IT in the Management of Design and Construction

KRISHAN MATHUR[1]
TOM MAVER[2]

ABSTRACT

This paper provides an overview of the developments in Information Technology (IT) and its impact on the Architecture, Engineering and Construction (AEC) industry. It takes note of what has transpired in the last two decades and how the evolution of this subject corresponds to the predictions which had been made at various times in the past. It concludes that changes in procedures, processes and structure of organisations are needed if the most effective use of IT is to be achieved, and it is timely to go beyond solutions which mimic and automate current processes. Strategic frameworks must be defined within which new solutions will emerge rather than specific technical solutions for individual design or automation tasks.

Concurrent changes in the AEC professions and the management of projects and organisations will be required to support the new tools and techniques offered by IT. Thus no promises should be made purely on the basis of emerging technologies. Hence the paper makes no attempt to predict the future of the AEC industry even though integrated systems may become available to support creative, cooperative, multi-disciplinary design, and though such systems will assist construction automation tasks, maintenance and facility management.

Key Words
information technology; construction; design; management; integration

INTRODUCTION

The pundits forecasting the power of information and the dawning of the information era need not wait any longer since the information revolution is taking place - now and globally. We can justifiably say, as we head for the turn of the century, that we live in an information society where the key resource is Knowledge. It was only in the realm of science fiction four decades ago that one could imagine carrying the giant number-crunching contraption - called the electronic digital computer - on one's palm. The

1 *Associate Professor, Faculty of Architecture and Building, School of Building and Estate Management, National University of Singapore, 10 Kent Ridge Crescent, Singapore 0511.*

2 *Professor of CAD and Director ABACUS, Department of Architecture and Building Science, University of Strathclyde, 131 Rottenrow, Glasgow G4 0NG, UK.*

parallel developments in telecommunications technology, now enable us to process information from remote locations and disseminate it simultaneously to many users. This combined technology - computing and telecommunications - called Information Technology (IT) is the driving force behind major decisions in all sectors of the economy, in particular in finance and manufacturing. IT has revolutionised the whole concept of management information systems.

It has been widely recognised that for many commercial organisations, IT is a strategic weapon and is critical to the success of the organisation. Since IT can be a high expenditure activity and involves many stakeholders (government, customers, suppliers, employers, etc), it is also being realised that IT matters need to be discussed at the highest management level (Earl, 1989). IT today is being used in many different forms: in hard technologies (such as robotics and teleconferencing) and in soft technologies (such as databases, expert systems and decision support systems).

THE CONSTRUCTION INDUSTRY

The construction industry - representing the architecture, engineering and construction (AEC) professions - remains highly fragmented. The fragmentation exists both within individual phases of the construction process (eg, the design phase), as well as across project phases from planning through design and construction and into facility maintenance and operation (Howard et al, 1989). Needless to say, this fragmentation is one of the causes of AEC industry's low productivity and competitiveness compared to those of the manufacturing industry. Without going into a detailed discussion of the historic reasons for this fragmentation and its implications for the individual 'actors' and for the construction process, it is suggested that technology - IT to be specific - may provide the mechanisms to cement this fragmented process - both horizontally, ie, within a phase of the total process, and vertically, ie, between different phases.

Computer-Aided Design - CAD

Computers have been used during some phases of the construction process for over three decades, in particular for engineering computations to take the drudgery out of repetitive calculations. Thus computers are valuable assistants, and any IT tool used in this capacity can be described as a CAD tool. Early computing tools, mainly in the form of software (programs) were not useful in architectural design - which is an intuitive and creative process. However, with the rapid advancement of graphical information processing in the last two decades, architects can manipulate designs in 2-D or 3-D views to carry out spatial organisation and simulate the experience of a 3-D model much more quickly and efficiently than the traditional media could provide.

With these developments CAD has grown from the minority time interest of a few eccentric academics into a multi-billion dollar business.

Metrics of Growth

Perhaps the best metrics of growth of the use of computers in building design have been provided by the UK Construction Industry Computing Association (CICA).

For most of its 22 years, the CICA has charted the availability of applications software and, during the 80's, the level of uptake by the building industry. This historical archive provided the basis for the *Building IT 2000 Project* (CICA, 1992) which predicts the likely take up of various information technologies by the year 2000.

Figure 1, produced by the CICA, charts the cumulative availability of different types of CAD software over the period 1975-1988, and the rapidly increasing number of UK firms using computers from 1973 to 1990.

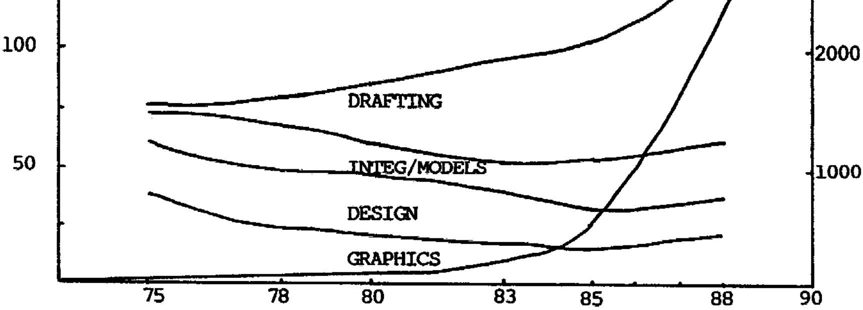

Figure 1. Use of IT Hardware and Software

Professional Perceptions

In 1977 in *The Automated Architect* Prof Nigel Cross of the UK Open University attempted 'a kind of technological assessment' which concluded that CAD would have large effects on the design process but little effectiveness in terms of improving the design of buildings (Cross, 1977). He identified a number of areas or issues in which the growing use of computers in building design could be seen as offering either a promise or a threat to architectural practitioners. These promises/threats were, for each issue, set out in starkly contrasting terms. For instance, on the issue of 'freedom or drudgery' the promise/threat were expressed as:

promise: the boring 'grunge' work of detailing, scheduling, drawing, etc is taken over by the machine, leaving the architect more time and freedom to pursue the creative aspects of design.

threat: considerable time, money and effort are spent in 'machine minding' - punching cards or tapes, writing programs, tracing errors, maintaining the machinery and waiting for it to be repaired after breakdowns.

In 1990, at the Ross Priory seminar (ABACUS, 1990), Cross put these 1975 promises and threats to 10 participants, asking each to make a personal assessment along a five-point scale of just how true (or untrue) each promise and threat had turned out to be. The results for two of the more important issues are summarised in Figure 2.

IT IN AEC INDUSTRY

How far will IT be able to carry its promises, in the next generation of Computer Integrated Design (CID) and Computer Integrated Construction (CIC) systems, to solve the woes of the AEC industry? While R&D efforts are actively searching for technical solutions, it is the management of IT that will make the difference. IT will change the work environment: decisions, for example, will not be made by individuals but collectively. Individual actors are thus not just responsible for the small 'link' in the linear decision-making chain. IT may require major reorganisation at the level of the work group, the department, and perhaps the whole organisation (Gerstein, 1987). After decades of professional delineation where responsibilities are divided, such changes may be fiercely resisted, perhaps on the grounds of professional liability.

IT will also raise some touchy questions of ethics. With the possibility of a 'knowledge store' capable of capturing all decisions and the intentions behind these, all the actions taken by the various actors can be scrutinized and called into question anytime during the life of the product.

It is easy to see the computational necessity to have a common design model from which different actors can extract the necessary information for their respective perspectives (views), thus obviating the need to store the same

Help or hindrance?

THEN

Promise

The architect is portrayed as skilfully operating a battery of sophisticated design aids ranging from a semiautomatic drawing board to large-screen CRT displays of 'walk-around' views of the proposed building.

Threat

The architect is seen surrounded by a buzzing, flashing, chattering confusion of computer hindrances poorly designed to match his limited human abilities in handling quantitative data.

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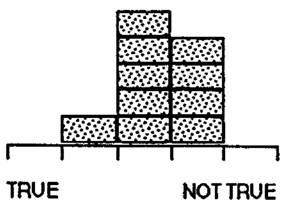

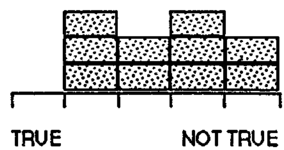

Enhancement or disruption?

THEN

Promise

The computer offers new possibilities in the way of data manipulation and the production of a variety of information other than conventional limited drawings.

Threat

The computer disrupts and destroys the architect's traditional skills in the preparation and interpretation of drawings, causing confusion and costly errors in the interpretation of alternative modes of presentation.

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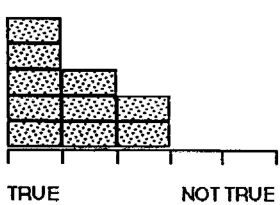

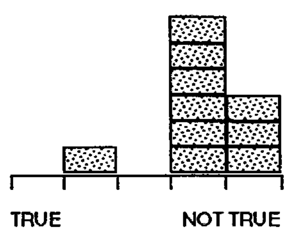

Figure 2. Promises and Threats of Using CAD

data many times over. However, 'actors' have 'personalities'; sharing a common pool of information alone does not constitute cooperative design. IT will provide a design-environment that facilitates keeping all actors informed of each others actions, but, in itself, does not constitute cooperative work.

The multi-disciplinary nature of design demands that as design progresses, the various attributes, such as, spatial planning, lighting, heating or air conditioning and cost are evaluated. 'Integrated' design systems have been proposed which enable such evaluations, albeit one by one. It is thus possible to check the performance of each attribute on its own. Few systems, if any, have the ability to guide the design process by recommending design changes to improve the performance of an attribute without adversely affecting that of others. Even this does not scratch the surface of the real problem where the design should be changed such that the performances of all the attributes improve concurrently and optimally. Integrated, cooperative design environments demand control strategies for guiding designs within the framework of an 'overall' optima and for conflict resolution.

Integrated systems further assume that all the actors would concur with the system's control strategies. One can plan strategies for routine design, and integrated systems will play an important role in the procedural aspects of the construction process and in product modelling. But for creative design, control strategies for guiding designs towards a satisfactory optimum is still an aim to be achieved. Predicting its fulfilment would be gazing into the crystal ball.

Product Modelling

The use of robots on the site for the construction of structures which are repetitive in nature and use prefabricated parts (such as industrialised buildings) is now possible and should become quite routine in the next century. The next step for IT research is to emulate the manufacturing process by taking the product data from the design stage and feed this straight into construction automation systems (eg, robots). This computer integrated construction - CIC - scenario has many other benefits. Product data models, if in a standardized format, can be used for detailed (routine) design for structural analysis, lighting, air conditioning, etc; on-site management (activity scheduling, inventory and cost management, etc); and the operation, maintenance and facility management for the whole life of the product. Such parametric models can be created using conventional CAD modelling tools when the design has reached a stage when no major changes in the product's overall form and shape will be necessary, ie, at the detailed design stage. For building design, R&D work is progressing for the standardization of product data for use with CAD systems (Penttilä, 1990), and this brings us one step closer to CIC becoming a reality in the near future.

A big gulf, however, remains to be bridged between CIC and CID - computer integrated design. The early, creative process of design demands the conceptualisation of the built-form in which the spatial form, the envelop, the structural system and the major services systems have to be integrated into a unified whole. This conceptualization treats spaces as continuous or solid entities, not as an assemblage of the parts enclosing the space. For all but the simple rectilinear shapes (eg, straight office tower), designers' best media to represent such concepts still are styrofoam or clay. Graphics modelling tools currently available on computer workstations are inherently limited in their ability to represent concepts involving complex shapes and spaces (such as an attrium). This is because objects are represented using basic geometric information (lines and polygons) and because of the limited ability to deduce geometric properties. The introduction of computer algebra systems will enable the representation of complex shapes involving curves and surfaces, and, through the manipulation of algebraic polynomial expressions, provide geometric reasoning capabilities to deduce higher level geometric properties (such as intersections) more efficiently than say, by ray tracing (Martin, 1991).

Algebraic systems are necessary for subsequent computability of the geometry so that a conceptual design model - generated and used to develop the outline of the built-form - can be linked with a conventional CAD system for subsequent detailing. This is the leap, from CID to CIC, yet to be made. Image processing tools currently used for solid modelling provide a suitable, albeit expensive, medium for representation of the built-form to simulate the experience of visual appraisal (such as a walk-through the building). The images so generated have little use for further analysis or design of the product. The subsequent product data model has to be generated from scratch using conventional CAD systems.

Wider Social Impacts

The wider social impacts of the increasing use of the information technologies on the building industry was the subject of a major report sponsored by the Commission of the European Communities in 1985 (EC, 1985).

The report identified a number of likely impacts on design practice, on the education of building designers, on the relationship between design and construction, and on the relationship between client and designer.

In tabular form (Table 1), the report attempted to summarise, over various timespans, likely impacts of the application of emerging technologies and to anticipate the educational and research responses which would be needed if maximum advantage was to be taken of the opportunities offered.

Table 1. Time-scales for Actions and Outcomes in CAAD

	Immediate (now)	Short-term (5 years)	Mid-term (5-10 years)	Long-term (10+ years)
Technology	Micros Drafting system Performance models	Supermicros Partially integrated systems Early expert systems	Worldwide networking Expert systems Fully integrated systems	Computer ubiquity AI and natural language systems
Applications	Spread of use of computers in offices Drafting	3-D modelling for visualisation Regulation revision	Performance specification Solid modelling for appraisal	Participation Client-oriented CAAD systems
Impacts	Expense/time to implement Job differentiation; losses and gains	Shortage of qualified people Shift from private to public sector Demise of medium size practices	De-skilling Responsibility and liabilities Breakdown of professional boundaries	Improved building performance Higher grade professionalism De-professionalisation
Education	Architectural students awareness and familiarisation System evaluation Teacher education	In-service training and re-education Clients awareness Undergraduate CAAD systems	Post-graduate and mid-career CAAD education Undergraduate syllabus changes	Computer-assisted learning in design
Research	Monitoring of spread of CAAD Evaluation of CAAD education experiments Validation of existing programs	Human-centred CAD systems Kernel and shells for integrated CAD Interfaces and knowledge bases	Systems for naive designers Computer-assisted learning systems	Optimisation in design Non-traditional ways of communicating with computers

CONCLUSION

The rate of development of the information technologies over the last two decades has been phenomenal. In such a rapidly changing technological environment it is extremely difficult to predict with accuracy the timescale for changes in the way we carry out building design. It is fairly clear, however, that the pioneers of computer aided design of building correctly predicted the general thrust of the impacts of computers on the practice of building design; indeed, even virtual reality was anticipated in the early 70's.

The current use of IT in construction is unlikely to provide a strategic advantage either to practitioners and the industry, or to clients and users of buildings. There are many reasons for this. Unlike other sectors of the economy, the construction industry is fragmented and not amenable to changes. There are currently no easy solutions, with or without IT, to achieve competitive advantage or a better built-environment. Changes in procedures, processes and structure of organisations may be required if the most effective use of IT is to be achieved. These are unique challenges for the construction industry.

If the full potential of computer aided design is to be realised, urgent research and development effort needs to be focused on a number of related

topics, including:
a) better ways of graphically hypothesising design alternatives,
b) systems for design decision-making which support the integration of the full range of cost and performance criteria,
c) faster feedback of cost and performance consequences of design changes,
d) the establishment of explicit cost/performance criteria for different building types,
e) client oriented CAD systems which facilitate building management, and
f) multi-media techniques which replace folded paper drawings in the presentation and communication of design ideas.

It is timely to go beyond solutions which mimic and automate current procedures and processes. We must consider the wider impact of IT and encourage the construction industry to evolve in a way which maximises the benefits to be gained from IT. At the same time we need to identify comprehensive solutions which must be developed. Lessons can be learnt by applying IT solutions borrowed from other industries such as integrating dissimilar CAD systems with programs for cost, time and contract management, and the design of structure and services sub-systems. Attempts to solve these problems appear fragmented at present. A major effort is thus needed at the international level to discuss the impact of IT in the next century when the use of communications networks, new media technologies and AI will be an integral part of the design, construction and maintenance of buildings, and to plan and prepare frameworks for such IT based support systems. A vision and an agenda for future research and development is urgently required. It will define frameworks within which new solutions will emerge rather than specific IT or computer solutions for individual design or automation tasks. It hopes to map out a direction for change for the construction industry in *symbiosis* with emerging *IT Support Systems*.

Above all, we need to educate architects and engineers to manage the new technologies with authority and imagination.

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