Spaces, Traces and Networked Design

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Abstract

A field study was conducted on a team of collaborating designers who used a variety of internet-based media to co-ordinate their activities. The paper focuses on their work practices, specifically those of their conversational resources in organising collaboration and structuring their workspaces for future reuse. The team was interdisciplinary and both locally (office spaces spread over a single site) and temporally (across different time zones) distributed. As well as face-to-face meetings, their resources included a shared web-space, web-development software, telephones, videoconferencing, email, Hypermail, and CAD software. Our findings demonstrate that it was not enough that the team maintained a persistent record of their communication. It was also critical that this record was archived and accessible in an appropriate media for rapid and effortless re-use, and that it be dynamically re-configurable to adapt to the team members' changing communication and informational requirements over the project lifecycle. From the findings we develop implications for the design of persistent network-based solutions for this information referral and review.

1. Introduction

This study investigates how a team working on a design project managed their distributed knowledge and stored information with a range of web based communications technology tools. The focus of the work reported on here relates to their 'conversational activity' and the means by which they did this distributed over space and time. It examines the use of persistent representations that arose through the team member's individual activities as well as through collaboration with one another, drawing from the methods of social science to investigate these phenomena.

That there is a long history to the investigation of what we would term 'persistent conversations' is evident in the field of organisational memory [1,5,15,22,24]. What most of this literature does not do is to demonstrate the use of what we have called persistent conversations - how they are generated, navigated and maintained. It concentrates on designing technologies for people to create and use as memories, rather than seeing what information groups, teams and organisations need to recall, and the physical and social mechanisms that they use to achieve this. We intend to demonstrate how this is done in a small organisational unit through the use of user-configured tools, which includes both non-technical and technical artefacts.

Exploring *how* people appropriate and use technology, integrating it into their patterns of work is a powerful means of providing designers with the understanding they need to support these activities. This work therefore focused on the 'communication protocols' and 'organisational structures' that the team members used in their persistent conversations. Detailed field studies were used to examine how a group of co-workers generated *traces* of their activity in what we describe as 'persistent conversations'. We investigated an instance of cross-disciplinary communication in a project team, and between several different stakeholders. These included an engineer, architect, construction manager, and web manager, and to a lesser extent, consultants and client. When working together, they had to maintain a common understanding of the problem to discuss issues affecting their own concerns. The technology available provided them with technical mechanisms for both managing ongoing communication and information use, and as a means of archiving it (in some form) in a manner that allowed it to be recalled when required for use in future activities.

2. Investigating Persistent Conversations – Data Collection

2.1 Field study of persistent conversations in action

The persistence of a communication is without value if it cannot be accessed later. Indeed, it is self evident that the form that information is stored in is of direct relevance to its later use, demonstrated by studies from the field of distributed cognition that show how the representational media is critical to its processing (e.g. [11,17,18]). However, rather than theorise about the cognitive basis of an persistent conversations, we propose that empirical investigation of their use is more likely to be of benefit to

designers, and describe the results on one such study in the rest of the paper.

An important arena for using persistent conversations lies in the area of engineering design. We highlight the role of persistence in the team's communications, in the strategies used and the resources appropriated to achieve this. Engineering design is a domain involving complex knowledge structures and large amounts of collaboratively generated information that may need to be re-accessed later on in the project life-span. The primary aim of this larger study was to describe and analyse the setting or context of the design and how this interplayed with the goal or task that the team had to resolve. This compliments previous qualitative studies into the work of collaborative design [3,4,13,16,17], but with a focus inclined towards the role of technology in the process, and especially its appropriation and use.

2.2 Fieldwork techniques

We draw from the methods of social science in performing this study, and it is ethnographic in nature - that is, it is qualitative and interpretative. Our intention is to describe the means by which the participants structured their work and environments in order to accomplish their goals. The ethnographic approach has a long history within anthropology and has been used extensively in social studies of technology and in the area of computer supported co-operative work (e.g. [9, Hughes *et al.*, 1992, 20]). Ethnography allows us as researchers to account for the 'situated' and organisational aspects of work. These social, contextual and artefactual contexts of work, and the interactions between them, accounts for much of people's behaviour in the real world [21], and such behaviours cannot easily be examined in a laboratory setting - and naturalistic studies of practice are more appropriate for this.

Ethnography is characterised by the collection of data from a range of sources. The ethnographer attempts to understand how activity is understood and practised by its participants. Van Maanen [23] describes it as being used to 'uncover and explicate the ways in which people in particular work settings come to understand, account for, take action and otherwise manage their day-to-day situation' (p. 540). The detailed investigative work of the ethnographic approach to data collection allows us to examine how groups manage the explicit and tacit aspects of their work. This approach is highly relevant to this study because these are the issues that we hope to uncover – how conversations are managed, made persistent, and used with reference to their context. Essentially, the intention of the ethnographic analysis in this study is to demonstrate *how* conversational – or communicative - work is managed by the team, and how it is archived and accessed for later reuse.

Data was collected by the first and second authors who worked closely with the informants, observing them, doing *ad hoc* interviews and video-recording their meetings where possible. Over 20 hours of video material was collected, transcribed, coded and segmented, and we had access to the permanent and shared electronic resources used.

2.3 The team and its organisation

The study was used to investigate the use of multimedia communications technologies in collaborative design with the aim of developing augmentative technology to support these activities. We gained access to this area through a masters level course run at Stanford University (the 'Computer Integrated Architecture, Engineering, Construction' - A/E/C) in the Department of Civil and Environmental Engineering. This was an educational environment that brought together the various disciplines involved in construction through the use of network and information technologies [6,8]. The students on the course were geographically distributed across Stanford University, UC Berkeley, Cal Poly San Louis Obispo, and Georgia Tech. It took a multi-site, cross-disciplinary, project-based, and team-oriented approach [7], which engaged several teams of students, faculty members, researchers, and professional practitioners from several construction-based disciplines.

The field study involved one team of these A/E/C students collaborating together on the design of a construction project in the academic year 1997-98 (data was collected late in 1998). Their task was to design a building which was owned by a 'client' (a staff member), and they were able to draw on the experience of consultants (industry based mentors with specialist skills). The team included an architect, located at Georgia Tech., and an engineer, a construction manager, and an apprentice, all located at Stanford University. With the exception of the apprentice, all were postgraduates with between two and ten years of relevant industrial experience. They had access to a variety of collaboration and productivity technologies to work with, including systems such as email, web editors and workspaces, desktop video-conferencing and 3D modelling software. The study took place over nine weeks, as the team was performing the second phase of the design - the detail design phase - fleshing out previous work into more detailed plans. They had already been using the technology for several weeks, and were able to configure and operate it with relative ease. It is important to recognise that the study was conducted two years ago, and consequently, the technology described reflects this,

setting the technological context. Needless to say, the laboratory infrastructure (at the pbl lab.) has developed greatly in the meantime, guided in part by the user studies described in the paper.

To all intents and purposes, the design project was as near to a real design task as possible. Whilst small in size, many of the team's needs and requirements were similar to those of larger organisations, and provided a unique perspective on information use because interaction between the participants could be easily examined and their work activities followed. The design team had to work within tight deadlines and constraints to complete the project on budget and on time, to a professionally acceptable standard. We do not however, claim that the setting is necessarily typical. Larger organisations operate with more people and may exhibit different behaviours, but believe that we can get a unique insight into technology use despite these limitations. Indeed, the group studied was performing the sorts of activities that generally characterise engineering design: they had to collaborate to perform problem solving, and most of the practical constraints that they faced were common across the industry. The non-commercial setting meant that it was possible to easily access project-related data even in what might have otherwise been commercially sensitive areas.

As is common in today's knowledge-intensive workplaces, the team members were engaged in multiple tasks, the A/E/C project being only one component of their ongoing work. The members had to manage their own time as individuals, and co-ordinate their schedules with the others to arrange meetings. All had offices in separate locations, although the three team members at Stanford had access to a computer room fitted with high end PC's, workstations and networking equipment. This was also where the team meetings were observed and video-recorded.

2.4 Technologies available for use

Whilst we do not wish to concentrate on the technology alone, but on its use as a resource in developing an environment for supporting and maintaining persistent conversations, it is necessary to briefly outline and describe the resources available to the team. These resources provided the team with the ability to generate and maintain a 'common information space' [2] to communicate with each other through, although they were given no formal instruction on how they were to use it. The team members all had basic experience of these technologies and they were encouraged to configure and use them as they felt appropriate, adopting a structure and determining its content as they needed. The communications media available broadly fell into the areas of text based (email, 'chat', web pages), audio (telephone), graphical (web based images, CAD files), multi-modal (desktop video-networking technology). The technologies themselves are considered below:

Web technology was provided in the form of a shared web workspace that all of the team could write to. They could store a variety of electronic files in this, and could access it through conventional web browsing tools. As well as text entry, images could be scanned in from paper and added to web documents, allowing sketches and photographs to be viewed on-line. The web (accessed through the Netscape browser) provided a technology that could be used as a common platform to integrate most of the other technologies noted below.

Email allowed the team members to perform standard person-to-person, asynchronous, text based interaction. An automated system called 'Hypermail' (a structured, persistent and searchable email archive) allowed emails sent to a group email address to be archived and viewed from the web space with minimal organisational effort on the part of the team. Emails sent to the group address could be sorted by date, topic or author if the reader wished to access them at a later time. This technology was expected to form the basis for maintaining persistent conversations.

Audio communication was provided through a telephone link. This allowed the team to make person-to-person calls, and it required, conference calls, because the device had a speaker and an external microphone. Video-conferencing software allowed real-time audio communication, but in practice this proved to be of too low quality to be usable.

Graphical/ pictorial information was accessible over the web, and could be used to display slide presentations, CAD files, and scanned in photographs, jottings and sketches. These were primarily intended for use as reference material. This information was not possible to update directly on-line, and needed to be 'hand coded' and uploaded asynchronously by team members.

Synchronous visual communications between remote team members was provided by video-conferencing technology running over a dedicated high bandwidth (T1) internet connection. The technology – Microsoft's NetMeeting software - also allowed the participants to 'share' windows and applications between the two locations so that the same visual information could be synchronously seen and interacted with at two or more locations. Integrated within this software package was a 'chat' facility, so that the team could synchronously

communicate using ASCII text by typing messages to one another.

Whilst most of these technologies could be used as stand-alone technologies, the team could integrate them in ways that they were not explicitly designed for. In combination, these technologies acted to support a wide set of media that could be flexibly combined in a variety of ways to support both synchronous and asynchronous communication. Our interest lay in how they would do this and how they would organise their activities to manage and take advantage of these technologies to support their work. Whilst the technology available to the designers provided them with the potential for providing a means of generating and accessing communicative resources across the network, it was not possible to know what particular aspects and configurations the team members would find useful in the performance of their work. We therefore needed to investigate how the technology was used in practice to see how the team developed, co-ordinated, and managed their distributed understandings of the developing design.

3 Communication, Collaboration and Technology Use

The data in this section is made up of material collected from the whole system that the designers used. We have not attempted to predetermine the form of the media used, nor the type of use that the designers were engaged in. Data from the field studies (discussed in more detail in [15]) are presented in vignettes below to characterise what we understood to be important aspects of technology use by the team with respect to their persistent conversations.

It was notable that the 'Hypermail archive' was not used at all by the team. Indeed, they did not even realise when the system broke down halfway through the design process. It was, however extremely useful as an overview for the analyst to examine their communications. It follows that a manager or new team member, who was interested in the team's activities at a gross level, would be able to peruse this database to get a flavour of the project, and the people contributing to various aspects of the work.

3.1 Use of multiple media in work

Different media were regularly used in combination to augment each other in communication. The following example shows how this operated in practice:

e.g. 1 – co-ordination of multiple media

> Structural engineer: 'There's a PowerPoint file in our group directory called...<breaks off and looks at the computer>...can you type it in the chat <i.e. the 'chat' window>...the name of the file, <architect>?'
>
> Architect: <reads filename out over the telephone>
>
> Apprentice: <shouts across room> 'Yeah, can you type it in...in chat...can you ask him to type it in?'
>
> Structural engineer: <looks at screen> '<the apprentice> wants you to type it in...can you have ...<murmur from architect>...chat, yeah!' <name of file appears> <pause> <she stands up> This is crazy.

In the above example, two media (audio and text) on a single computer are combined in order to work around the problems of file length. There is a problem in reading out long file names because they can easily have transcription errors made in them, and the increased clarity and persistence of the text medium in the chat window provides a workaround mechanism to support this.

A similar example shows how this was performed over physical space and on different computers. In this interaction, the team had to locate the file on the group's shared hard drive through UNIX because the file had not been placed on their web page yet.

e.g. 2 – distributed use of verbal and text based email

> Construction manager: So what is the name of your file? <speaking to architect>
>
> [...cut...]
>
> Architect: Look in your email directory
>
> Structural engineer: <tries to find the email in the 'elm' <UNIX email> session she is now running on a separate computer in the same room> I'm looking...<she finds the email with the filename in it>...Oh yes! <quietly> It's a very long name [...cut...]
>
> <Structural engineer then reads out the filename to <construction manager> who types it in to the NetMeeting/ networked PC, which they try to use to share the file with the architect>.

Here, two computers were used, one for communication using a shared screen (via NetMeeting, displaying the UNIX file structure), and another for text based communication (used by the structural engineer) using an archived email message.

3.2 Navigation and search

Locating and recovering information from the set of communications archives proved to be an integral and occasionally problematic experience of the team. In the example below, the participants (architect, construction manager and structural engineer) are looking for the agenda to the meeting. The architect is remote, the structural engineer on the videoconferencing networked computer, and the construction manager at a separate computer looking for the agenda which was sent out in an email to him.

e.g. 3 - searching for an archived email message

Construction manager: <cuts into ongoing conversation>'When did you send the agenda?'
Structural engineer: <turns to face construction manager> This morning, around 9.30
Construction manager: 'Summary of Friday's meeting'? <this refers to the visible email 'subject' text he is reading>
Structural engineer: 'Summary'?...um...not 'summary of Friday's meeting'...it should say something like 'today's meeting'.

In this instance, they used the title of the email to find its content, although it is not an optimal means of searching through the large database of emails with similar sounding 'subject' labels. Another example below makes it clear how paper has an advantage in this kind of navigation.

e.g. 4 – use of paper to support information navigation

Construction manager, structural engineer and a mentor search for a paper document originally from the construction manager's file; they begin by <from field notes>:...searching the desk, then the file then the mentor finds it on the floor behind him - very much based on it's physical (and not informational qualities) properties. The construction manager then files it in his file.

This is an interesting behaviour, because it illustrates the use of two features of paper that are not evident in the groups web pages: a) that paper can be searched for by criteria other than content [cf. 14,19], and b) that paper can be reorganised in a flexible way, according to the needs of the task (cf. micromobility [12]). This can be done in a cognitively non-demanding or resource-intensive way, and can therefore be carried out in parallel with other tasks. In this example, the paper was removed from the construction manager's file, put aside until needed, and then searched for and relocated without having to traverse through all of the paper in the construction manager's file. In this case, the flexibility resulted in the loss of this information, but it illustrates the general point about the flexible reorganisation that paper allows in ongoing communications – the hypertext documentation of the group's web space did not permit this kind of *on the fly* behaviour.

3.3 Recorded discussions in 'chat' forums

Regular meetings were held by the team to collaborate and to co-ordinate their activities. These generally took place twice a week and lasted between 1 to 2 hours, increasing in length and frequency over the project. As the quantity of the design-related information grew in complexity, co-ordination of each of the designers' work components had to be integrated with that of the others. As one of the design team was located at a distant site, and not all of the team were co-present at the same location (although might be logged on at a remote terminal), the videoconferencing software was frequently used. On these occasions, the team would sometimes switch to using the 'chat' facility on the videoconferencing suite. This was particularly useful for recording discussions and information that the team determined might be useful for later re-use and reference. This process appears similar to the paper based minutes that used preserve a permanent record of the content of a co-located meeting. However, in this case, the team members did not use another (i.e. a text based) media in *parallel* to the verbal channel, but entirely switched the media of their discussion from a verbal to a text based medium to preserve its content. An example from a recorded chat session demonstrates one of the ways that they used this:

E.g. 5 - Use of 'chat' as a permanent record of a conversation about the design

Georgia Tech: "I will keep this record for collaboration evidence."
[...]
Stanford: "good-do you want to send it to our hypermail archive?"
[...]
Georgia Tech: "Maybe after some editing!"
[...]
Stanford: Please save and upload this meeting record for future reference. Bye."

The conversation also demonstrates that the archive was not necessarily a reliable record of actual events, because it might be amended later for improved clarity and to add materials or information that were not available at the time. As we shall see, this is an important element of use that designers must be aware of if they are to design collaborative technologies to support persistent conversations.

3.4 Structuring the web archive for re-use

The 'design forums' were the largest and most organised repository of information that the team used. The team had created these themselves using the web as a development platform, in which they could view and discuss their opinions about the design and the design process. These were intended to implement a "formalised process for documenting the design intent, concepts, perspectives, and solutions" (from the team's documentation). Whilst the design forums were generated collaboratively, they were largely maintained and structured by the apprentice who took responsibility for organising and managing their content. Prior to the study, these had evolved from three initial forums to four, and over the course of the field study, these grew to six. An additional, semi-permanent forum was also created for 'catch all', unstructured information. The first forum provided an area in which the team agreed protocols for discussion in the other forums, the second discussed what they called the 'design intent', the third discussed technical issues, and the fourth discussed design alternatives. Of the final, two new forums, one was used to discuss the design methodology and collaboration process, the other was as a holder for information about the final design solution.

With so many people contributing to the design and adding material to the website, discovering who had added this information was potentially problematic. Knowing the identity of the contributor was of importance because it provided an insight into their design rationale. Understanding this would make discussion and design negotiation simpler, as it would add a context for follow-up discussions. To support this, the team agreed to use different colours to differentiate between recent and old comments (text from forum 1):

> .... I think each new person should highlight their newest comments with a color or some other feature and change any old comments to normal text, so new comments can be easily differentiated from old ones.

Over time, the forums evolved and this use of colour changed. Rather than showing comment recency as previously, using a particular colour came to mean that these comments were made by a particular person. In addition, whenever changes were made by one of the team members to the text in a design forum, the team agreed to send out an email saying that they had done so (again, from forum 1).

> ... Also I think each new update should be accompanied by a group e-mail so everyone can read the new comments. Lastly, I think before someone begins to update the forum, that person should post a note stating that they are updating, and during this time, no one else should mess with the file. This will avoid accidental over-writing.

This demonstrates how a co-ordination protocol was used to avoid file conflicts (called here "over-writing"). This is similar to Rogers' [20] description of the mediating artefacts used to avoid file conflicts in the drafting process: whenever file changes were to be made, this information was posted onto a board so that file users were aware of this.

3.5 Developing organisational and social protocols for interaction.

The team had tried to specify formal protocols for communication, but these mechanisms were limited to basic instructions about the use of various media in specific circumstances. Indeed, much of the fabric holding the group together was social, and not structured or formally organised. For example, the team members formally co-ordinated their meetings by agreeing to place their time schedules on the web, showing when they could all attend. Another example drawn from the teams' web space shows a protocol on how to use email so that it could be accessed over the Hypermail system; this required email to be sent from and to a particular address for it to be catalogued and archived (NB the team members each had two email accounts, with different access and retrieval functionalites).

E.g. 6. Instructions on the use of email.

- Use Hypermail for intra-team communication so that your communication is archived and "project memory" is initiated.
- E-mail messages sent to mentors should be sent from pbl accounts, not leland accounts, so that they are archived

However, the team's day-to-day interactions and co-ordination procedures were managed more flexibly in an as-needed fashion, without the need for involving formal co-ordination procedures to ensure the integrity of the design solutions. We speculate that this was made possible because the technology added persistence to these informal conversations. With the addition of structure (from their placement in the design forums) informal discussions were transformed into more formal resources that could be referenced and used to organise later actions. Without these resources adding a degree of persistence to these informal communications, the team would not have been able to co-ordinate their collaborative activities as easily.

3.6 Appropriation of technology for co-ordination.

The team was extremely versatile in their use of tools, using a range of communications software and devices for collaboration. The most commonly used mechanism that the team utilised to co-ordinate their occasionally diverse and divergent perspectives on the design was through email. Together with meetings, the other main form of communication used was email. Over the course of the project as a whole (4 months), a total of 348 email messages (between the team, as well as mentors and client) were received. The main purpose of email appears to have been that it allowed asynchronous contact that could be both sent and browsed when the sender or recipient had the time to deal with it. This, for example, could be used to communicate non-urgent messages, allowing the sender to manage their time resources more flexibly. Team members used email as a reminder whenever they updated information in their web based group space that they thought the others would need to know about. These emails were often brief, on many occasions having only a subject line, for example:

E.g. 7 - Entire content of an email informing the team of an update.

Date: Thu, 4 Jun 1998 15:01:51 -0700 (PDT)
From: engineer <engineer@leland.Stanford.EDU>
To: AEC Team <aec@pbl.Stanford.EDU>
Subject: updating forum 6

The team's choice of tool for a particular activity appeared to be as much to do with the limitations of the network, or particular circumstances, than because it was the most appropriate mechanism for co-ordination. For example, they made use of the 'chat' system when they could not make contact through the telephone (e.g. when the line was poor). In a fascinating insight into this, during a meeting that the researchers were video-recording, a mentor attempted to co-opt the video as a communications device because the phone line being used was very poor and kept breaking up:

E.g. 8. Novel medium for communication (from field notes)

Mentor: I'm wondering if we have a tape recorder, or video and can send you...a copy of <looks at the researcher and the video recording equipment>...okay, you have a video <points at the researcher>, okay, yeah, <looks back at the team> we have a video of this, so maybe we can send you a video discussion later, so that you can watch it.

Whilst this was an isolated incident, it clearly illustrates the artful use of technology that people use in co-opting a very diverse and unexpected range of artefacts for their own communicative purposes.

3.7 Summary

One of the major problems noted by the participants in the study was that they found it difficult to co-ordinate their often contradictory objectives. Whilst the participants were all involved in the process of design, their areas of expertise and responsibility differed. The problem of co-ordinating these different user objectives was further exacerbated by having a large and expanding physical design archive. In order to manage the increasingly complex system of documents and other information, the team developed working practices and organisational procedures for document management that enabled them to make use of this archive in a way that best suited their requirements.

Communications media were used in a wide range of ways, each appropriate to the ongoing tasks and constraints on action. Email was used as a means of distributing collaborative work over time so that shared work could be carried out when convenient to its recipients. Email could be tightly targeted at particular people and did not take up 'group time', which was a valuable commodity. Audio technology (video-conference and telephone) was used as media for discussing the designs over distance. These could not be used as a permanent record of a meeting, and when they realised that important decisions needed to be taken in these media, these communications were followed up or confirmed with an email.

Ongoing 'chat' correspondence was used so that a permanent record existed of a synchronous collaboration. This medium was selected over audio so that a physical record would be preserved. Email was used in the same way for asynchronous communication. The web was used as a platform for sharing reference material referenced in conversations continued from other media, and were usually embedded and structured within larger text documents. This archived material was used as a resource by the team members who monitored it to maintain an awareness of the other team members' responsibilities, but who also used it to acknowledge their own responsibilities in a public forum. However, communication protocols were hard to establish in on an *ad hoc* basis, and the group tried to formalise these by publishing a set of 'rules' that explained how the asynchronous communications media were to be used. In synchronous communications, these were usually negotiated as required.

4. Discussion: Persistant Interaction

The fieldwork provides us with a detailed source of information about how the team members organised themselves and the technology. The team's use of the technology available resulted in the emergence of a common informational space that they used as a resource to co-ordinate their activities, and the development of new work practices and procedures. We recognise that this summary of the activities performed described above can only capture a very small part of their collaborative involvement with one another. However, it clearly shows how the team developed mechanisms of collaboration that allowed them to draw on each other as well as from existing informational resources.

The media used by the team were used for two different things – as media for directly communicating with, and media for providing a reference to support individual and collaborative work. Thus, email and video-conferencing technology was used for communicating with people, whilst material on the web pages formed an archive that provided a context around which the communications could take place. This archive could be called up, pointed to, referred to in communication, or browsed independently. Our interest in this paper is how these two functions interacted with one another to provide the basis for a persistent conversation: the processes of generating an information resource and re-accessing it at a later time for work.

The web-based design forums allowed the team to undertake a structured discussion, so that the individual points could be discussed sequentially without losing focus, as might occur in a less formalised medium. They also allowed asynchronous conversations to take place, so that detailed discussions could take place over a long period of time. By recording the conversations they made into a persistent medium, the team could spend more time on reflection and referencing additional information than they could in a synchronous meeting. Of course, many of the discussions went unrecorded by the team. Most interaction took place over the telephone and did not result in the creation of a permanent document or physical archive: the web-based technology was mainly used to support *distributed* communication and rarely for co-located interaction. This was reflected in the heavy emphasis on architectural issues in the web archive - the persistent traces on the computer archive tended to be from discussions with the architect precisely *because* he was communicating from a remote site.

The fieldwork also provides a number of examples illustrating the 'user-structuring' that was performed and which allowed information location by the team. Retaining a stable archive structure throughout the design process over time was not possible. Over time, the design developed and information was added to the web archive. With the addition of this new information, the organisation of the site had to be changed according to the users' circumstances and needs. As the team retained old, out of date information that was important for reference they had to create a new 'old links' section on their web page. Another example of dynamic user structuring occurred in the use of colour in the forums, initially to highlight ordering information, but later to denote authorship of the communication.

This process of restructuring was more complex than simply as a tool to support to the design process. Whilst the structure of the electronic archive was an important aspect of the design work, the design information represented in the electronic group space was not a 'pure' record of the actual design process. Rather, it was socially constructed by the team to reflect internal and external pressures on the process; in practice, it was an abridged and expurgated version of the design process, created and used for reasons additional to the technical process of design. In addition to its use in design, the archive was also used to demonstrate the 'professionalism' of the team members to their tutor. They therefore did not always include information that showed their uncertainty about their design solutions in the archive. This was intended to make themselves appear more confident about their solutions; for example, emails considered to be 'uncertain' were not always forwarded to the Hypermail archive (see example 5).

5. Conclusions and Implications for Design

The development of communications technology has made it increasingly possible for collaborating teams to work remotely. This study has shown *how* existing technologies are appropriated by users to support their ongoing interactions. These findings suggest a number of areas that relate to the development of organisational technologies to support collaborative information use. By providing technologies that make conversations and discussions persistent, designers can manufacture the conditions that encourage the development of well co-ordinated yet flexible organisation teams.

As well as maintaining a repository of the design information currently in use, the team maintained a record of out-of-date design information, for example to re-use it, or to try to understand the rationale for the design. The fieldwork demonstrates that a significant problem for usability arose in this: the structure of the archive changed as its content changed. Where this structural change to the

archive occurred, information could not be found in its original location, and in practice could be as hard to locate as to recreate from scratch. This needed to be considered when the team updated the archive although they never fully resolved this problem. Larger teams, working over longer time frames, and producing larger volumes of documentation are likely to find this problem even harder to solve. An alternative method of changing or formalising aspects of the archival process may provide improved ways of making the archive of persistent communicative material more easily re-accessible. Planning the structure of the archive so that the categories used are easily modified to accommodate changes would seem an important element to consider in its early conception.

Perhaps more important than discussing how or why the technology supported the design process is the simple observation that the team managed to complete the design effectively. They did so without requiring 'heavyweight' co-ordination technology solutions developed specifically for collaborative design and instead produced an organising structure, fashioned from both social and technological components, appropriating technology and constructing a social organisation to modify existing patterns of work when it was required. Any technology developed to 'support' collaboration, particularly in a setting in which the problem space is dynamic - as in design, or more generally in knowledge work - should not exclude users from being able to flexibly utilise the technologies available to them and to modify their organisational structures through socially managed channels. New communications technologies to support collaboration and information re-use should not hinder this process by enforcing a rigid informational structure on their use. These may, however, increase the rigidity of the system, by hindering the powerful social mechanisms groups develop in response to specific co-ordination problems. We do not suggest that designers give up on their attempts to support co-ordination technologies, but that they should consider that users may attempt to appropriate the technology to support different types of work at different times.

Technologies based upon supporting activities that do not take place or that disallow those that do will hinder the A/E/C designers; what the designers need, therefore is a technology, or suite of technologies, that integrate with their work. By providing design teams with technologies that they can configure themselves, both technically and setting up their own social protocols, the communication process can be enhanced in a simple and effective manner. In the field study, the A/E/C team neatly side-stepped the problem of applying particular techniques at particular times in a formally prescribed manner, and they were supported in this by the technology which they could configure as and when they needed it. This however, had costs attached to it - at each stage of uncertainty, the team had to negotiate how they were to configure the tools at their disposal and to develop and hone the social protocols to manage their interactions through.

Privacy is also an important factor in the development of a useful design archive, as shown by the lack of willingness by the team to place information of an 'uncertain' nature onto their archive. To account for this factor, the developers of an archive may need to design different levels of privacy to mark off areas where people who are not necessary to the design development are restricted from visiting. Perhaps this could be managed by the users themselves specifying who could access particular information. There are, of course, questions of a political nature here. In a commercial organisation, senior people might not want to be excluded from accessing this information. Where files were protected, they might see this as a signal to them that they should investigate more closely: rather than improving openness, it might conversely act as a flag that this was an interesting area to investigate. One design option would therefore to make these areas 'invisible' to those without access permissions.

It has been very apparent from the data collected and their analysis that the conversational resources used by the team in the design process - their archiving, management and re-use of information - were critical to their effective performance and collaboration. Not all of the conversations that were conducted were captured and recorded, partially due to infrastructural problems as well as the perceived value of committing conversational material to an archive. In some cases, only a trace of the original communication remained as an informational resource. Nevertheless, the team made extensive use of the communicative traces in their archive as a design resource in a number of ways. By examining their *use* of this information we can begin to derive what value the users ascribed to it and how distributed and networked design could be further supported in this with additional, augmentative technology.

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