Information Technology and the Construction Industry: Another Tower of Babel ?

J.L. ALTY*

ABSTRACT

The application of information technology (IT) to the construction industry has not been outstandingly successful and does not seem to have produced the benefits which other industries have achieved. A number of reasons for this are highlighted, some already well-known. However some serious mismatches between the technologies and the requirements of the industry are also identified. It is suggested that new developments in multimedia interfaces and computer supported co-operative working may reduce this mismatch and result in a higher level of take-up of the technology.

Key Words

human interface; group working; multimedia; construction industry; groupware

Why has IT not solved the Communication Problems of the Construction Industry ?

The construction industry has a very heterogeneous nature. The planning, designing and execution of a major construction project requires a large number of different companies, consultants and individuals to combine, discuss and exchange information at many levels. Although some of these participants are large, many others are small to medium enterprises (SMEs) or professional groups. Clearly, to be successful, such groupings must exchange information rapidly and effectively and avoid duplicating common and essential data. However, the industry does seem to have experienced difficulties in achieving this objective. For example, at a meeting of important construction experts in 1985 it was concluded that the underlying issues of the information flow process in the construction industry were not properly understood and therefore needed urgent research (Ibbs, 1986). Two years later, another study concluded that "in spite of this amply demonstrated awareness of the communication problems, the solution has, by and large, continued to elude the industry" (Ndekugri and McCaffer, 1988).

Most people in the industry would probably agree that effective use of IT would contribute significantly to a reduction in these communication problems through the provision of common or shared databases, networks, and

* *Professor of Computer Science, Loughborough University of Technology, Loughborough, Leicestershire, LE11 3TU, UK.*

electronic data interchange; so why has progress been so slow ? One might think that cost considerations and unfamiliarity with new technology would be major reasons for the lack of take-up of technological solutions. However, Lockett (1990), in an analysis of a number of successful and unsuccessful new projects in the manufacturing industry, found that cost was not a significant factor in 70% of the projects analysed, and that whilst the newness of the technology contributed to technical problems and over-running, of itself, it actually contributed a small positive factor towards success.

There are a number of reasons why IT has not been taken up so readily by the construction industry. Firstly, there are the obvious, often-stated, reasons:

- because of the interaction between a large number of bodies, the introduction of standards is difficult, and standards are often an essential precursor of successful communication between dissimilar entities.
- unless every participant in the grouping has, and uses, the technology, the benefit of installing it can be relatively low.
- probably the most important reason is the degree of support (and IT awareness) exhibited by top management. For example, a study by Kearney (1984) identified this latter reason as the one that distinguished leaders in successful exploitation from the rest.

However, such reasons alone are not necessarily enough to explain the difference between the construction industry and others who exploit IT more effectively (such as banks). There are other reasons, which are more closely associated with the way in which construction work is carried out:

- there is a lack of supporting technology for really close cooperative working between different people in the groups mentioned earlier. Architects, Designers, Quantity Surveyors, etc need to co-operate remotely, not just send data to each other.
- installing the technology on-site (an essential part of the construction process) can be problematic. How can one communicate effectively with an on-site worker who is actually walking round the site ?
- the different educational and cultural backgrounds of the people involved in construction will result in severe interface problems - with different traditions and expertise in different sections.

Since the earlier reasons have been dealt with at some length in the literature, this paper will concentrate upon this second set of reasons, which, if not dealt with, could still result in failure even if the first set were to be overcome. Fortunately, some recent developments, particularly those involving multimedia approaches and computer supported co-operative work, may assist in solving this second set of problems.

Multimedia Interfaces

Communication between a human being and a computer requires a medium of communication. In the case where two human beings are communicating via a computer, we can effectively regard this as two, linked, human-computer communication systems. But what is a medium of communication ? A medium involves a language of communication which encompasses an underlying syntax and semantics. Early systems, for example, used scrolled text as an output language, and a simple text commands as an input language. Although this appears to be the same medium as written text, it is not (for example, the one-way scrolling renders browsing virtually impossible). One must therefore be careful when describing the properties of input/output media since there are many variations from the media we use outside the computer world. In this real world we use a variety of media with which to communicate. Examples include pictures (both still and moving), gesture, text, diagrams, sound, speech, music, animation and 3-dimensional renderings (both video and audio). Many of these media can be used in parallel, hence the term multimedia. Recently, a large variety of media have become available on computer systems at an affordable price.

Such multimedia presentation systems are now becoming commonplace. They can be installed on personal computers such as the MacIntosh or IBM PC, and are also available on workstations such as the SUN. Although there are some technical problems associated with synchronization, with the handling of large moving pictures and with real time performance, most of these problems have been, or shortly will be overcome. Thus there are no technological reasons why we should delay in applying multimedia techniques.

Marmollin (1992) has argued that the multimedia option should be seen as a new approach to systems design rather than a new technology and that our definition of multimedia should not be based upon current technology. He also pointed out the very important observation that multiple media are not just built up out of simple parts which can be experimented with separately. Multimedia representations attempt to utilize the whole mind. Thus we cannot simply carry over results from single media studies when considering how the new multimedia presentations might affect users.

The point can be illustrated with reference to, say, the presentation of a game of Billiards, Pool or Snooker. A colour video camera placed vertically above the table would faithfully record the essential action, but the addition of sound is known to considerably aid understanding. This multimedia approach provides us with a "natural" interface, full of redundancy and complementary cues. The human brain is used to operating in multimedia mode, so that anything less is regarded as inferior.

Although in the past computers have provided us with a paucity of media with which to get our messages across, we now have a huge set of possible communication media available. The problem we now face is how do we do them effectively ? The technology is exciting and beguiling and it is easy to fall into the trap of thinking about the technology for its own sake.

The multimedia approach can be viewed either from a technological point of view or from a user-centred viewpoint. The technological point of view is a list of common technical characteristics of systems claiming to be multimedia systems such as multidimensional presentation techniques (integration of text, pictures, sound, video, etc), multimodal interaction (the use of different modalities such as voice, gesture, pointing, etc) or hypermedia techniques (non-linear data structures composed of nodes and links). The focus in this technology perspective is on the medium or on the technology. A user-centred perspective, on the other hand, focuses on the possibilities offered by the technology for improving the quality of the interaction between human being and computer.

"A user centred definition would characterise multimedia systems as systems enabling the usage of multiple sensory modalities and multiple channels of the same or different modality (for example both ears, both hands, etc) enabling the user to perform several tasks at the same time and several users to perform the same task at different times"

In searching for appropriate uses of multimedia technology we should avoid the technological approach. Instead of working outwards from the technology asking

"what might users *be able to do* with this new technology ?"

we should ask

"what might the users *want to do* with this new technology and will it allow them to do it more efficiently, with less errors, more enjoyably, etc?".

The literature is full of unproven assertions about the power of Multimedia approaches particularly from an educational standpoint:

"What is new and exciting is the innovation of mixing text, audio, and video with a computer. Computer-supported multimedia is a new technology based medium for thinking, learning, and communication. Users can browse, annotate, link, and elaborate on information in a rich, non-linear, multimedia database......will allow students and teachers to explore and integrate vast libraries of text, audio and video information".

Whether users actually want to do this is never questioned. What is needed is some real science which investigates why certain media are better than others in getting a particular point across.

Emphasis on the educational aspects of multimedia has obscured other, perhaps more important, applications. For example, it is well known that using both visual and audio channels simultaneously to explain a complex diagram is better than using only one channel. It is also true that human beings use the richness offered by multiple channels to improve their understanding of situations, an example being the use of gesture, audio and visual cues whilst taking part in a multi-user conversation. Anyone who has tape-recorded a meeting will appreciate this point. An apparently perfectly understandable group meeting turns out to be virtually unintelligible when confined to tape. In the meeting we are using gesture, stereo sound, the movement of lips, and the movement of heads to understand what is going on. The sound conversation is only a part of the communication process.

Multimedia interfaces therefore offer an interesting way forward for improving the human-computer communication process by providing a much more "rounded" interaction space, but we can only exploit them if we fully understand their power and limitations.

Computer Supported Co-operative Work (CSCW)

In most industries, and especially in the construction industry, people collaborate actively with their colleagues and associates, either formally or informally. Most human-computer activities supported to-date have either been of a solo nature, where a designer develops an approach in isolation, or, if collaborative, are of an off-line nature, where the designer carries out some work and then communicates the results to another person for comment or further processing.

Grudin (1991) has pointed out that computer systems were first designed to support organisations. This was because of the high cost of early computing applications and the centralised nature of the approach. The next step, in the 1970's, leap-frogged over the requirement for groups to communicate and instead provided individual or personal computing. Only in the mid-1980's was the idea of providing computer-based systems for supporting people engaged in common tasks in a shared environment seriously considered and attempted. The software to carry out and support such working is known as groupware (Johnson-Lentz and Johnson-Lentz, 1982). Groupware must be distinguished from multi-access time-sharing systems. In groupware there are the two above-mentioned essential characteristics - a shared environment and one or more shared tasks. In theory groupware can be in real-time or not in real-time. In practice it tends to refer to real-time working. Ellis, Gibbs and Rein (1991) suggest a simple matrix for categorizing groupware technologies:

	Same Time	Different Times
Same Place	face-to-face interaction	asynchronous interaction
Different Place	synchronous distributed interaction	asynchronous distributed interaction

Meeting Room technology would be placed in the upper left quadrant, a real-time document editor in the lower left, a physical bulletin board in the upper right, and electronic mail in the lower right quadrant.

There were many reasons for the lateness in considering groupware. Firstly, high-intensity group communication by computer is a very new field of endeavour and is not well understood. Secondly, successful approaches are very dependent upon telecommunications developments and these are usually under the control of the telecommunications companies. Thirdly, the benefit to those joining groupware activities is not uniform. Some who take part may have to take on additional work, which might be vital for the success of the application but which may not, to them, be worthwhile.

One example of non real-time groupware, electronic mail, has been a great success. The reason for this is that it provides equal benefits for both senders and receivers and the work is done by the person who needs to do it. For example, the person sending the message has to type it in, whilst the person reading it has a much simpler job of simply selecting and reading it. If the work had been distributed the other way round electronic mail would probably not have succeeded. Electronic mail, however is essentially an off-line activity and it is thought that the real benefits of groupware will come from on-line working.

When fully developed, groupware will allow geographically separate people to work together on a spreadsheet, to discuss and exercise a design, to meet "together" to discuss a contract and to allow managers at the construction company head office, the architects and local site managers, to have an on-site meeting without leaving their desks.

At present there are problems. Consider two designers working in a CAD environment. They wish to work at the same time on one object, modifying different parts and each being aware of the changes made by the other, whilst at the same time conversing, highlighting and arguing. Current database systems would have difficulty in supporting such activity.

The Power of a Combined Multimedia and CSCW Approach

Earlier three reasons were mentioned for the lack of the take-up of new technology in the construction industry:

- a lack of supporting technology for really close cooperative working between different groups.
- installing the technology on-site (an essential part for the construction process) can be problematic.
- The different educational and cultural backgrounds of the people involved in construction will result in severe interface problems.

All these problems can be overcome by a combined use of multimedia techniques and computer supported co-operative working.

Close Co-operative Working

A common shared environment is essential for successful co-operative working. There are a number of aspects to such an environment. Firstly there must be common working surfaces which contain material under investigation and manipulation. There are a number of systems which support this type of working; for example the GROVE group editor (Ellis et al, 1991). However there are many who would argue that this is not enough. For example, in face-to-face meetings participants observe each others' facial expressions, make eye-contact and respond and make gestures. Such contact is important in building trust. This is where multimedia technologies can be used in conjunction with shared work spaces to improve co-operation.

Alty and Bergan (1992), have enunciated a number of principles of multimedia design. One of these is the principle of Telepresence.

"The first, and perhaps obvious, observation is that multimedia approaches allow us to regain something which we have lost over the last twenty years of interface design - that is - connection with the real world. We have increasingly put our operators in closed rooms away from the plant they control. Gone are the days when the operators could FEEL the plant under their feet, HEAR it in operation, or SEE what was happening. ... One function of multimedia interfaces therefore is simply to transmit elements of "telepresence" to the operator"

Although the area of interest here was process control, the point is even more valid when applied to co-operative working. A combination of video and audio links enables interpersonal spaces to be created where gestures and eye-contact can be monitored and used.

The difficulties with using the current technologies arise from the creation of an arbitrary "seam" between the shared environment and the interpersonalised workspace (Ishii et al, 1992). The nature of this seam will depend upon different implementations of the environment and the workspace. Some examples include:

- a live video image alongside the shared workspace on a separate screen
- a live video image positioned opposite the user simulating face-to-face interaction across a table
- the video image and the workspace are shown in different windows on the same interaction screen.

This results in an awkward shift of focus between the two spaces which does not happen in real-life encounters. Ishii et al point out that we frequently shift this focus in face-to-face encounters.

"Even when drawing, we briefly glance at our partner's face to attract attention or to gauge comprehension. Similarly, our partner's head turning, eye movement and gestures also attract our attention and trigger our focus shift".

To solve this problem they designed a system based upon the idea of a "clearboard". This is a metaphor of looking through, and drawing on, a clear glass pane. The pane contains the workspace (written onto by felt pens) and, whilst this is taking place, the participants can see each other through the pane. Thus there is minimum movement involved in the shift of focus between workspace and shared environment . The computer implementation has the added bonus that the problem of inversion of the image through the glass can be overcome (which is not possible in the original source of the metaphor).

The approach has also been used in the Looking Glass system which employs the ROCOCO sketchpad (Clark and Scrivener, 1992). However Clearboard allows indirect drawing devices and hand movements to be observed as well. In the first version the users drew directly on the display screen and the video image of the user was taken through that screen using a half-silvered mirror. Images were reversed so that a common orientation is achieved. The second version used pen-based input technology and a drawing tablet.

The prototype system worked well. Users frequently glanced at each other's face and achieved eye-contact whilst drawing and conversing. Focus switching required almost no head movement. In contrast to earlier work, users did not hesitate in drawing on the image of their co-worker. They clearly saw the other participant as "behind" the screen not on it (Ishii and Arita, 1991). What seemed to be really important was what Ishii calls "gaze awareness", that is, the ability to monitor the direction of a partner's gaze and thus the focus of attention. Early experiments with the system did confirm that the frequency of eye-contacts increased as the gap between the interpersonal space and the shared working surface was decreased.

Other interesting results on co-operative working come from an examination of how using a group editor influences group activity (Olson et al, 1992). Thirty eight groups of three professionals each were studied. The shared editor had a profound effect on their mode of working and the outcome. Olson et al report that

"the designs they produced were of higher quality than those of the control groups who worked in a more traditional fashion.... They actually did a less extensive exploration of the design space than the traditional, unsupported groups contrary to our expectations. Instead of encouraging a more exhaustive look at design ideas, something about the technology led them to a more selective examination of what turned out to be better ideas. They seemed to focus more on the core ideas, and captured and examined by reading what they were thinking *while they worked*, rather than in two stages".

The CSCW technology is therefore now getting quite close to providing something which could solve the major problems of co-operative working in the construction industry. Designers and architects could collaborate remotely and discussions with the construction companies could take place remotely. No-one is, of course, suggesting that this technology will replace normal contact. However, it will allow more regular contact than is currently possible, and allow queries to be dealt with more effectively, and discrepancies ironed out via a simple technology hook-up.

Clearly, all the above developemts will require high quality broadband links for both video and audio. It is important to note that the simple video cameras shot (which will be fine for a Videophone application) will simply not be enough for full conferencing facilities. For such facilities to be successful there will need to be provision of "spatial video" - that is a video effect which gives a spatial dimension to the conversation, so that when one speaker interrupts, other participants will see all the others look in that speaker's direction. This is really difficult to achieve and will require more than one camera at each location. This could also be backed up with stereo sound.

Installing Technology On-site

There is often a need for discussions to take place between those off-site and those on-site. The situation is complicated by the fact that the site is not in a finished state (and when it is the job is done !). In the early days of construction there may be very limited technology on-site. Furthermore, a fixed terminal in a site office does not satisfy the requirement because there may need to be detailed inspections of aspects of the site requiring images to be sent down the line to those off-site.

Work is in progress in a European RACE project called BRICC (BRoadband Integrated Communications for Construction) which is investigating the coordination and interchanging of the computer based data required on many building sites. One novel feature of the project is the provision of the "multimedia hard-hat" for mobile on-site workers. This is a normal site hard-hat which contains a camera (providing a view of what is currently being looked at), a cellular telephone link and a 1 inch cube "private eye" display mounted below the peak of the hat which shows a full resolution PC screen floating at infinity in one eye (Leevers, 1993). At present the hat is under development and it is planned to have Sony optically stabilised Camcorder and private eye radio link installed in 1993. In 1994 the workstation will have a resolution of 1000x1000 pixels and might even be in colour. There are many problems to resolve still, but the BRICC approach shows that communication with on-site mobile workers may not be that far off.

BICC are also developing the concept of the Virtual Meeting Room. This uses the metaphor of the Meeting Room (like the now very common metaphor for the Desktop) to hide the details of the communications technology from the users. The room has a shared whiteboard, documents can be imported to the room, project documents are stored within the room, and each individual has a private briefcase which contains private documents and tools. Important moments of the discussion can be preserved on video if all agree. All participants need not have the full facilities of the room. Some for example might not have video links.

The video link can be of quite low quality. Leevers claims that the provision of high quality audio links is much more important than video links (which cost much more). He also claims it is not necessary to synchronize the movement of lips with audio speech. Video is mainly used for showing who is there but not speaking.

The metaphor is further enhanced by the concept of Video Open Plan. This provides understandable access and communication mechanisms for all participants.

Interfacing Problems

The acceptability of a computer application usually depends upon how usable the system is. In other words the design of the human-computer interface is absolutely crucial in determining the final acceptability of the application. The construction industry is mainly made up of people who are not computer specialists and who do not have any real interest in computing applications per se. The spectrum of possible participants is very wide - ranging from designers, who may have an in-depth experience of using CAD systems, to architects and quantity surveyors who are likely to have reasonable, but less deep practical experience of using computers, to managers and project leaders who are used to using computers for database or project information, to on-site workers who traditionally have not had to become involved with any computer aspects.

This wide spectrum of requirements on the design of the human computer interface for the construction industry poses serious problems which the provision of multimedia facilities might alleviate. Recent research (Alty and Bergan, 1993) has shown that in process control applications, the choice of output medium does indeed have an effect on the comprehension of the operator. Concepts which were straightforward could be communicated in almost any medium. Those concepts which are exceedingly difficult to comprehend (and for which the operator had no significant knowledge) could not be communicated whatever choice of medium was adopted. Finally, the middle area, involving those concepts which were reasonably understood by the operator under normal circumstances but which were presented as part of an extraordinary situation, appeared to benefit significantly from choice of appropriate media. This is an important result because this is the area where most misunderstandings on interfaces take place.

Two further principles from Alty and Bergan 1992, which, if applied, could assist in improving interfaces using multimedia techniques, are:

The Principle of Apparent Redundancy - more is better. Human beings prefer parallel sets of redundant information. For example, providing spoken text alongside written text can be very beneficial to comprehension. Placing numerical values on graphs also aids comprehension. The more we use redundant (but individually useful) information, the nearer we get to exploiting the "whole" mind.

The Principle of Secondary Cues - media (particularly video and audio) carry information which cannot be easily characterised as having a particular use. Good operators simply "know" that there is a problem from hearing sound from the plant, yet they may be unable to define what it is about the sound that alerts them. Designers tamper with such information at their peril.

The first principle stresses the importance of multiple media cues for users who have a low computer literacy. People who have never used computers are always disappointed with the paucity of standard computer interfaces. The real world is much richer and much more forgiving. It usually provides us with a number of parallel cues to assist us in disambiguating information. On building sites this redundancy might be vital especially where the site is noisy.

The second principle points out how human beings use all sorts of cues in real situations (often not explicitly knowing that they use them). It is always dangerous to cut down information flow because "it is not useful".

The multimedia approach therefore offers us a much wider set of options in interface design and should enable us to match interface designs with expectations and likely use. For example, an on-site worker is unlikely to accept a command driven interface which might be perfectly acceptable to a quantity surveyor. The more infrequent the user, the more a "rounded" approach is likely to succeed.

Telecommunications Requirements

We require high quality services in all of the nine Generic User Services defined in the RACE User Reference Model (deVictor and Melchior, 1991). We need Human Conversation (both Audio and Video synchronised) in parallel with Machine-Machine services to support the shared workspace. The Audio and Video requirement is, however much more than a Videophone link. Special terminals will be needed to provide the minimum shift of focus and, for group conferencing we will need to utilize stereo audio as well as "spatial video" as mentioned earlier. Such services are now under serious discussion within the International PTTs so the industry should begin to plan now.

CONCLUSIONS

A number of reasons have been put forward as to why the construction industry has not really been able to fully utilise IT to improve information flows. These reasons are in addition to the more conventional ones of top management awareness, the quest of standards and the problems of participation, and relate to limitations imposed by the technology on mechanisms for co-operative working.

New developments in multimedia interfaces technology and computer supported cooperative working should enable more effective and supportive environments to be developed and to widen the use of computer technology to on-site working and across a broader range of users.

It is important that the industry starts now with some experimentation in co-operative working using the new technologies.

References

Alty, J L and Bergan, M (1992), Guidelines For Multimedia Interface Design in Process Control Applications, *Proc of the 5th IFAC IFORS IFIP IEA Conf on Man Machine Systems, The Analysis, Design and Evaluation of Man-machine Systems* (Stassen, H, ed.), The Hague, June 1992, pp . 249 - 255

Alty, J L and Bergan, M (1993), Multimedia and Process Control: Some initial Experimental Results, to be published in *Computer Graphics*.

Clark, S and Scrivener, S, The ROCOCO Sketchpad distributed shared drawing surface, *LUTCHI Report No. 92/C/LUTCHI/0150.* LUTCHI Research Centre, Loughborough University of Technology, UK.

Ellis, C A, Gibbs, S J and Rein, G L (1991), Groupware: some issues and experiences, in *Communications of the ACM,* Vol 34, No. 1, pp 39 - 58.

Grudin, J (1991), Seven plus one challenges in understanding social dynamics for groupware developers, in *Computer Supported Cooperative Work and Groupware*, Tutorial Presented at CHI '91, available from the ACM.

Ibbs, C W (1986), Future directions for computerized construction research, in *J. of Construction Engineering and Management,* ASCE 112, September.

Ishii, H, Kobayashi, M and Grudin, J (1992), Integration of Interpersonal Space and Shared Workspace: Clearboard design and Experiments, in *Proc. CSCW 92: Sharing Perspectives*, Turner, J. and Kraut, R, (eds.), ACM Press, pp 33 - 42.

Ishii, H and Arita, K (1991), Translucent Multi-user interface for TeamWorkStation, *Proc. of ECSCW '91,* Kluwer Academic, DorDrecht, The Netherlands, pp 163 - 174.

Johnson-Lentz, P and Johnsen-Lentz, T (1982), Groupware: The process and impacts of design choices. In *Computer Mediated Communication Systems: Status and Evaluation* by Kerr, E B and Hiltz, S R, Academic Press, New

York.

Kearney, A T (1984), The barriers and opportunities of information technology: A Management Perspective. *Management consultative Report* prepared for the DTI, London.

Leevers, D (1993), Multimedia Communications, *National Computing Centre Annual Conference (1993)*, NCC, Manchester, UK.

Lockett, M (1990), Factors behind successful technology innovation, Chapter 16 in *New Technology and Manufacturing Management* (ed. Warner, M, Wobbe, W and Brodner P), John Wiley and sons, Chichester, UK, pp 239 - 252.

Marmollin, H (1992), "Multimedia from the perspectives of psychology", in *Multimedia: Systems, Interactions and Applications,* (L. Kjelldahl, ed.), pp 39 - 52, Springer-Verlag, Berlin.

Ndekugri, I E and McCaffer, R (1988), Management information flow in construction companies, in *Construction Management and Economics*, Vol 6, pp 273 - 294.

Olson, J S, Olson, G, Storrosten, M and Carter, M (1992), How a group editor changes the character of a design meeting as well as its outcome. in *Proc. CSCW 92: Sharing Perspectives*, Turner, J and Kraut, R (eds.), ACM Press, pp 91 - 98.

deVictor, B and Melchior, E (1991), *User Reference Model*, Service Definitions, available from British Telecom Research Laboratories, Martlesham Heath, Ipswitch. UK.

c. 1993, Management of Information Technology for Construction, K. Mathur et al (Eds), World Scientific Publishing Co., Singapore.