLICATION FORM FOR RESEARCH INVOLVING HUMANS



SECTIONS: Page

Appendix 2 Research Methods Workshop

A workshop was held on Tuesday 28th October, 2003
Room 308 3rd Floor Wilkinson Building, University of Sydney. It was attended by members of the CRC team who are concerned with the industry design studies form University of Sydney and CSIRO Melbourne.

Timetable

10.30 am	**Introduction**
	Research Aims and Objectives
	Human Ethics
	Research Approach
11.30	**Methods**
	Technical Preparation
	Context Analysis
1.30	**Data Collection**
	'Observable' Events
	Role of Observer
2.45	**Collating the Data**
3.00	**Data Analysis**
3.45	**Analysis Examples**
4.00	**Discussion and Review**
4.30	**End of Workshop**

A full set of slides is available.

Appendix 3 Software Support for Analysis

Software packages exist for qualitative analysis and observational data analysis. These packages enable the researcher to code, retrieve, build theories and conduct analysis of the data. Most packages are able to work with text, graphics, audio and video sources. The aim is primarily to support the researcher in the very difficult task of reducing complexity and marshalling verifiable results from large sets of heterogeneous data. Some applications that are being investigated include:

HyperRESEARCH" which enables the coding of any type of source text, audio, video and image, comes with analysis tools (such has Hypothesis Tester) and it can integrate cases from multiple study files.

ATLAS.ti (by Scolari) is an application for the visual qualitative analysis of large bodies of textual, graphical and audio video data. The goal is to uncover complex phenomena hidden in the qualitative data. It provides rapid search, retrieval and browsing of all data segments and notes relevant to an idea. It has Hypertext links which enables quick browsing through the narrative structure of the data. The paper and pencil look of the interface seems to be an advantage from a usability perspective.

Observer (by Noldus) is for the collection, analysis, presentation and management of observational data. It can be used to record activities, postures, movements, positions, facial expressions, social interactions or any other aspect of human or animal behaviour. It reads time codes directly from the video file, and can plot a graph of observational data against time. It has statistical analysis tools and also a sequential analysis tool using a technique which examines how often certain events are preceded or followed by other events. The package also has a Reliability analysis tool which measures the level of agreement between different ratings derived from the same data set.

INTERACT (by MAngald) package has most features of the above applications and seems to have a better pattern analysis tool which can be integrated into the package. P.A.T.T.E.R.N. takes several parameters into account, such as order, duration and relative position of behavioural events. For example,. 'Person A is talking while person B is not listening and person C is arguing against person B'. This combination of single behavioural codes ('A talking', 'B listening', 'C arguing', etc.) now forms a complex new behaviour of the whole group of observed people. INTERACT can handle more than one video file to be coded in a single code, which would be an advantage to the particular project under consideration as three cameras will be recording simultaneously and therefore, it is advantageous see three files on one interface and to be able to code them synchronously. (Ref http://www.mangold.de/english/intlatest.htm)

Another data collation and analysis tool is SphinxSurvey which provides facilities for both statistical and lexical analysis. Sphinx can be used to create structured interview or survey questions, to collate the answers to those questions and to perform analysis on both numerical results and free text data.

One of the most commonly used tools for analysing verbal protocol data is an application called Non-numerical Unstructured Data Indexing Searching and Theorising (NUD*IST). It was used in a recent empirical study to analyse observation data which was an important pre-requisite for providing measures of cost benefit of the introduction of a new on line design data exchange method.

In order to handle, a very large set of heterogeneous data, software support to assist with its management and analysis is invaluable. The structured analysis of such data is a first step towards converting the data into numerical form for quantitative analysis. The NUD*IST (Non-numerical Unstructured Data Indexing Searching and Theorising), software (QSR, 1997) has been used for many research studies that required this form of data analysis. In NUD*IST, data are stored as sets of text documents, which can include field notes, interview transcripts, communications between individuals (especially email communications), and any other form of textual data. Entire documents or sections of them can be assigned to categories or *codes* which are set up by the analyst. Here, a "code" is a key word attached by the user to a text document to provide a link to related documents. These nodes are structured in a hierarchical tree form that enables logical relationships between codes to be represented by their structure. Data is coded by storing a reference to relevant text at the node required. Some nodes contain references to entire documents (e.g. document author) and others to only relevant text (e.g. all pieces of text relating to a particular requirement). The codes are represented as a set of interconnected nodes in a tree structure called the *index tree*. The position of each node within that structure can be changed at any time. This enables logical relationships between ideas (such as sub-classes of codes) to be represented by their structure, and this can be altered as new relationships are discovered during analysis. Further details about the data analysis techniques using NUD*IST can be found in Britton et al, 1998. The context of development and use of the method described is the European Community projects, SEDRES and SEDRES-2, which have a primary goal to improve data exchange capabilities for multiple site systems engineering design teams (Johnson et al, 1999).

Appendix 4 Field Observation Notes

Field diary notes provide us with the basis for inductive analysis of communication or behaviour. From the field diary we can extract the information about patterns of coordination (who does which task? who coordinates the task allocation) and patterns of information transfer (the direction of and amount of transfer and content of transfer). The notes shown in Figure A4 and the images are taken from the field diary of the researcher during the prior observations stage of the project:

No pin-ups on the wall
(10.30) They (P1+P2) talk about materials.
P1 trying to explain how the material should be [he remembers that he has the colored copies, he goes back to his desk to find them (10.55)]
(11.00) P1 comes back and shows the example pictures for materials. He gives the example of Crawford house, he likes the idea: "it is gonna look good just like the Crawford house"…

Conversation interrupted

(11.15) [someone walks in. They look at her, they look at each other (P1 + P2), then go back to the layout]
…….

(12.20) Checking the layout with the tracing paper on it and drawing columns and revisions on the tracing paper (P1+P2 taking turns)…(layout sketch01)

(12.28) P2 suggests that "we re gonna define materiality, the material has to support services and has to be robust".(12.45)…Still discussion going on about materiality.

(12.50) They start talking something private (P1+P2). They wanna talk in private (they whisper to each other, they don't want me to hear them. After whispering they left the library, went to the other part to talk in private).

(13.10) First P2 comes back. P1 talking on the phone. (13.22) They come back to the library table. (13.30) P3 brings the 3D model of the apartment…

Figure A4. Notes from a field dairy

Appendix 5 Forms of Data Analysis

Analysing Representations

Representations are continuously produced during the design process. During the context analysis phase, we observed that there are various types of representations produced (which also refer to the different stages of the design) and those representations are produced in various ways. Representations tell us not only stages of the design process but rate of changes in ideas, decisions as well as intensity of the activity involved. Thus inspection of specific aspects of the representations during development of the design enables us to observe the changes in the work environment, idea patterns, and changes in the ways they are produced. Figure 4 shows some produced sketches in the situ.

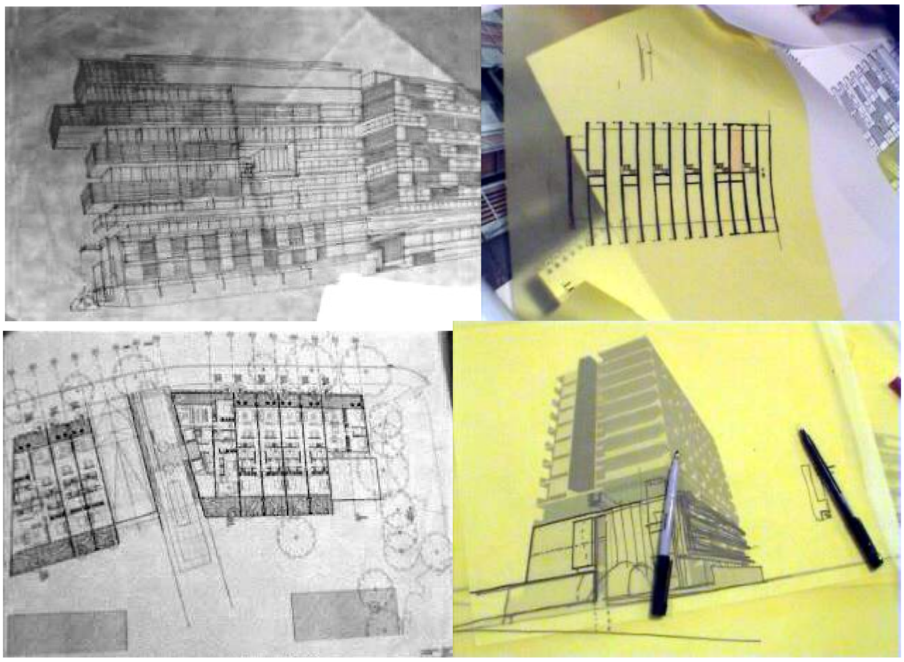


Figure A5 Materials (Clockwise pic1, pic2, pic3, pic4)

The representations could be the material produced during the design session (drawing new) or it could be a previously produced material (drawing old). There are specific ways of producing design material depending on the individual working preferences of architects. Distinction between the ways of producing the material is important in the analysis stage as well as the representational nature of the material. In order to define different production methods, specific activity modes have to be identified during the period of prior observations and context analysis (refer to the activity modes in analysis of behaviour section). The activity modes are either developed with a bottom-up approach, through careful observation of the design process or borrowed from previous sketch/design cognition studies. For example, in the current case, architects traced their sketches on a previously produced drawing or a CAD printout. We coded this activity mode as Dts: Tracing on a previously produced drawing.

Representational distinctions are necessary to compile and collate the worksite material effectively. Types of materials produced are recorded on Table 3 below. We also recorded the time spent with the associated material. To provide an example to an analysis chart we categorized the total time spent as, ‘time spent on looking at the material’ (coded as DLt) or ‘time spent on producing the material’ (coded as DPt). This level of detail is coded at the protocol analysis phase.

Table A1. Material chart

Material	Type	DPt (min)	DLt (min)
Pic 1 (old)	Façade drawing		20
Pic 2 (new)	Elevation drawing	30	15
Pic 3 (Dts)	Façade sketch	25	5
Pic 4 (old)	Layout drawing		5

This observation has directed the protocol analysis phase to consider further explorations of the ways in which representations are produced.

Analysing Longitudinal Data

The field diaries include researchers' observations in a brief mode. Longitudinal data is collected during the continuous context analysis period. Data is stored as sets of text documents, which can include field notes, interview transcripts, communications between individuals (especially email communications), and any other form of textual data. NUD*IST (Non-numerical Unstructured Data Indexing Searching and Theorising) supports the efficient management, structuring and manipulation of large amounts of qualitative data. This frees the analyst from tasks associated with managing such data, allowing him/her to spend more time interrogating and reflecting on the data. In addition to the obvious benefits arising due to the automation of clerical tasks (i.e. more 'reflection time' therefore more ideas and more robust interpretations), NUD*IST provides more direct support for the analysis process.

Entire documents or sections of the text data can be assigned to categories or *codes* which are set up by the analyst/researcher. NUD*IST software represents codes as a set of interconnected nodes in a tree structure called the *index tree*. The position of each node within that structure is defined by the user, and can be changed at any time. This enables logical relationships between ideas (such as sub-classes of codes) to be represented by their structure, and this can be altered as relationships change or new ones emerge (Britton et al, 2001). Figure 5 shows example of an observation record which was processed in NUD*IST for the SEDRES project.

* Observation Record

*Observer: NM***
*Date: 14/10/97
*Start & end time: 11:26 - 12:00
*Company & Engineer: ***/ GH
Task: Import Risk Reduction material from G

%G***,%TASK/USx,%RISK_REDUCTION_MATERIAL,%IMPORT, %CHECKLIST_USED
*Receiving transferred file via Internet
%EVENT TYPE? 11:26 Start %Observer: Import started at 11:26
%SNAG/PROBLEM 11:26 Wait %Observer: Waiting for Team Links to wait & see if there's a message %Engineer: Usually takes from 1 min to 2 hours. Don't know when sent, only when received
%HELP SOUGHT 11:27 Question %Observer: What are we importing?
%EVENT TYPE? 11:28 Comment %Observer: Email question about sending email to A*** successfully delivered / transferred %Engineer: Only A*** gives these messages supposedly.
%SNAG/PROBLEM 11:30 Email %Observer: Email problems when sending to L***to postmaster %Engineer: Apart from this, NOT difficult to send email
%EVENT TYPE? 11:13 Reading %Observer: Reading file in email
%SNAG/PROBLEM 11:33 Receiving %Observer: Received file but PCMS does not work. Tailored config . problem %Engineer: Don't know how long it will take.
%HELP SOUGHT 11:34 Break %Observer: Ask question about what actually happened to import file sent to himself

Figure A5 Example coded observation record (Britton et al, 2001)

Most of the analysis work involves reflecting on the implications of quantitative and qualitative representations of the dataset, and contextual information surrounding such data. Emerging ideas and other notes can be recorded as *memos* attached to relevant nodes or documents. Memos can also be used to document changes to the database made as new ideas emerge. Entries can be date-stamped to provide an audit trail of developing ideas. This is especially important during longitudinal studies where ideas may change considerably during the course of the analysis (Britton et al, 2001).

Data Collation

Table 2 shows the collation of a collected data sample. We divide the design process into sessions and activities and record the related analysis material such as notes in field diary, audio recordings or audio/video recordings. The last column in Table 2 indicates if protocol analysis is involved regarding a particular activity.

Table 2 Data collation chart

SESSION	START	FINISH	ACTIVITIES	DIARY	VIDEO	AUDIO	PROTOCOL ANALYSIS
1	9.00	9.45	P1+P2 Brief requirements review	Y	N	Y	N
2	10.12	10.45	P1 + P3 sketch and discuss	Y	Y	Y	Y
11.00 am Coffee break- P1							
3	11.00	12.00	P3 drawing the elevation	N	Y	N	N

Over the extended period of the research we need to include other types of data into the collation charts. The current research involves management of various data from observations as shown in Table 3.

Table 3 Overall data collation

Field Diary Notes	Case1	Case 2	Case 3
Researcher 1 (ZB)	√	√	√
Researcher 2 (LC)	√	√	√
Prior observations	√	√	√
Sound Files			
INTERVIEW	Tr 8	.--	Tr 7
Prior Observations 1	Tr 4, 5, 6	Tr 2, 3, 4, 5, 6	Tr 2, 3,
Prior Observations 2	Tr 9, 10	Tr 7, 8, 9, 10, 11	Tr 4, 4cont
on server/ file name etc.	√	√	√
Produced Design material			
DAY 1	Sketches	4	
DAY 2	3D model Façade drawings		
DAY 3	Layout in AutoCAD		Pics
Materials in prior observations/training	Sketches, pictures, 3D models	Digital drawings…	
Video Recordings			
VHS	Tape 1 - 20.6.02	Tape 2 - 27.6.02	Tape 3
Work in Progress			

9. BIOGRAPHIES

Professor Mary Lou Maher is the Professor of Design Computing at the University of Sydney with a joint appointment in the Faculty of Architecture and the School of Information Technologies. In 2002 she was appointed a Visiting Professor in the Faculty of Architecture and Planning at Massachusetts Institute of Technology and Adjunct Professor at the School of International and Public Affairs at Columbia University in the USA. She was Head of the Department of Architectural and Design Science at the University of Sydney from 2000-2001, during which time she started a new undergraduate degree program in Design Computing and helped restructure the administration of the Faculty. She has a Bachelor of Science from Columbia University in Civil Engineering in 1979, a Master of Science from Carnegie Mellon University in 1981, and PhD from Carnegie Mellon University in 1984. She is the founder and editor of the International Journal of Design Computing, and the editor or co-author of 8 books and over 150 papers including published designs of virtual architecture, and serve on the editorial and program review board for numerous journal and international conferences.

Professor John Gero is concurrently Professor of Design Science and Co-Director of the Key Centre for Design Computing and Cognition at the University of Sydney in the Faculty of Architecture and Visiting Professor of Design and Computation at MIT. He is the co-author or editor of 36 books and over 450 published research papers in the fields of design science, design computing and design cognition. He has been a visiting professor of architecture, civil engineering, mechanical engineering and computer science.

Dr. Linda Candy is Senior Research Fellow at the University of Sydney in the Key Centre of Design Computing and Cognition, in the Faculty of Architecture. She has a first degree in English and French from the University of Adelaide, a Masters in Computer Aided Learning from De Montfort University, a doctorate in Computer Science from Loughborough University. Her research areas are empirical studies of collaboration and computer support for creative design. She has published widely on these topics. She has carried out a number of projects in collaboration with industry including BAE Systems, EADS, Saab and Lotus Engineering. She is Co-Chair of the International Symposium on Creativity and Cognition sponsored by the ACM Special Interest Group on Computer Human Interaction. She has published over 80 papers and articles and presented her work in Europe, Japan, Australia and the USA.

David Marchant is IT Manager - Global for Woods Bagot Pty Ltd – an international firm of architects. He is also Adjunct Associate Professor of Design Computing in the Faculty of Architecture at the University of Sydney. David has a Bachelor of Architecture from the University of NSW and a postgraduate Diploma of Architectural Computing from the University of Sydney. He has been a registered architect since 1983, but has predominantly worked in managing and developing IT software applications in architectural practice. He has also been a contributing member to a number of ISO standards in CAD and related areas.

Cooperative Research Centre
for Construction Innovation

9th Floor, L Block
QUT Gardens Point
2 George Street
BRISBANE QLD 4001
AUSTRALIA

Tel: +61 7 3138 9291

Fax: +61 7 3138 9151

Email:
enquiries@construction-innovation.info

Web:
www.construction-innovation.info

Established and supported under the Australian Government's Cooperative Research Centres Program