Co-ordinating Joint Design Work:

The Role of Communication and Artefacts

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An increasing number of technology developers are orienting their efforts towards supporting the group work of designers and engineers, yet there are relatively few in-depth workplace studies of this type of work. To help fill this gap, two case studies of design work in engineering companies are presented and compared. The findings suggest that design and engineering is constructed through the interactions of multiple actors, and that artefacts and representations of the design process have a key function in the organisation of this work. We note how current design and communication technologies fail to take these dimensions of work into account, and provide suggestions about areas where further reflection is needed.

Keywords: Case studies, engineering design, collaborative design, computer supported design, teamwork.

Groupware systems designers are increasingly creating systems with a view to supporting the work of design and engineering groups. Initial research efforts included experiments with the use of multi-media technologies to support groups of distributed designers[1,2,3]. More recent research has widened the range of potential technologies, and the nature of the application areas: fashion design[4], architecture[5], and engineering[6]. The growth of interest in "Concurrent Engineering" as a research field proposes theoretical and prescriptive models for managing heterogeneous design groups, and researchers have made proposals on specifications and architectures for computer systems to support engineering design. Such applications identified as facilitating co-located or distributed design work include: shared screen (whiteboard), shared editor, designer's notepad, videoconference, intelligent agents for conflict detection, issue based information system (IBIS), work-flow management, people locators and awareness system, and virtual meeting room. These technologies are developed and marketed as solutions to what are perceived to be problem areas for designers. In short, it would appear that group-based design and engineering is yet another form of work which would benefit from the increased use of computer and communication technologies.

1. Collaborative design and computer technology

In this paper, we suggest that it is unlikely that a simple technological "fix" will result in dramatic improvements in design efficiency. To substantiate this claim, we turn to methods and results from a different field of research. A growing number of ethnographic reports suggest that design work depends on ongoing and subtle social interactions, and on transformation work involving design artefacts[7]. This evolving, agonistic process[8], is in our view, not easily improved by new information technology. Along with others[4], we suggest that a deeper understanding of the limitations of proposed technology can be gained by examining the social and interactional dimensions of design work. Failure to do this could result in the design of inappropriate or ineffective technologies, or the implementation of counter-productive procedures and technologies. Whilst it may be possible to create integrated design-and-manufacture processes, we caution that a richer understanding of current practices is required in order to suggest which technologies may support and enable them.

The objective of this paper is to highlight and establish the importance of two key dimensions of joint design work: social and organisational interactions, and the ongoing nature of the knowledge representation and transformation work that takes place through the use of design artefacts. These two intersecting paths will take us into the heart of what it is to do design work. Independent of this research, Robertson[9] has emphasised the importance of these dimensions in design, and the case studies presented here will further support this observation. However, in contrast to Robertson's study of a distributed design group, the two case studies presented here are primarily of co-located groups, and much of the communication critical to their work is not within the designated design group itself, but is intra- and inter-organisational in nature.

The case studies presented ground and illustrate discussions about the two dimensions. Although not entirely novel as a methodological or analytical approach, few direct comparisons have been carried out of field or ethnographic studies of design groups. As well, the two case studies involve design domains that have received relatively little attention: mechanical and construction engineering. The main exception has been Bucciarelli's seminal book[10], in which he reports on three field studies of engineering projects. A comparative approach is potentially fruitful in that it could help draw out features that are common to design groups.

Finally, although this paper is primarily concerned with providing further details on the contexts of design work, the study has implications for the design of groupware systems to support design work. These are noted in the conclusion.

1.1. Shaping design work through communication

Previous accounts of design or engineering work point to various ways in which design work depends on communicative activity[10,11,12,13,14,15,16,17,18]. The potential range of people who may be consulted during the design is extensive, and these may be external to the organisation in which the design group is located (clients, model users, managers of users or clients, suppliers, technical experts, other designers), or internal (production personnel, organisational managers). In addition, consumer groups can lobby so that certain design needs are met, and "downstream" manufacturing personnel may request or provide information. Even groups in the same company as the designers may pressure the design team to incorporate particular technologies, although they may not have a formal role in the design work[19]. As well, the resources which sustain design work [i.e. instruments and personnel[10,11], may be negotiated between various actors.

1.2. Artefacts produced for and by design work

The second key dimension of design work analysed here involves the use of artefacts. Artefacts allow the externalisation and representation of objectives, constraints, form, function, assembly, materials, and so on[20]. Examples of artefacts are pen and paper sketches, tables of data, guidelines, cardboard models, and visualisations produced by CAD applications or virtual reality technology. In engineering design, there are *design* artefacts, such as plans, models, prototypes, and visualisations, and there are *procedural* artefacts, which may include forms, change requests, office memos, letters, schedules, and Gantt charts. Design artefacts represent thought about a design, whereas procedural artefacts convey the anticipated design process and help to orient people to it.

Artefacts are the objects of interaction; they have an important role as a communicative resource[9]. Objects can be pointed to, talked about or sketched on. Artefacts also become the terrain on which conflicts and collaboration occur[21,22]. Agreements are reified in artefacts[10]. Design artefacts can function as mediators between different individuals or groups in design. Star[23] discusses the use of 'boundary objects' as vehicles for communication between diverse groups with different interests and agendas. Henderson[24] develops on this with the notion of "conscription device," whereby engineering drawings are used as network-organising devices, drawing different people into the design work as the inscriptions reach certain stages.

The communication dimension and the role and transformation of artefacts in design work intersect in that the artefacts are subject to discussion, negotiation, and alteration. They are the focii of much of the social interaction, as contested symbols, objectifications of temporary agreements, and symbolic representations of potential productions.

2. *Case studies*

Two case studies were carried out of independent engineering design projects. One of these was of a group of consulting engineers working for the building industry; the other was of a precision pump manufacturing organisation. The consulting engineers in the building firm worked closely with one another to produce drawings of mechanical and electrical hardware. The pump manufacturing company was designing a range of pumps to replace its current line.

Ethnographically informed fieldwork was carried out in the two organisations. Fieldwork in both cases was oriented towards developing an understanding of the communication structures and activities accompanying design work, and of the role of artefacts in the design process. This entailed interviews, observations of work, and an examination of archived documents and artefacts used by the designers (hardware, software, paper documents, models, design tools, etc.). In addition, several design meetings were observed.

The fieldwork used two different approaches for the data collection. One of the authors took a longitudinal approach to the process, with 10 days on site spread over 6 months, whereas the other spent a month in the workplace. The studies were conducted independently, although both researchers had similar objectives of developing a better understanding of the communicative and artefactual dimensions of design work. Very few researchers have attempt to directly compare their field observations, although we believe this to be a useful tactic. This is likely to help identify regularities across organisations, and encourage researchers to reflect further about any observed differences.

3. Designing a pump

A small manufacturing company (60 employees), produced a limited batch precision pump used as one component in a food processing chain (pumping products such as ketchup or yoghurt). The senior management had decided that a new pump was required because of a need for increased efficiency, and a desire to reduce the "parts count" (to reduce inventory and the total cost), and assembly time.

Two graduates were hired to help design the new pump. Their work was specified by the managers, who divided it into two segments. One graduate would design a rotor and the inside of a rotor case (the moving head that propels the liquid), and the other (whom we shall call the pump integrator) would design the body of the pump (shaft, gearcase, gearing, and housing). A third graduate was employed later to design rigs for testing prototypes. The three were initially supervised by an experienced technical director, and together formed the core design group.

When the study began, the rotor design work was largely completed, and a significantly new rotor had been developed. However, the overall design concept was criticised by a steering committee on the basis that the estimated manufacturing cost was too high. The rotor designer and the pump integrator then worked on establishing costed design options.

3.1. Patterns of communication

The core design group were co-located above the manufacturing site shop floor, in the same room as a group of draftsmen. The three design engineers had direct aural and visual communication, and the pump integrator had visual, and "on-demand" aural communication with the technical director: a window between the two could be opened or closed. Thus, the core design group was continuously aware of each others activities, and spontaneous comments and questions were frequently observed. In addition, the core group held regular design review meetings.

It rapidly became apparent that the core designers were interacting with people outside their group, and that these people contributed significantly to the formulation of design issues and solutions, as well as to the organisation of the work. For example, information about ongoing work, the results of tests, and design options was provided to the steering committee. The committee appraised the design specifications, indicated where more work was needed, and decided among design options.

The technical director (and later a project manager) managed the design project on an on-going basis. He was at the hub of the communication taking place around the design work, monitoring, directing, and approving the work of the three designers. He also provided design ideas, defended the designers' productions with personnel who were concerned about their lack of experience, critiqued and approved planed prototypes, and helped liaise between the design group and the manufacturing engineers.

Both the rotor designer and pump integrator had frequent communication with shop-floor personnel, particularly when they were establishing costs for possible designs. Sketches were shown to production engineers involved in procurement, and these provided information on how costs were established, along with cost estimates for the parts. Sometimes the designers asked potential suppliers for similar information. Eventually this cost information was synthesised and collated, and presented to the steering committee.

Communication was not uniquely driven by the designers. For example, a draftsman was assigned to "draw-up" the pump integrator's drawings so that a prototype pump could be made. Although the engineers' CAD sketches were sufficient for internal discussion about the cost of a part, they were generally not suitable for producing prototypes or production drawings. When there was insufficient information in a sketch, and the draftsman would approach one of the engineers, and ask for clarification.

To sum up, the design group had a considerable number of communication partners, on and off site, all of whom contributed to some degree to the design work. For the most part, this was initiated by members of the core design group, yet at times they could be solicited by others, and asked to explain, or to be more precise about design configurations.

3.2. The range and role of artefacts

A variety of devices were used by the engineers to aid them in their work. This section identifies these artefacts, notes their contribution to the design work, and highlights both the transformations that some of them underwent, and the limitations experienced by the designers.

One design tool used frequently was a CAD drawing package. At the time of the study, the engineers had recently installed a new system, AutoCAD. However, they rarely used the package to create production drawings, but rather sketches of the rotor, parts of the pump, or test rig. The draftsmen, however, used a different (and incompatible) application, IBM CAD. Thus when the designers passed sketches on to the draftsman, this was done by handing over print-outs of the sketches (sometimes accompanied by pencil drawings and oral explanations).

Large scale printed drawings were frequently used to support discussions about the design of the parts. For example, a discussion was observed between the designer of the test rig and the technical director. An outline of the rig had been drawn and printed on a large paper sheet, then taken to the technical director's office. A discussion took place over the drawing, with both participants pointing to parts and writing on it simultaneously. Pencilled and coloured annotations were added to the document (at times, simultaneously by both), and comments and sketches were made in white spaces. The large size of these drawings should be emphasised (A1 format; "zoom-ins" and "zoom-outs" were not required as on a computer screen).

The designers frequently faxed drawings to suppliers in order to obtain part quotes. This frequently entailed the printing of a drawing on the plotter, going to a photocopier in another room to shrink it, then going back to their room to fax it. The designers noted, however, that pertinent information available in the original colour document (on-screen or paper) was often lost when it was faxed, and that they sometimes had to ask the sender to re-send the original. Facsimiles received were stored in folders, or in a shared filing cabinet.

Closer examination of the testing process also suggests the interplay of various artefacts, the transformations that some of them underwent, and the communication activities surrounding their use. For example, a university professor suggested that a realistic liquid should be used in an extensive set of comparative tests of the current, new, and competitors' pumps. After consultation with their Danish sister company, a recipe was obtained for a suitably thick liquid. A test plan was established, and this was detailed in a Gantt chart. For each of the tests, data was collected on the test rig computer, and transferred by diskette to another computer and imported into a spreadsheet. The testing process consisted of the gradual transformation of physical characteristics into comparative numbers and graphs. These were discussed by the design group and entered into decisions on rotor and shaft configurations.

We have attempted to convey here the surprising number and range of artefacts that were "participants" in the design process. These included common design tools (pencil, paper, and calculator), drawing tools (CAD and plotter), activity and co-ordination management tools (Gantt charts), information management tools (common filing cabinet, large table surfaces), calculation tools (spreadsheet, specialised applications), communication tools (telephone, fax, whiteboard, a window that opened), prototypes (cardboard model, prototype pump, parts stockpile), and testing tools (digital test rig, competitors' pumps, stroboscope, camcorder, thick liquid). All of these contributed to the design work.

4. Building design

A parallel study was carried out of the "Building Engineering Group", or BEG (with around 50 employees) of a large international engineering organisation. Building engineers transform the conceptual specifications of an architect into forms that can withstand stresses placed upon them, and ensure that the design conforms to appropriate regulations and standards. Fieldwork was carried out in a unit within the BEG which was participating in the design of an office block. Their task was to design the mechanical, electrical and structural aspects of the building. Several other organisations were also involved, including the client, construction company, architect, electrical contractors, a piling company, and quantity surveyors.

The work of the BEG was ongoing, initiated about a year before the fieldwork, and expected to finish nine months after it. The early stage of transforming architectural drafts into engineering drawings was nearing completion, and detailing of the "fitting-out" of the building was beginning, including building services and non-structural features. These fit-out elements had to be integrated with the structure to ensure its safety and to facilitate ease of maintenance and comfort for its occupants.

Two teams within the BEG were studied, the Mechanical and Electrical group (M&E, usually four engineers), and the structural engineering group (seven engineers). The two groups worked closely together because M & E features and structural schemes had to co-exist in the building. Thus the two groups participated in extensive joint planning and co-ordination activities.

Due to the complexity of their work, the design problem was broken down into smaller parts. These sub-problems ranged from answering minor queries, such as where to situate electrical sockets, to more substantial decisions about the location of load bearing walls and the integration of building control systems. Division of labour on the project was problem based, with groups of designers who dispersed once the design problem had been resolved. In many cases, designers were involved in multiple sub-groups (from more than one organisation), and these shrunk or grew according to requirements.

4.1. Patterns of communication

Design tasks were allocated by team leaders, who allowed a degree of autonomy once the initial work had been assigned. Team leaders managed their workers loosely, and often only checked final designs, rather than monitoring progress. This was partly because of their participation in multiple projects and full schedules.

Design problems were principally identified from the architects' drawings. Occasionally, the architectural designs had to be modified, and this involved negotiation with the architect. As the designs developed, conflicts occurred with other areas of the design; to resolve these, the engineers had to be aware of the work of the other designers, and to integrate their own work with that of the others.

Both teams of engineers in the BEG were co-located in an open plan office, allowing them to see, hear and speak to each other. All of the M&E team, who were situated within several metres of one another, were separated only by partitions (1.25m high). The structural engineers were distributed over several sites, but three of their members (including the senior engineer) worked together in the office, separated from the M&E team by several partitions. This co-location also allowed team members to draw on the experience of other engineers around them, and regular informal meetings and communication took place within and between the two teams. A meeting table was located centrally in the office, which allowed discussions to be overheard, and enabled team members to join the meeting or to shout comments across the room.

Two main forms of communication were observed. Brief communication sequences typically involved queries, where an answer was needed to a problem (i.e. a well-structured problem) that was understood, but for which the answer was not known. These might last as little as a few seconds, usually took place at a desk or in a corridor, had a high degree of closure, and were frequent. Longer communication sequences typically involved the discussion of a less well understood problem (ill-structured problems[25]). In these wide ranging discussions, the engineers discussed what they knew about the problem, ways to solve it, and how changes might affect the rest of the design. Often, these discussions would conclude without a solution, and were followed up with further discussions, or the exchange of a document. They often took place away from the engineers' desks, and involved the use of artefacts, such as drawings or sketches.

Communication was also influenced by the other organisations collaborating on the design project. The location of these organisations, half an hour away by taxi, was said to be a major determinant of the form and frequency of the communications. Again, several forms of communication were observed.

Informal communication between people in different organisations usually took place through telephone conversations; these could be combined with a fax, which would then be discussed verbally. Faxes were used to transmit spatial information, or tables of written information too complex to be read out aloud. Telephone calls were generally brief, except when the participants were unable to meet (conference calls were never used). These calls were used to discover information, or to update people on minor changes; they were also used to arrange meetings so that more people could participate in the discussion of complex problems.

A third form of communication between individuals and organisations involved the transfer of design representations, in the form of artefacts. These generally involved paper documents (text or drawings), but occasionally, CAD models on floppy disk were exchanged. These were an important, but separate component to the interactions noted above.

4.2. The range and role of artefacts

A range of design artefacts were used in the design process, both within and between teams in the BEG, and between different organisations. Design documents were passed between the engineering designers, and then on to the architects, contractors, and other organisations. A large amount of incoming documents also had to be channelled to the appropriate people in the BEG. Who received what was determined by each person's responsibilities, set out in a quality assurance system (QA). Document control was central to the QA process, ensuring that only current documents and designs were in circulation. There was less control of the use of artefacts between organisations, leaving scope for misunderstanding and confusion. In particular, out of date drawings were regularly used in error.

Paperwork for the project was maintained in the "dayfile". This contained all of the letters and paperwork relating to the project. It was required reading for the teams, who had to read and initial each day’s contents. This was intended to increase information related project awareness, although in reality, it created a problem of information overloading.

The most visible part of design in the project involved the construction and use of several hundred drawings, and these were frequently updated. Drawings littered the workplace, often several layers deep on desks. In conversation, the words "design" and "drawing" were often used interchangeably, denoting the importance of the drawings to the designers.

Throughout the BEG and the other organisations, various types of drawings existed, which represented various stages of the design, and different kinds of problem ownership. For example, architectural drawings were the property of the architect and were used to communicate the aesthetic design. Signatures and stamps (e.g. "for comment", "for construction") on the drawings denoted who to query if problems arose. Drawings were occasionally annotated with comments about the underlying calculations, or with file references to further information.

The drawings were frequently annotated. Indeed, drawings on the desks were often covered in highlighter ink, identifying checks and changes that had to be made. Comments at meetings were occasionally written directly onto the drawings. When it was not possible to have face to face meetings, the drawings could be faxed to recipients (after being photocopied and reduced). These drawings were occasionally annotated and faxed back (with a resultant loss of legibility). However, drawings were difficult to produce during meetings: they had to be prepared in advance and any updates distributed afterwards.

The walls of the BEG were covered in pinned up drawings and printouts of computer generated images. In meetings, these would be constantly referred to, pointed at, and compared. They appeared to provide a common basis through which people with different skills and perspectives could gain a common understanding of the problems discussed.

In the office of the client, a cardboard model of the completed building had been created, and in meetings, speakers would occasionally point to locations that they were talking about, moving their hands as if they were twisting parts of the structure to different angles, or dragging part of the structure to another location.

Many forms of artefacts were used in the design process, as aids for communication, and as a means of organising the design. They included drawings (of various kinds), a CAD system, a physical scale model, a dayfile, a mailing system, a filing system, annotation and marking tools, desks and walls to pin drawings on, duplication and shrinking technology (photocopier), and communication technologies (telephone and fax). Effort was made to control these artefacts, to try to insure that only the appropriate documentation and design artefacts were in current circulation. This was a major problem in the project, as much time was spent reviewing the circulating material.

5. *Discussion*

This study directly compares two independent workplace studies of different design situations. It provides observations of day-to-day engineering design practices, some of which were specific, whilst others were common to both situations. The pump design work primarily involved a small group of engineers working on the design of around 30 component parts, whereas the building engineering study involved a larger group, working on a range of problems in a complex system of interrelated sub-components. In both cases, the core design groups were co-located, within speaking and hearing distance of each other.

Designers in both projects maintained extensive contacts with people outside of their immediate group. In the case of the pump design, links were established and maintained with external groups, and for the building designers, this occurred with the architects and construction company. Communication with external groups was less frequent than with internal personnel, but when it took place, it was considered to be highly significant.

A range of informal communication was observed in both projects. Chats about the developing design, and the creation of sketches "on the fly," were observed. The telephone was also used frequently. Indeed, the amount of communication taking place through the telephone and in unscheduled chats suggests that, in both projects, there was a great deal of informal verbal interaction taking place in parallel with the relatively formal drafting work.

Periodic formal meetings with planned agendas were observed in both projects. Although these did not necessarily solve a particular design problem, they reminded the designers of major issues, brought those present up to date with current issues, and created an opportunity for discussing co-ordinated approaches to problems. In the building design situation, meetings helped to insure that actions taken by one group would not interfere with those of another. However, sketches and proposals of new design ideas were also suggested at these meetings, suggesting that these meetings were as much an opportunity for trying out new ideas on others, as a moment for decision-taking.

In both studies, it was apparent that a common practice was to discuss paper drawings in a group. Discussion would be accompanied by annotations with coloured pens, with highlights of features that need to be attended to. When sending drawings, it was usual to first shrink them on a photocopier, then to send them by fax, although detail (colour or legibility) was occasionally lost. In both cases, it was apparent that discussions around the drawings contributed to the evolution of the design. In the case of the pump design, other design artefacts (videos of stroboscoped movement, tables of comparative results, etc.) were also discussed. Advancement of the design work depended on the circulation and scrutiny of these artefacts, and on subsequent discussion or written annotations.

The design process was tightly bound up with the creation and modification of a variety of design artefacts (drawings, sketches, prototypes). These were the public representations of the state of the design at a given moment in time. Design changes were publicly signalled to others through the modification or generation of a new artefact. In turn, the production and modification of the artefacts were determined through communicative activity. This was most noticeable in meetings, where the drawings would be taken out and discussed. Modifications to the design were not made directly on the artefact, but first took place in verbal descriptions. Discussions about the artefacts allowed information represented in them to be highlighted, problematised, changed provisionally, and confirmed, at which point the artefact (drawing) could be modified. Artefacts were therefore a resource for discussion, although they were also generated and modified through these discussions.

In both organisations, the drawings did not encapsulate the totality of "design knowledge." In the pump company, knowledge about the trade-offs between part configuration and cost was represented in tables of options and costs. In both organisations, "design knowledge" also existed in the documentation that accompanied the drawings, such as the specifications of the construction techniques to be used, or the expected costs of manufacture and maintenance.

Other design process artefacts carried information about planned activities and played a key role in the co-ordination of the design work. For example, initial project documents outlined the roles and responsibilities of the core design team, external suppliers and consultants. Minutes of meetings captured management decisions concerning task allocation and projected work. In the pump design project, Gantt charts were used to project the activities of the designers on a weekly basis. These provided a visual representation of how the work would (in theory) mesh together at critical points, such as during the production and testing of prototypes.

In both settings, the design artefacts themselves carried information about their creators, and their location within the design process. For example, drawings were first initialed by the draughtsman, and continued to be initialed by other stakeholders. In the BEG, approval would literally be stamped onto a drawing, and in the pump company, drawings had to be initialed by the technical director before prototype parts could be made. In effect, the production process and the design management (the division of labour and document control) were intertwined with the drawings themselves.

The design process artefacts helped to co-ordinate design activities (e.g. task lists, faxed notes of work to be done, letters of intent). In this regard, the building design project had a more extensive correspondence filing system than the pump company. This would suggest that the variety and number of design process artefacts could be an indicator for both inter-organisational complexity, and of a strategy of formalising the distribution of information.

Finally, meetings were a central feature of the design work in both studies. The main function of the meetings was to help with co-ordination, rather than to directly design components. They were also a means of conveying information about current state of progress and recent design changes.

To summarise, the two studies suggest that although there were notable differences between the organisations studied (i.e. authorisation and control structures, and the range of design organisations involved), there was also significant overlap, particularly in terms of the critical role of inter-group and extra-organisational communication, and the important role of design and design process artefacts.

6. *Conclusion*

Early authors who wrote about design viewed it primarily as an individual activity, conducted alone and with a small number of simple tools. This is being challenged as an increasing number of researchers in the area of computer supported co-operative work (CSCW) investigate design[4,11,15,24]. This study provides empirical observations which tend to reinforce general conclusions about the design process proposed by social scientists working in this field. Design work can no longer be adequately conceptualised in terms of individual "intelligence," nor as a linear process with a set of design stages, but rather as a situation in which joint, co-ordinated learning and work practices evolve, and in which artefacts help to mediate and organise communication.

The observations reported here have implications for the development of tools to support design work. Many technology developers believe that design and engineering work will be facilitated through the development and introduction of group oriented computer tools. The case studies and discussion have highlighted three main insights which indicate that this will not necessarily be the case for all (or even many) design settings:

1. Key dimensions of the design process are the interactions between designers and other resource holders, and the way in which a variety of artefacts and design tools are used and created. This observation extends the findings of design theorists such as Bucciarelli[10,13], who has concentrated on the role of artefacts (the object world), but under-emphasised that of social interaction. It reinforces the discussion by Henderson[16], who underlined the pivotal role that social negotiations can play. Much of this negotiation takes place in face to face settings, and it is not obvious how this will be easier or more effective when technologically mediated.

2. In our case studies, several of the people who contributed to the design effort were located at a principal site, whilst others were not. Even "ordinary" design and engineering projects are likely to include off-site participants. Technologies to support the design process must therefore allow different organisations (with their different technical and organisational systems) to pass information back and forth

between themselves. This will be a major difficulty. As well, many design groups are likely to be located in small organisations, and the uptake of computer and network technology among these organisations is likely to be slower than many technology developers appear to anticipate.

3. Artefacts form a part of the process of product design whilst at the same time orienting the participants to the co-operative aspect of their work. Artefacts often reveal information about their "location" within the process, and who has acted on them. Computer technologies designed to facilitate the design process have so far not attempted to link design artefacts to their role in communication and co-ordination. Thus we have cad systems and e-mail systems, simulation and document management tools, rather than integrated suites of tools[26]. We suggest that computer-based design tools need to go beyond the categories of design or communication technologies, and be designed as technologies flexible enough to support both these dimensions of design work.

Finally, in the introduction, we suggested that technological "solutions" are unlikely to be a simple remedy which improves design efficiency. The organisations observed had numerous informal means for rich and varied communication, and technology is unlikely to improve this directly. The organisations did have frequent communication between on and off-site participants, and appeared satisfied with the communication means already at their disposal (meetings, fax, telephone, and letters). Several parallel communication channels (gesture, voice, gaze awareness, paper or whiteboard) were used when artefacts were discussed face to face, and extremely sophisticated technology would be needed before spatially distributed discussions could be held as easily (e.g.. Large displays, high quality audio, high bandwidth network connections). Perhaps a more fruitful developmental approach will be to augment the facilities already available, by adding "simple" technologies that can be adapted, as the fax and telephone have proven to be.

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