INFORMATION AND COMMUNICATION IN CONSTRUCTION : CLOSING THE LOOP

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ABSTRACT

Both nationally and internationally, the architecture, engineering and construction (AEC) sector is highly fragmented : it is dominated by small and medium-sized enterprises (SMEs), the nature of information and knowledge can be dispersed among firms and organisations, and consortia are frequently formed from geographically dispersed firms. In recognition of the potential improvements to be gained through an integrated approach to project information used throughout the design, documentation, construction and operation processes, research is underway in Australia to "close the loop" of information flows between designers, engineers and constructors.

The paper discusses the technology platform in terms of information and communications technology (mobile, high-speed and wide area networking linking the design and engineering offices with the construction site) as well as the information platform in terms of communications between project stakeholders and the exchange of requisite information (spatial and non-spatial data) of key concern to the stakeholders at various stages of the project lifecycle.

Keywords : *integration, design, construction, communications, information technology.*

INTRODUCTION

For the last fifteen years at least, the architecture, engineering and construction (AEC) sector has seemingly been poised to seize major improvements in efficiencies and productivity with talk of extensive penetration of Information Technology (I.T.) providing benefits such as those gained by other industries in the office productivity scenarios, and also with widespread industry integration. However it is only just recently that such improvements may finally be coming to fruition with major developments on multiple fronts such as: better understanding of the required information flows between AEC project stakeholders; and international initiatives to enable seamless exchange of design information (utilising accurate, well-defined objects used by stakeholders in their communications) linked to intelligent (object-oriented) CAD.

Other factors simultaneously influencing developments are: substantial price reductions plus technological advances in computer software (operating systems, advanced CAD systems, distributed computing) and hardware (extremely powerful processors and graphics options); plus the widespread availability of suitable communications (Wide Area Networks, highspeed capacity, and mobile technologies) which all provide an opportunity for overcoming AEC fragmentation through integrated design, life cycle optimisation and virtual project teams. Additional key drivers to move research into practice in the areas of design and construction include a move to performance-based standards designed to stimulate innovation in design which requires tools for performance appraisal, with minimal effort in checking compliance with regulations; and the need for innovation in the Australian AEC industry that enhances our built environment (DIST, 1998).

PLATFORMS

Information Platform

A holistic approach to building and construction projects – through planning, concept design, detailed design and documentation, construction, and operation and maintenance – is necessary in order to ensure that the benefits that potentially may accrue through using an IT-based approach are in fact captured. To gain the maximum benefits of an integrated approach, then data entered at one stage of the process should be available at other stages for further use or subsequent refinement – without the need to re-enter it. Various stakeholders in the building and construction process have different views of the data that is required to satisfy their individual requirements, and a system which exhibits flexibility and a distributed approach is believed to best serve our industries needs.

Information flows, scope and breadth

The Architecture, Engineering and Construction (AEC) sector is made up of a large number of small organisations, which are specialists in particular parts of the industry. While this existing structure means that the industry can be highly competitive and efficient at the small scale, the fragmented nature of the industry makes large scale, coordinated change difficult.

The introduction of I.T. to the AEC sector has allowed narrow slices of the industry to be computerised, but there is no coordinated system for exchanging information between the numerous computer programs that are used. This means that much time and effort is wasted in converting or re-entering information that has already been entered into another program (Figure 1). It also introduces errors and makes coordination and checking of information difficult.

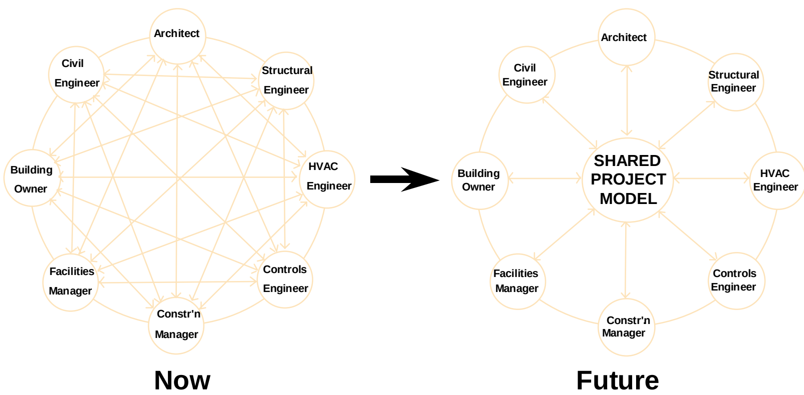

Figure 1: Reducing Complexity with IFCs

The obvious solution to this array of communication problems is to develop a vendor neutral interchange format that allows all of the different computer programs to exchange information into and out of this neutral format. After many early attempts at such a format, in 1994

AutoDesk founded a group of software developers to develop a neutral format for the AEC sector – this group was called the "Industry Alliance for Interoperability". After giving the first demonstration of the system, the IAI was opened up to the whole industry as the "*International* Alliance for Interoperability", and now has eight chapters spread throughout the world, with the most recent chapter being the Australasian (Australia/New Zealand) one. The Industry Foundation Classes (IFCs) provide this latest vendor neutral interchange format, however there are several problems with this approach. The major problem is to get all of the software developers to agree on a neutral format. The technical problems are defining the information that needs to be exchanged and developing the methods to exchange that information (IAI, 1997).

IFC's – Industry Foundation Classes

The IFCs are descriptions of the building elements, resources and processes that are used extensively in the AEC industry, and they use a four-layer structure (Figure 2). The user sees the Domain level, which covers the particular interests of the various groups working in the industry, such as architects, clients and contractors. The Interop layer sits beneath the Domain layer and provides the communication mechanisms between the different groups, while the Core layer contains definitions that are shared across the groups, such as walls, floors and columns. The "lowest" level is the Resource level, which contains definitions of basic information such as measurements and units that are used by everyone.

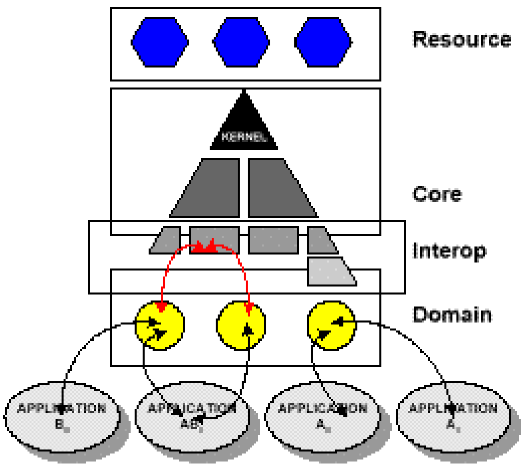

Figure 2: IFC Model Architecture

Intelligent CAD

The linking of expert systems to CAD engines has been a long-term aim of the research and CAD vendor communities. The intention is to support the designers and constructors of built facilities in using a wider range of information than is currently common practice, which will in turn, improve the quality of design solutions presented to clients, and will assist in reducing the impact of buildings on their surroundings.

Development work over the last fifteen years has indicated that the most appropriate method of adding intelligent support to CAD systems is to add "modules" which are independent of each other (Figure 3). The designers work on a model of the building and its environment through a variety of user interfaces, and the "intelligent" modules can then assess the current state of the design and communicate advice to the user(s).

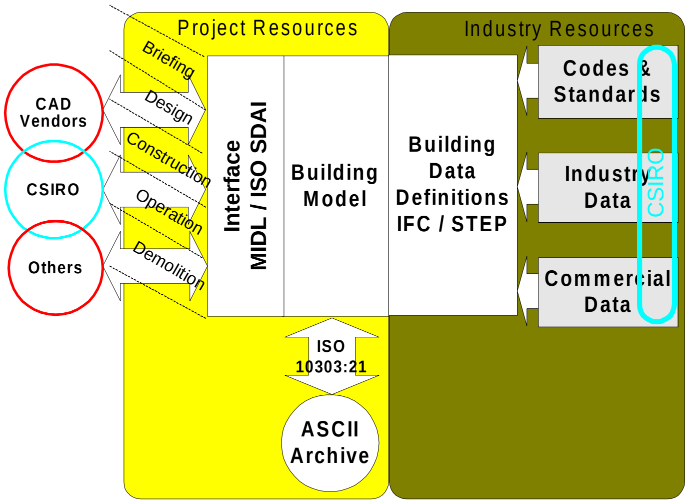

Figure 3: Intelligent CAD platform

There are several factors, which have slowed the introduction of intelligent CAD. The most significant factor is the lack of industry-agreed definitions of the items and objects that need to be considered within a building project – this is being addressed by the aforementioned Industry Foundation Classes which allow the various information providers (e.g. Australian Standards; proprietary product databases, etc.) within the AEC sector to provide their information in computer interpretable form. Appropriate technology must also exist to support access to the information, and this may be covered by the use of Standard Data Access Interfaces (SDAI) to databases (ISO 10303:22, 1994), and the various Interface Definition Languages (IDL) (e.g. Microsoft's IDL under Windows), while the STEP Part 21 file format (ISO10303:21, 1994) can be then used to archive data as ASCII files for long term archiving. The information can then be linked in to building data definitions, which are shared across the whole industry. As a project is designed, a building model is developed based on the IFCs, and IDLs and SDAIs provide interfaces to software packages.

Communications and I.T. Platform

Emergence of Virtual organisations

Traditional (current) practice tends towards the physical assembly of a project design team in relative physical proximity to the project site. The limitations of this approach include an inability to "assemble" the best team, to access key "head office" resources, and to work across several projects at the same time, etc. However, in the late 1990s, key shifts in information and communications technology and management thinking are identifying opportunities for a new organisational paradigm for industry which features team-based work, a highly integrated organisation and an enterprise which is capable of establishing and sustaining external strategic linkages.

For the AEC industry this provides opportunities for the formation of *virtual project teams* where communications, video and CAD technologies can be employed to electronically link members of a consortium who are geographically dispersed and located at some distance from the site of the project. For such teams, a technology platform and the supporting infrastructure is now emerging which is capable of providing support for collaborative work during concept discussions, design and documentation, as well as construction and fit-out (Figure 4).

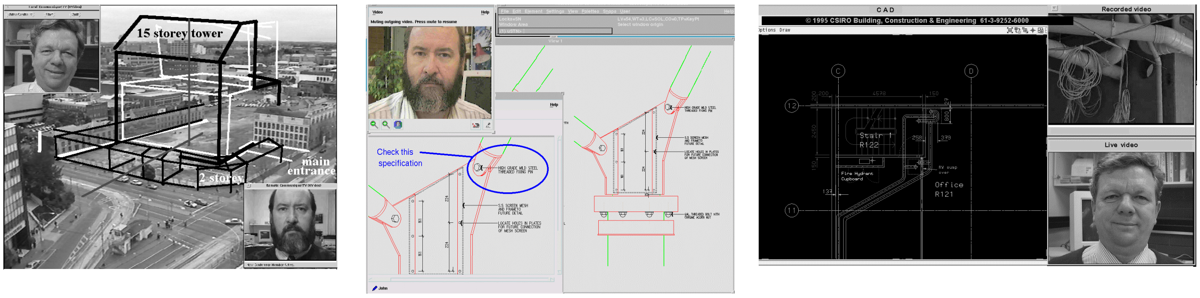

Figure 4: Real-time collaborative working on design, documentation, and construction.

The wide-spread availability in many developed countries of higher speed commercial communications services such as ISDN – Integrated Services Digital Network, Frame Relay and ATM – Asynchronous Transfer Mode, along with the international standards governing their implementation, means that higher capacity communications to support operations of virtual organisations is becoming far more common. However, in construction at least, the cost (of both hardware and communications) to establish and support the virtual organisation still remains a major issue amongst project stakeholders, and consequently the critical mass of stakeholders able to participate in these virtual design and construction organisations has not yet been achieved. In the short term, Internet access by the various stakeholders (at relatively low speeds using existing networks) is providing some level of low-cost connectivity for file transfer and document updates, but issues of information security and privacy still remain.

Globalisation and Wide Area Networking

The emergence of a *global information infrastructure* (Brett, 1993) provides a new platform for supporting Australian-based companies involved in international engineering and construction projects (Warf, 1991; 1996). In Australia, the market for construction is relatively limited, but global telecommunications however, in combination with a more open environment for international trade in business services, provide the ingredients for a global market for construction. Harnessing the capabilities offered by higher speed communications diminishes, to a certain extent, the problems inherent in managing offshore projects. It is apparent that Australian companies must become more proficient with I.T. in construction – since global competition is the "down-side" to a global market.

Even prior to the widespread installation of optic fibre cables near residential properties in Australia, the impetus towards working at home had been highlighted in the growing literature on telecommuting (Riley, 1996) – although firm estimates of numbers involved are difficult to establish (Newton *et al*, 1994). For the growing class of information workers – which includes a significant proportion of those linked to a construction project, whose primary task is the creation and manipulation of symbols (viz. CAD drawings, textual documents, quantities of building materials, financial modelling, work-flow schedules, etc.) – *where* they work will increasingly become a matter of personal preference and organisation practice. Wide Area Networked computing (i.e. widely distributed computers linked by high-speed wired or wireless communications) will provide the platform on which this new mode of working will evolve.

Visualisation; virtual and augmented reality

Compared to just a couple of years ago, powerful microprocessors at relatively inexpensive prices plus major advances in graphics hardware and software are now making possible, at the desktop, that which was only previously available to users of specialist workstation computers at a cost of tens (or even hundreds) of thousands of dollars. Researchers and leading-edge design and construction professionals dreamed of these capabilities in the early 1990's, and relatively low-cost desktop computers are now capable of running sophisticated visualisation, simulation and CAD software which were previously only in the realms of very large companies, research laboratories and university departments. For instance, the ability to digitally capture, in real time, images from a refurbishment project or a construction site and combine these in various ways with information from design and project databases provides a whole new approach to visualising and understanding detailed plans, models and the location of facilities. This further step goes beyond simple electronic whiteboarding – which may use captured video images as a background to the session – to a point where the video image (held in conjunction with accurate positional information) will be an integral part of the process of "augmented reality" to assist site personnel in locating and visualising features, while "virtual reality" techniques and tools are starting to assist designer/users in model analysis and more sophisticated decision making.

Mobile technologies

In order to complete the loop between design office and construction site / office and ensure that key project information once collected is retained for use by others – to be subsequently expanded and refined as the project proceeds – we must give personnel on the construction site, or in the field, the ability to collect and provide, or to gain access to, correct, accurate and up-to-date project information (Figure 5). Increasingly this ability to form part of the project information loop will be supported by mobile or wireless technologies, and by providing on-site or field users with graphically-oriented tools matched to their level of computer-literacy/naivety, of course agreeing that "site workers should be trained for the proper use of information and other new technologies" as Tupamäki (1997) notes in his report on RTD Strategies for European Construction.

Graphically oriented, icon-driven (rather than keyboard-oriented) software – written specifically for the construction industry – and implemented on a single, small, portable handheld device (similar in size to existing site radio facilities) will provide on-site users with the ability to generate or collect accurate data and project information, and to retrieve and exchange information with other stakeholders, as their project role requires.

Combining features such as dual digital cameras, a Global Positioning System (GPS) receiver, inclinometer, digital compass, touch screen and pen interfaces, bar-code reader, and wireless radio/mobile communications – all integrated into the single handheld device (Alexander *et al*, 1997) – will allow users on-site to, for instance, take easy measurements of construction objects from instantaneous digital photographs (allied with the accurate location and orientation of camera and object), and to provide this information to other stakeholders working across- or off-site. Cameras provide the necessary documentation for field observations and also simplify record keeping, while two-way wired or wireless communications will provide access to the design office, corporate facility, and customer databases. Using a central base-station nearby the construction site provides on-site communications between workers as well as giving access to data and transfer through such handheld communicators equipped with inexpensive two-way digital packet radio modems. Some applications are less time-critical, but many are time sensitive and rapid updates to project information are necessary to maintain data synchronisation and to prevent information concurrence problems – the age-old design and construction problem.

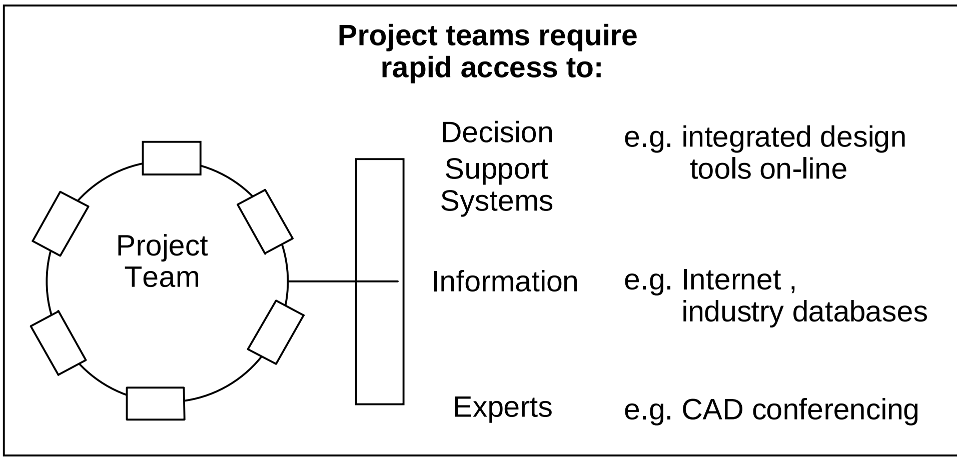

Figure 5: I.T. systems for construction project teams

At present in Australia, the public digital mobile networks do not support data transfer rates higher than 9600 bits per second, so that direct off-site communications are restricted to short message services (SMS) and the like. However with better video compression algorithms on the client side and a likely upgrade in public mobile transmission speeds, the use of such handheld communicators to access other graphical data sources such as corporate facilities and customer data bases directly across the mobile network will soon be possible. Again as Tupamäki (1997) notes " modern information technology, together with modern tele-communications and multimedia, offers great opportunities for the construction industries to apply these techniques to the production process itself. Information flow from and to the construction site should be taken care of with modern communication technology, which would shorten the construction time. Managing mobile communications on the building site will be indispensable ".

In order to effectively "complete the loop" between designers, engineering contractors, and constructors the current level of computer-awareness of potential users on a construction site must be raised, and the approach recommended is one of tailoring hardware and software systems to provide purpose built tools for specific uses. Research has shown (Coble, 1994) that such a system must be closely integrated so that carrying and fitting additional parts and cables does not burden the user; it must have sufficient battery power to not require constant recharging when used in the field; that the device must be sufficiently small to be easily handled and managed, and yet must be large enough to provide information in meaningful "chunks" to the user; and for personnel generally more used to simple technology, it must be graphics- or speech-oriented with little or no requirement for typing or keyboard skills. A device with a high resolution touch-sensitive screen in conjunction with sophisticated yet simple-to-use software is seen as the best vehicle to encourage on-site workers to participate in the "I.T. revolution", for project information to be retained and made accessible to appropriate stakeholders – in other words for the information loop to be closed.

TOWARDS AN INTEGRATED SYSTEM FOR COMMUNICATING INFORMATION IN DESIGN AND CONSTRUCTION

Turnkey systems are popular across many sectors of industry in that they deliver an integrated system that supports key operations for an organisation. Whether the components of such an integrated system for communicating information in design and construction are combined as part of a commercial turnkey system will be driven by market requirements. It is clear, however, that maximum benefit will result from a situation where pertinent information resident in a project database can be seamlessly accessed by remote members of the project team, whether they be architects working out of their head office or superintendents on a construction site (Figure 6), and furthermore, that all participants in a construction project can access appropriate information held on "remote" industry databases, accessible via ISDN, the public Internet, or a private 'intranet'. As Okamoto (1997) observes " If the system to share building related information from upstream to downstream is established with the cooperation between the country and private companies, productivity of the construction industry, …. , can be drastically improved. " .

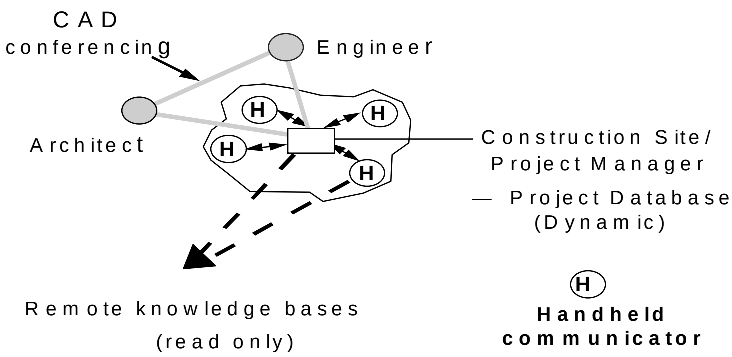

Figure 6: Integrating the communication of information in construction

CONCLUSIONS

The new paradigm of global networked computing will provide opportunities for radical change in the AEC industry capable of delivering substantial efficiency benefits provided the stakeholders cooperate. Firms that are prepared to compete against time as well as cost and quality will be the ones to capitalise on these opportunities. *Cost* is the most deeply entrenched influence within industry, but in recent years has been joined by *quality* (Randall, 1995) and also *time* (Stalk and Hout, 1990) as additional dimensions of competition.

The project team will, however, constitute a central focus for change where networked computing – linking design, engineering and constructors on-site – can deliver access to the best people, the best information and the best software – any time, anywhere. The research community and leading-edge AEC industry practitioners need to rapidly demonstrate this potential through Research and Technological Development, and encourage on-site workers to participate in the "I.T. evolution" – for vital project information to be collected, retained and made accessible to other appropriate stakeholders – for the information loop to be closed.

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