Networking Construction: Electronic Integration of Distributed Information

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ABSTRACT

Construction in all advanced industrial societies is fragmented. On a single project, a variety of design technologies reside within different AEC firms which are frequently dispersed geographically (increasingly international). Coordination during design and construction can be enhanced via electronic networking among the various AEC firms and the Project Manager. This paper describes a prototype CAD Conferencing system jointly developed by CSIRO and Telecom Research Laboratories capable of operating on high speed wide area networks linking heterogeneous CAD platforms (hardware, software, networks). The paper highlights the technical as well as management issues to be resolved and the costs and benefits of CAD conferencing versus traditional methods of operation.

Key Words

communication networks; CAD; construction; information technology (IT)

A Revolution in Telecommunications

The ability to network graphical and spatial information — such as that generated by CAD operations — will have moved from the status of field trial to that of established practice by the end of the 1990s. Multi-user, multi-media databases will be interactively accessed via regional, national and global broadband networks. Large textual and graphics files will be electronically couriered as routine practice. Videotelephony and videoconferencing will be enhancing the wide area networking of spatial information systems. In short, organisations will have the technological freedom, as never before, to re-shape the geography of their operations as to which activities are undertaken where.

Recent developments in communication and information technologies (CIT) will make possible the real time transfer of high resolution images between remotely located sites (Newton *et al*, 1992). The dramatic growth in local area networks (LANs) has stimulated the need for such interconnection. LANs are typically established within a building or campus-type environment and represent local sources of information. High speed telecommunications, such as fast packet switching and broadband ISDN (B-ISDN), will provide interconnection of LANs at speeds of 10 Mbps and beyond. From an

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organisational perspective this creates a single 'enterprise-wide' LAN allowing the flexible connection of workstations to servers, facilitating distributed applications (Figure 1).

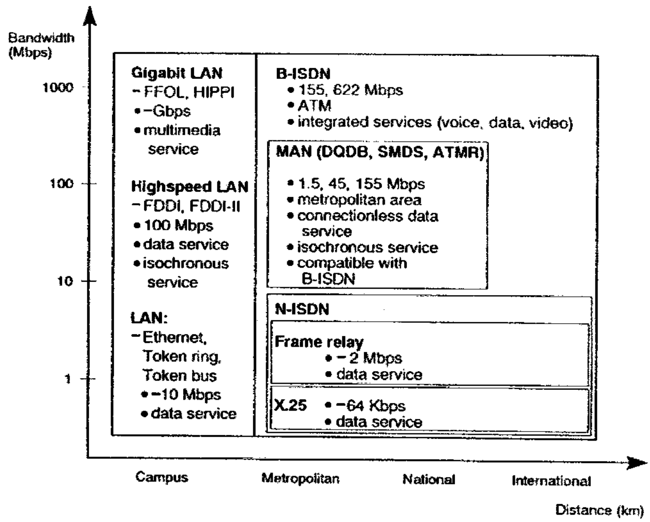

Figure 1. High Speed Communications Networks

Networking in the 1990s will see more applications such as distributed computing, office automation, image transfer and videoconferencing within organisations as well as between organisations. Networks at local area, metropolitan and wide area levels are the necessary infrastructures which enable the exchange of information via computer-to-computer communication (typically a MAN covers a city while a WAN can extend over a country or the world). The effectiveness of networking in enabling distributed processing is closely linked with interface standards, data exchange standards, advances in database technology, LAN-MAN bridges, routers and transmission speeds of LANs versus MANs (for example, most current wide area networking is built upon the public network infrastructure with the consequence that performance levels are lower than those achieved on LANs). However, new classes of MAN based on IEEE 802.6 on fibre optic networks will enable LAN-like performance over a wide area (Zwart and Newton, 1991).

This is illustrated in Table 1 which indicates the radical improvement in data transfer performance as one moves from the public switched telephone network (with modem) to ISDN to broadband ISDN-type networks.

Table 1. File Transfer Rates for 1 MByte (8Mbits) of Information

Line Speed	Transfer Time
9600 bps (PSTN + modem)	14 minutes
64 Kbps (ISDN)	2 minutes
10 Mbps (LAN/MAN)	0.8 seconds

With a basic rate of 155 Mbps, future broadband ISDN represents in excess of a thousand-fold increase in information-carrying capacity compared to the current basic ISDN user rate of 144 Kbps. Other key features of B-ISDN networks include:

- their ability to take advantage of the high capacity fibre optic transmission networks that are becoming well established at metropolitan and inter-metropolitan levels;
- their ability to support a mixture of services such as video, voice and bursty data. The latter is especially relevant to the CAD, multi-media and spatial information systems community where bit rates may vary considerably during transmission; for example: image retrieval requires high peak bit rates in order to provide screen retrieval delays of less than one second, but average rates will be well below that peak as users engage in more passive (from a telecommunications perspective) activities such as thinking, reading manuals to check procedures, keyboarding, *etc*; and
- their connectivity. As a public switched network, B-ISDN will be capable of servicing the requirements of a geographically dispersed organisation or user community with greater reliability and reduced cost — since redundant capacity is shared among many users.

Networking Construction

The building and construction sector is highly fragmented and geographically dispersed. In Australia, for example, the number of private sector construction establishments is close to 100,000. Furthermore, these establishments are required to interact in a diverse arena which embraces financial and investment services, property services, engineering and technical services, government services, education and training services, building products manufacturing, wholesaling and retailing, and building operation and maintenance.

In this environment enhanced performance can result from the electronic integration of distributed information. Figure 2 identifies a wide range of telecommunications services which can be (and in leading edge organisations are being) incorporated into their mode of business operation. One area in particular is identified for examination in this paper: networking CAD in design and construction.

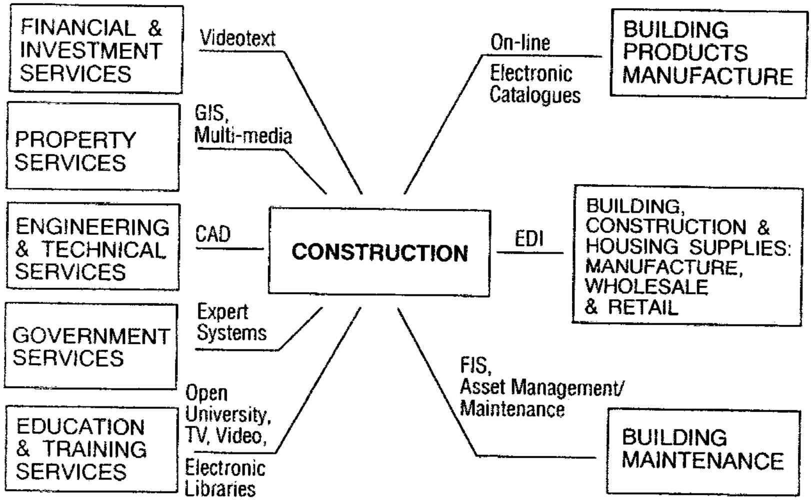

Figure 2. Construction and Telematics

ELECTRONIC CAD INTERWORKING

Major construction projects are highly information intensive. A typical file representing a single 'document' such as one floor of a building contains a minimum of approximately 600 KB of data and may range up to 2.5 MB for a full design description of one floor (see Table 2).

Table 2. Information Volume (Number of 'Documents') by Project Value (Indicative Figures)

	Project Value				
	$700M	$80M	$50M	$15M	$10M
Contracts	300	170	100	80	50
Tenders	1,200	700	400	300	200
Drawings	30,000	5,000	4,000	1,000	200
Drawings issued	400,000	150,000	100,000	48,000	30,000
Variations	10,000	5,000	1,000	300	150
Site instructions	30,000	6.000	3,000	1,000	600
Rooms/areas	3,000	100	50	11	7
Consultants	15	12	11	8	5
Cash flow/month	$14M	$2M	$1.5M	$0.6M	$0.5M
Approvals/week	70	26	20	18	13
Meetings/week	30	20	11	10	6

Source: MB-CHAA et al (circa 1991)

Notwithstanding, recent Australian studies (Atkin, 1990) have found that only 10 per cent of construction industry work employed any sort of IT, compared to 60 per cent penetration in the manufacturing sector and 76 per cent in finance and banking. Clearly, the *potential* for the application of IT in this sector is very large, especially given the enormous volume of information generated by a single large project.

On a single project, a variety of design and engineering technologies come from separate AEC firms. Because designers (architects, engineers, *etc*) find coordination among themselves difficult, they leave this task to project managers or construction contractor(s). CAD drawings are required to document details, but potential conflicts among contractors are often unrecognised until construction begins. Several undesirable effects are caused by this lack of coordination (*eg*, delays, litigation, *etc*). Hence there is a marked decrease in productivity. Overcoming current problems requires significant changes to the design process together with the technology base capable of supporting computer integrated construction.

The benefits of sharing *CAD and related data* between all members of the design team are that everyone is working on the same information; coordination is easier and more accurate; and there is a reduction in the amount of repetition, as the need to redraw information is eliminated. The result is an increase in the accuracy and speed of production of drawings. The utilisation of CAD (with agreed standard conventions for data exchange — see later) and high speed networks means that the AEC team for a particular project can be dispersed nationally and even globally. The advantage is clear — ability to assemble the best possible team, irrespective of where each 'player' is based. This confers significant quality benefits to a project.

Electronic CAD interworking (ECI) is about time-based competition as much as it is about total quality management. As conceived here, ECI embraces at least three levels of CAD operation: file transfer, networking CAD and CAD conferencing (see Table 3).

For some construction projects (particularly those of smaller scale) electronic file transfer between the project manager and AEC consultants will suffice, providing a substitute for courier or postal services. With the latter form of service, by the time the 'latest' disk of CAD drawings is received via courier, they are often out-of-date — superseded by drawings which have been subject to on-going work by the consultants.

Networking CAD and CAD Conferencing provide higher-order levels of integration in the design and construction phases of infrastructure projects than is possible with file transfer. A greater investment in hardware and software is also required (see the notes associated with Table 3). Networking CAD is seen to involve *file sharing*, allowing practitioners on a construction project to read files remotely without the need to retain a local copy. The key benefit is that the accessed file is always the most up-to-date.

Table 3. Key Operations in Electronic CAD Interworking

	HARDWARE SYSTEM	
CAD operations	PC 386/486	Workstation
File transfer	a → e	A → E
Networking CAD		
— file sharing (optional)	a → f	A → F
— window sharing (whiteboard, *etc*)	a → e plus f (optional) plus g & /or h (1)	A → E plus F (optional) plus G &/or H
CAD conferencing		
— (all of above plus videoconferencing)	a → i(2)	A → I

KEY: PC 386/486

a — Network connection (modem, Ethernet, ISDN, card, *etc*)
b — at least 8-16 MB of RAM
c — high-resolution colour screen
d — large capacity hard disk (>200 MB)
e — SuperVGA (or better) graphics card (*ie*, 800x600+ resolution)
f — LAN/operating system (Novell; NFS, *etc*)
g — electronic whiteboard facility (screen-capture and mark-up software)
h — software to make PC act as X-terminal
i — live video capture, compression and transmission hardware and software

KEY: Workstation

A — Network connection (modem, Ethernet, ISDN card)
B — at least 16-64+ MB of RAM
C — high-resolution colour screen
D — very large capacity hard disk (>800 MB)
E — 8-bit colour graphics card
F — distributed file system (usually provided with operating system)
G — electronic whiteboard facility
H — X-windowing software
I — live video capture, compression and transmission hardware and software

Notes: (1) CAD running remotely on workstation; display only on PC: CAD & whiteboarding currently mutually exclusive on PC
(2) Cannot currently be supported

Window sharing also permits CAD drawings to be viewed simultaneously by 'local' and 'remote' AEC practitioners (see Figure 3). The 'local' practitioner is considered to be the initiator of the interactive CAD session. This may be the Project Manager or the architect or mechanical engineer, *etc*. There are many possible images which can be assembled on the screen of a particular workstation. For example, a Project Manager may be simultaneously comparing his latest version of a particular CAD layer with a revision provided by the architect. Elements under deliberation can be 'marked up' or highlighted in a number of ways, including 'whiteboarding' and be seen by both local and remote parties.

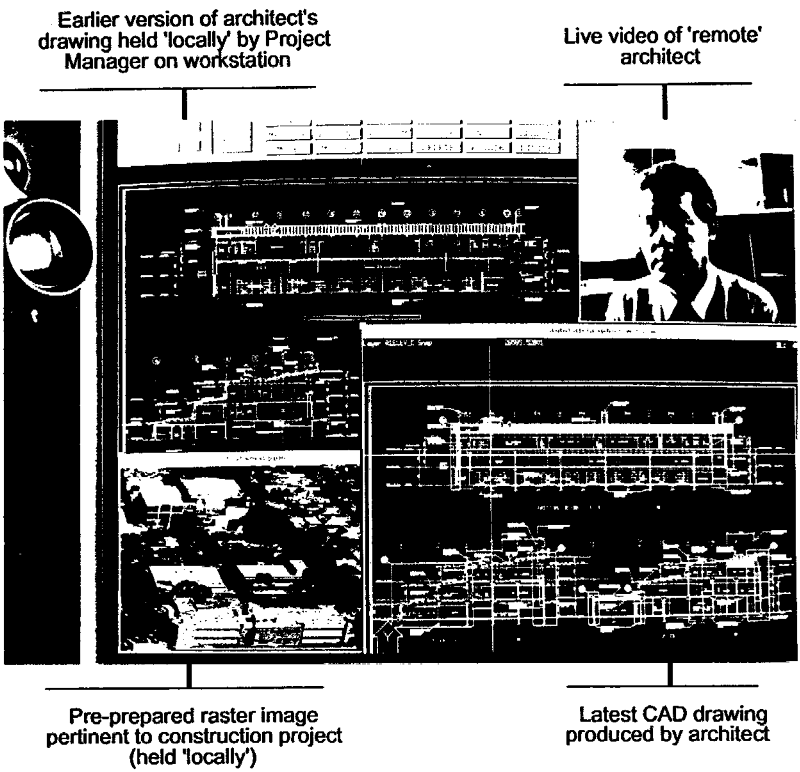

Figure 3. Workstation Screen as Seen by 'Local' Project Manager (initiator of CAD Conference)

The advantages that such a system confers include:

- *efficiency* — significant reduction can be effected in turnaround times;

- *quality management* — fewer omissions or mistakes;
- *integration* — outputs from heterogeneous CAD platforms and hardware systems, which are likely to be common among an AEC consortia, can be accommodated in networked systems such as these; and
- *integrity* — it is important for individual practitioners within a project consortia to maintain appropriate levels of control over the drawings for which they have responsibility both for reasons of copyright and legal liability.

Hardware Issues

This paper is not the appropriate venue to discuss hardware issues in detail; readers can draw inferences from the information presented in Table 3. CAD Conferencing applications are, however, memory-intensive, so potential users of such systems need to be aware of requirements at the outset.

The Influence of Organisational Strategies on Potential Network Usage: File Access Options and Implications

In relation to most major building and construction projects there are likely to be multiple players who are dispersed geographically — suggesting a decentralised CAD operation with varying levels of centralisation concentrated around the Project Manager for purposes of control. In some cases, however, a single construction company may embrace all design-construct operations. Yet even here, the corporation is likely to have its centres of expertise geographically dispersed, requiring a measure of inter-organisational interchange within some framework of control or centralisation.

The range of network interactions which can be expected to occur in relation to CAD interchange on a construction project will be predicated, in large part, by organisational attitudes towards two important criteria:

- centralisation vs decentralisation of processors and applications
- centralisation vs decentralisation of data storage.

Various data communications opportunities may be pursued under different organisational approaches to CAD networking (see Table 4).

Clearly there are a host of organisational issues to be resolved with the entry of real-time wide-area networking into project management. Preliminary reaction by construction companies to the demonstration of the CSIRO/Telecom CAD Conferencing prototype suggests that a 'star' approach is likely to be the dominant organisational structure employed, especially in the design and documentation phase where systems for checking and control are so important (Figure 4). A more open 'mesh' approach may well be a possibility for the concept phase, although face-to-face meetings may well supplant them, unless key consultants were located at some distance from client and Project Manager — say overseas.

Table 4. Potential CAD-Related Usage of Broadband Communications Under Different Information Management Approaches

Approach	Degree of Centralisation in ...		Possible CAD-Related Usage of High Speed Communications Networks
	Processing	Storage	
1	Decentralised	Decentralised	• 'Browsing' of remote files prior to retrieval • High speed file transfer between sites
2	Decentralised	Centralised (All CAD layers stored on Project Manager's central file server)	Any activities possible through network file sharing, including ... • Copying of selected files to local workspace • processing, modifying, displaying centrally stored files
3	Centralised	Decentralised (Local storage of CAD layers with individual AEC consultants possible: CAD 'master' layers held by Project Manager)	• Unlikely scenario as it implies consultant has own machine with local disk but using PM's CAD software running on PM's machine, *ie*, operating as terminal to PM's machine, but storing CAD drawings on local machine.
4	Centralised	Centralised	• Display and redrawing processes would comprise the major CAD-related traffic load on the communications network

A Preliminary Modelling of the Economic Effects of Networking Construction

Potential for Time Saving

CAD Conferencing has the potential for saving considerable time during the design stage of projects because there is likely to be less re-entering of data amongst the design team, less correcting of drawings because of mis-understanding or mis-timing of changes, less checking because of the common database and less seeking of irrelevant details. The impact of time saving to the building client should not be underestimated even when the professional fees are not reduced.

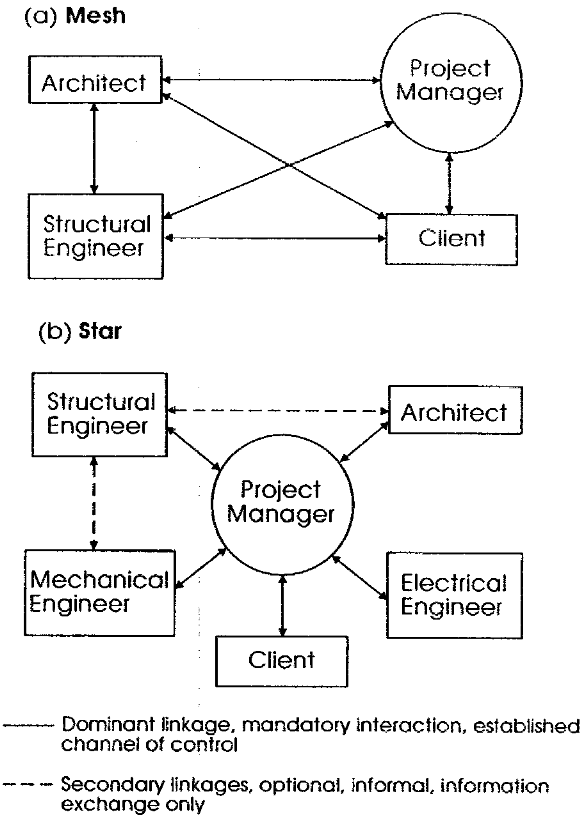

Figure 4. Alternative Configurations for CAD Conferencing

Saving of time will be minimal when there is only one professional team involved such as during the preliminary discussions or concept development by the architect. The advantages of CAD Conferencing are most likely to be utilised during the design and documentation stage where exact detail is important in decision making and creating accurate drawings and specifications. Reduction in time during the construction stage due to CAD Conferencing is likely to be less, as delays are caused by a myriad of problems, many of which could not be assisted by CAD Conferencing.

To illustrate the scale of the potential cost savings to the client due solely to shorter design and documentation stage of a building, the reduction in rise-and-fall and holding charges were estimated for a simple example of a large office building.

Office Building Example

The example chosen was a typical large office building in Melbourne where the construction price was set at \$100M based on the approximately 2000 $\$/m^2$ price for a 50000 m^2 building. The time for preliminary design development was set as 6 months, the documentation time at 12 months and the construction time at 24 months. All times are for a project completed in the best quarter of times achieved for such a building in the past.

The professional fees associated with such a project were based on advice on typical buildings and are as shown in Table 5.

Table 5. Fee Structures for AEC Consultants on Example Project

Consultant	Fee \$	Fee (%)
Architect - preliminary design	1,250,000	1.25
Architect - documentation	2,000,000	2.00
Architect - administration	1,750,000	1.75
Engineering - structural	1,850,000	1.85
Engineering - electrical and lift	1,650,000	1.65
Engineering - mechanical	1,500,000	1.50
Engineering - other	1,000,000	1.00

The composition and timing of fees followed common practice for large buildings in that the fees were paid monthly during the period that the consultant was engaged. Thus the architect (documentation) fee was only during the documentation stage and the architect (administration) fee was only during the construction stage while the engineering fees were spread over both stages each one starting and finishing at times appropriate to the activity required (*eg*, the engineering (structural) fee began before the engineering (mechanical) fee; see Figure 5).

Only the architect (administration) and engineering (electrical and lift) fees had cash flow profiles which were not constant values per month. These two fees followed the construction cash flow profile commonly known as an S-curve when presented cumulatively. That is, the monthly payments begin slowly, rise to a peak during the project and decline towards the end.

Methodology

Major projects are generally costed at a price which is adjusted for inflation (rise-and-fall) using a standard procedure and an interest charge based on cash invested or borrowed to construct the building. These overheads of rise-and-fall were included at 0.3% per month (approximately 3.6% per annum) and holding (interest) charges were at 1% per month.

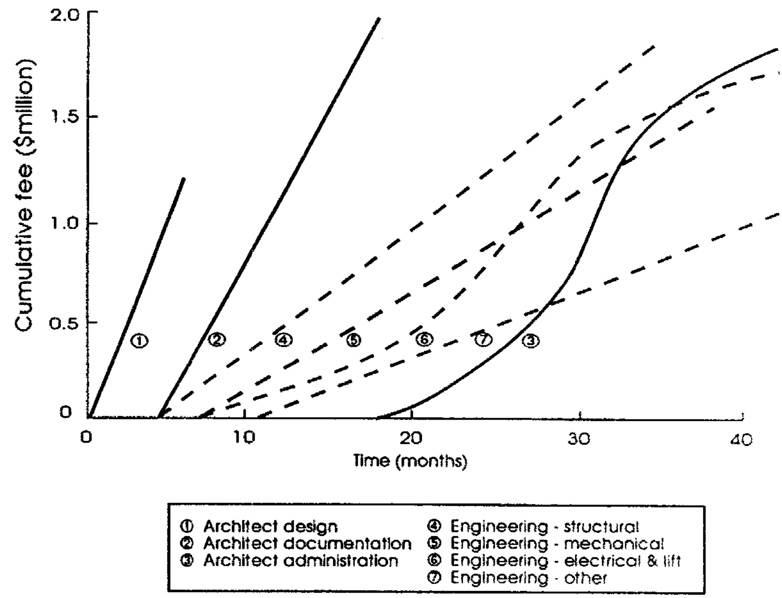

Figure 5. Fee Profiles for Consultants

The calculations were performed on the individual cash flow streams of each fee and construction price using FINCASH, a computer model developed for, and used by, industry for estimating and monitoring the total cost of a construction project (Tucker and Rahilly, 1989). Rise-and-fall was calculated from the beginning of the design phase. The consultants' fees are assumed to be expressed as a percentage of the contract price including rise-and-fall. This practice may decline as specific fee agreements become more common.

A base case was established, and two scenarios for improvement resulting from CAD Conferencing were created. The first scenario assumed that the documentation stage and related architect (documentation) fee payment period, was shortened by one month (*ie*, one-twelfth) and that all engineering consultants' fees were spread over the same periods as for the base scenario. The construction and preliminary design times remained unchanged. The three and a half year project thus was completed just one month early. A second scenario assumed that three months were saved during the documentation stage and the periods over which the engineering fees were paid were reduced by one month regardless of the period over which they were paid. The project was completed three months early.

Cost Savings

The estimated cost savings on rise-and-fall and holding charges were as shown in Table 6 for both the consultants' fees and construction.

Table 6. Estimated Savings with CAD Conferencing

Time savings	Rise-and-fall		Holding charges	
	Cost ($)	*Savings (%)*	*Cost ($)*	*Savings (%)*
Consultants' fees				
Zero	682,749	0.00	2,750,456	0.00
One month	661,854	3.06	2,691,245	2.15
Three months	620,487	9.12	2,559,954	6.93
Construction stage				
Zero	9,294,563	0.00	13,101,131	0.00
One month	8,979,651	3.39	13,078,955	0.17
Three months	8,321,092	10.47	13,022,376	0.60

The savings in rise-and-fall on both fees and construction costs for the two scenarios are substantial at approximately 3% and 9%. For the holding charges, the percentage savings are reduced to approximately 2% and 7% for the consultants fees and an almost negligible 0.2% and 0.6% for the construction phase. The minimal change in holding charges during construction is to be expected as the construction time remained unchanged and the cash flow differed only in the small changes in rise-and-fall. The consultants fees are reduced only by the flow-on corrections made to the contract price for rise-and -fall (*ie*, the allowance for inflation) and so there has been no loss of real income to the consultants.

The impact on total costs of reductions in time during the period over which there is the greatest interaction between consultants is thus likely to be significant enough to attract major project clients to insist on better time performance at the same (or possibly higher) level of fees. These preliminary estimates indicate that CAD Conferencing has the potential to be of significant benefit to the building client while improving the efficiency and quality of the service provided by the consultants. More refinement of the model will be necessary as the real benefits (and costs) of CAD Conferencing are identified.

TOWARDS NETWORKING CONSTRUCTION

In conclusion, it is possible to identify a number of factors which are encouraging a move towards a more innovative use of telecommunications in construction (against current inhibitors which include evolving standards for networking, CAD data exchange and uniform CAD nomenclature).

Shifts in Computing Paradigms

In recent decades there have been a number of paradigm shifts in computing which have taken us from batch processing in the 1960s to 1970s time-sharing and 1980s desktop systems (Tesler, 1991). In the 1990s, the shift is towards *networked computing*. Networking is the infrastructure that permits distributed processing; that enables expertise and critical mass to be assembled and integrated for major projects without the need for geographic centralisation and the added upheaval in personnel and costs associated with this form of organisational change. Networked computing will allow key specialist personnel to remain in their preferred working environments, yet make critical input and play central roles in major projects involving a consortia of skills and expertise. Centralisation becomes an option rather than a necessity.

Available information (Atkin, 1990) suggests that the construction sector has been slower than most others in embracing IT. It follows that uptake of networking technologies (initially LANs, then MANs and WANs) will also lag other sectors. But in AEC there is sufficient evidence of leading edge practitioners capable of embracing those technological advances in communications which can be expected to deliver real benefits to efficiency, productivity and profitability.

Integrated Information Systems for Building and Construction

Once electronic datasets become available, opportunities for development of integrated information systems multiply rapidly. Much has been written about the development of integrated project databases that would be accessible to the design and construction team — a system specific to a particular project which would be maintained through the design, construction, commissioning and occupancy phases as well as maintenance and refurbishment . All data gathered during the life of a project can be valuable; without electronic storage it is often lost.

Damping Cyclical Downturns in Construction

The property sector has a history of boom and bust and the downswing in such cycles brings with it a significant contraction of employment in the AEC sector and the design profession in particular. This provides opportunities, as has always been the case, for AEC firms to shift their 'business' from a region where construction is flat to areas where there is growth. The ability to shift staff electronically rather than physically — to provide expertise via telepresence as opposed to in situ — affords business a responsiveness to changing opportunities that has previously been unavailable to them. For the larger multi-locational AEC firms this means opportunities to optimise their key resource, skilled professionals and practitioners, by linking them into a broadband intra-organisational communications network capable of providing real time access to remote databases and software. For the smaller firms based in a single city, strategic alliances can be formed with complementary firms to form AEC consortia to bid for construction projects. With the advent of broadband communication, the barriers to competition that distance alone until now has enforced are beginning to disappear. The most difficult of all barriers to overcome would no longer appear to be technological but rather organisational, political and cultural.

Internationalisation

Internationalisation of the building and construction sector is continuing and will intensify during the 1990s. To ensure their future growth, AEC firms in advanced industrial countries will need to, among other things, utilise communication and information technologies in an innovative way to develop global AEC networks.

Time-Based Competition

Developments in telecommunications over the past 50 years have continued to offer opportunities for compressing time and abolishing the effects of distance. Indeed, our society's present industrial base is built upon a communications network capable of delivering real time voice and text capability nationally and internationally. For certain sectors of industry and categories of business this provides the opportunity for undertaking work in a radically different fashion, *viz*: where they work, with whom, when and how. Figure 2 is suggestive of the range of networking opportunities now available to the construction sector. The AEC community is but one such example in relation to the CAD interchange.

In conclusion, the verdict is not yet in in relation to Networking CAD and CAD Conferencing, principally because members of the jury — the AEC practitioners, Project Managers and infrastructure developers — have not yet witnessed the key exhibit, namely the type of prototype systems outlined in this paper. In our view, however, all signs point to a decision in favour of an intensification of networking in construction, of substituting new for old practices. Levels of substitution will increase as telecommunication costs fall and as innovative practitioners begin to experience the advantages of real time communication and information exchange.

Note

1. All currency ($) figures in this paper are Australian unless otherwise indicated.

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