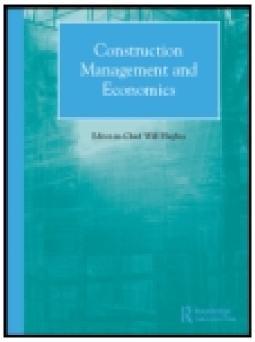

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Strategies for the construction sector in the information technology era

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The construction industries in many countries are starting to consider seriously the strategic use of information technology (IT). The use of information technology in construction is extending beyond the stage of piecemeal application for improving the efficiency of discrete operations by individual organizations to the advanced stage where IT is applied strategically in commercial enterprises, government agencies and professional institutions. Progress in construction in this regard appears to lag behind that in most other sectors of the economy. This paper considers the nature and the background of this progression in construction by examining proposals by Earl (1989) of nine basic prerequisites to the IT era which make a strategic approach timely. Each prerequisite is outlined and how it has been met in other sectors of the economy considered. The extent to which these prerequisites apply in construction and the scope for their application in the near future are examined. It is argued that all organizations involved in construction will ultimately have to think strategically about their use of IT, and how some are already doing so is described.

In discussing the factors which hinder the strategic application of IT in construction, the nature of the design and construction processes and initiatives that may be necessary to overcome the perceived problems are examined in detail. The strategies that are evolving at a national level in Singapore are outlined.

Keywords: Information technology, strategic planning, construction sector, Singapore.

Introduction

It is clearly evident that the information age has already dawned. Like many other writers, Earl (1989) suggests that we live in an information society at present, where the key resource is knowledge and where information technology (IT) is the enabling mechanism. This is evinced by the fact that information workers form the largest category of employees in some advanced economies and that technology accounts for the highest proportion of capital formation in some sectors. Earl suggests that the conditions precedent to this dawning are three areas of dynamic change in technology advancement, commercial globalization and social advancement.

The IT era is replacing the data processing (DP) era and Earl (1989) suggests that the distinction between these two is based on the much greater need for IT and its implementation to be planned and managed; IT should also be used strategically by organizations. The IT era has not necessarily dawned equally brightly in all sectors of all economies, but if such eventual progression is accepted, then it can be assumed that all sectors can potentially reach and embrace the era at some point in time. This paper examines the extent to which it has

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happened in the construction sector and the likelihood of it happening further in the near future.

Gerstein (1987) refers to the present technology change as the IT connection, stressing that IT has a large impact on the business of today and that changes will have to be managed carefully. He lays down five rules for how IT should be approached and the dilemma that the top management will have to address:

1. The key to the successful utilization of IT is effective strategic thinking. Without an appropriate strategic perspective and robust conceptual models, it will be difficult to identify an appropriate role for IT.
2. The chief strategic architect must understand the strategic nature and potential of IT and specifically manage its evolution.
3. Various uses of IT may require major reorganization at the level of the work group, the department and perhaps the whole organization.
4. Applications of IT that alter the firm's core technology, and which are therefore closely related to its culture, may be fiercely resisted.
5. Managing the IT function has become increasingly difficult as a result of these considerations.

The critical element according to Gerstein (1987) is that it is neither the application area nor its underlying technology that makes IT strategically important. It is the specific role of a particular technology application to a given industry at a point in time that makes the difference.

Gerstein (1987) takes a more pessimistic view of the effective management of IT. He identified nine causes of failure to the successful strategic application of IT:

1. Reluctance to accept that IT can alter the economics, redefine the industry and change day-to-day life in the workplace.
2. Using conservative and prudent decision making based on historical evidence to evaluate an innovative use of new technology.
3. Believing that being a follower is safe.
4. Permitting high-level executives to resist change.
5. Believing that IT is difficult to manage.
6. Leaving the formulation of technology strategies to the technologists.
7. Underfunding technology development; relentlessly pushing for short-term earnings.
8. Settling for mediocre systems leadership.
9. Managing IT as a technical rather than a complex organizational change.

According to Eason (1988), the potential of IT in organizations is immense. It is important for senior management to be involved in the planning of an organization's IT applications strategies and policies for the reasons outlined below.

1. The strategic application of IT depends on conceiving ways in which technology can be harnessed to serve the organizational objectives which are set by senior management.
2. The application of IT can be used to strengthen the power of some sections of the organization against others. Therefore, the involvement of senior management will prevent the development of sectional interests.

3. IT involves data processing, text processing and telecommunications. This might involve three different departments within an organization. It is then the responsibility of the senior management to make the decision regarding the control of an integrated system.
4. The implementation of IT must be carefully monitored as it should take place simultaneously with major organizational changes, and the establishment of future forms of organizational structure and the management of the change process should be under the jurisdiction of senior management.

Eason (1988) also gave the following propositions which, in his opinion, will ensure the successful creation of IT systems. First, it will have to be known that IT technical design alone is not enough. Compatible social and technical systems should be created so that the systems can be effectively harnessed and exploited by the users and that they serve some important organizational purposes. To achieve this, the design process will require a planned change which creates the appropriate systems and creates in the users the willingness to exploit the technical capabilities. This will involve the participation of the stakeholders in the design process and an individual collective learning process. Both organizational and human change will have to go through evolutionary development so that decisions are made on the basis of mature reflection. Lastly, the concepts of the systems must complement the existing design procedures and organizational change practices.

The views of each of these three authors of how IT can strategically be used forms a useful basis for examining the construction sector. As an example of how strategic views of IT can change our thinking, we have applied Earl's (1989) nine propositions to our knowledge of the situation in the construction sector. The other two approaches (Gerstein, 1987; Eason, 1988) could equally have been used for this purpose.

What makes the IT era?

Earl (1989) refers to nine propositions that he believes distinguish the IT era and by examining these in turn we can comment on the extent to which they have been reached in construction.

IT: A high-expenditure activity

The proportion of revenue spent on IT can be used as a guide to the extent to which a sector is participating in the IT era. There are average levels for a sector or an industry as a whole, but Earl (1989) observes how enterprises that are industry leaders have a proportion of IT expenditure from revenue higher than the average. The figures he quotes for different industries range between 1 and 5% for industry averages and 2 and 7% for industry leaders. In the UK, the study by Peat Marwick McLintock (1990), in which samples of contractors and consultants were asked to state their IT expenditure, suggested a pattern of expenditure as in Table 1. This suggests median expenditures by consultants of about 1.5% and by industry leaders of less than 10%. For contractors, these figures may be closer to 0.25% and over 10% respectively. In Singapore, more than 75% of all types of construction firms spend less than 2%, with the mean being less than 1%. There is a large range between firms with less than 10% of the industry leaders in this regard spending more than 5% (Cheah and Tian, 1989).

On the basis of this analysis, it must be concluded that construction needs to invest more

Table 1. IT expenditure by UK consultants and contractors

% of fee income or turnover	% of consultants (105 respondents)	% of contractors (64 respondents)
Under 0.1%	10	25
0.11–0.25%	5	31
0.26–0.5%	11	20
0.51–1.0%	11	11
1.01–1.5%	11	5
1.51–3.0%	25	3
3.01–5.0%	18	2
5.01–10.0%	8	0
over 10%	0	5

Source: Peat Marwick McLintock (1990).

heavily in IT resources. Although some of the industry leaders appear to be investing sufficiently, the majority of firms make inadequate investments, which prevents them fully entering the IT era.

IT: Critical to many organizations

Some sectors such as financial services, particularly personal banking, are fast approaching the stage where IT is critical to the success of entire organizations. Others have IT playing a much more supportive role to their activities. McFarlan and McKenny (1983) suggest a strategic grid, as shown in Fig. 1. IT is a support activity if it is not critical to either the current operations of an organization or to the strategic plans for the development of that organization. At the other extreme, an organization could be said to be using IT strategically if it is critical to both its current operations but also to its future plans for strategic development. Figure 1 also gives examples of some different types of enterprises that may currently be placed in different segments of this grid.

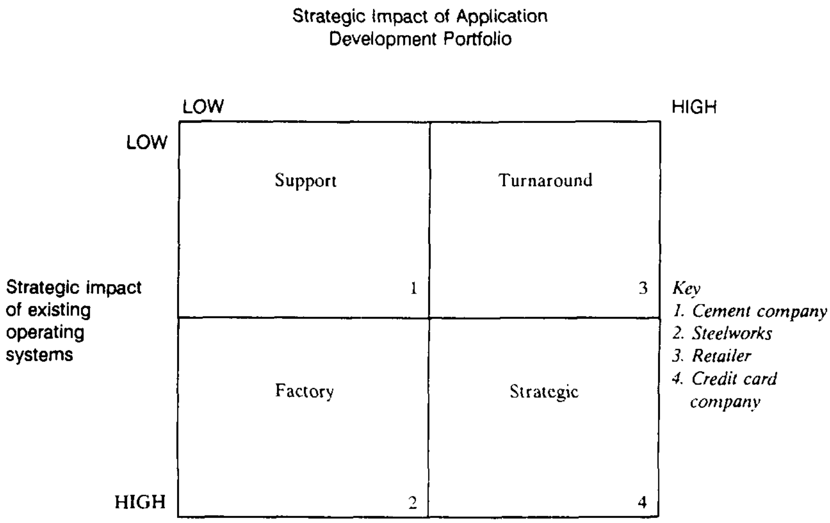

Fig. 1. IT: Critically strategic.

In thinking about where construction organizations fit on to this grid, we must distinguish between different types. The construction sector within an economy is made up of a number of different overlapping industries which comprise a large number of different enterprises. Some enterprises are large, but most are small/medium-sized enterprises (SME). Some enterprises have loose or formal associations between them and form working relationships between each other when they combine on projects. Individuals working for enterprises may be grouped into professions, which may have a strong influence over current and future procedures and activities.

Several studies have outlined the benefits which firms in the construction sector could derive from the effective use of IT. Brochner (1990) suggests that the use of IT by a construction firm leads to improvements in co-ordination, inspection and translation, enabling the organization to offer greater employee incentives and reduce transaction costs. Firms using IT could expand and diversify their activities in several different ways, leading to changes in the structure of the industry. However, for the vast majority of construction enterprises, one can only conclude that IT is a support activity. The impact of IT on existing organizations has been shown to be small by different studies (Chow, 1989; Peat Marwick McLintock, 1990).

There are isolated examples of some construction sector organizations making IT a critical part of their strategic development plans, if not of their current operations. Koskela (1985) describes the detailed plans of a number of Japanese contracting firms who are clearly planning to exploit the full range of IT, including data processing, telecommunications and automation technologies. It could also be argued that the professional institution representing surveyors in the UK, the Royal Institution of Chartered Surveyors (RICS), is aiming to exploit IT strategically, albeit in a less extensive way. Their initiative in participating in the Alvey research programme (Brandon *et al.*, 1989) to create new strategic opportunities for their members suggests that they may be making IT critical to their future plans, even though it may only have a minor impact on their current operations.

From both of these examples, it could therefore be argued that some construction organizations have reached the turnaround stage in their progression through the strategic grid and that as time passes these and other construction organizations may find themselves firmly in the strategic quadrant of IT use. For the construction sector generally, it must be concluded that IT is still being used mainly in a supportive capacity and that it is far from being critical of the operations of the majority of its organizations.

IT: A strategic weapon

It can be argued that IT offers new opportunities as a strategic weapon to (1) gain competitive advantage, (2) improve productivity and performance, (3) enable new ways of managing and organizing and (4) develop new businesses. The way in which strategy can be implemented can also be achieved in different ways according to the combination of business strategy and application orientation (Lim, 1990). Figure 2 illustrates how this combination can lead to IT being used strategically to improve internal productivity, external productivity, internal competitiveness and external competitiveness.

The following examples from Lim (1990) show how each of these strategies has been followed in other sectors. The Ford Motor Company and its process of supplying parts to dealers and wholesalers offers an example of the use of IT to achieve internal productivity. An IT-based distribution, storage and stock management system has been implemented, which

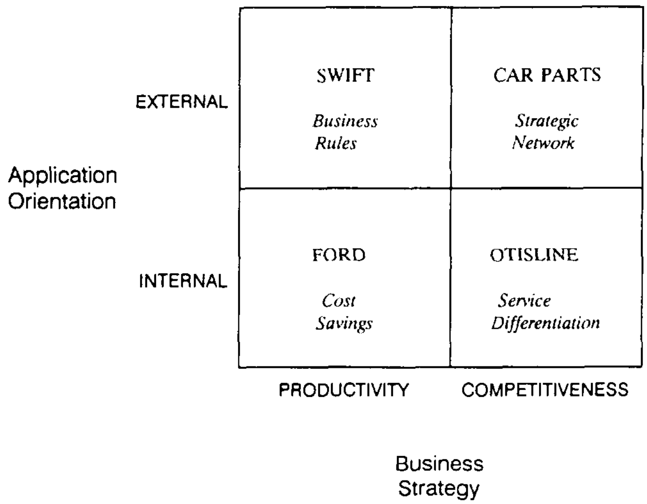

Fig. 2. Application strategy (after Lim, 1990).

has led to major increases in the productivity of the organization itself. The Society for Worldwide Interbank Financial Telecommunication (SWIFT) is an international financial network for the exchange of financial messages between different organizations throughout North America, Japan, Southeast Asia, Latin America and Western Europe. It is an inter-organizational system which has become the industry norm and which all new enterprises must participate in if they wish to survive. It improves the productivity of all organizations externally. OTIS is a major enterprise in lift and escalator installation and operation. In such a business, much competition between enterprises is based on the speed and efficiency with which maintenance can be performed. OTISLINE is an example of how an enterprise has strategically used IT to create an internal competitive advantage over other enterprises. The system helps in allowing a highly efficient maintenance service with faster and better performance than competitors. The example of the strategic use of IT for external competitiveness is particularly relevant because it comes from what (like construction) is considered to be a low-technology industry. Selling used-car parts would seem to offer few opportunities for strategic IT use. However, a group of geographically dispersed non-competing suppliers in the USA has combined to use an IT network to enable each of their stocks of parts to be considered as a larger pool from which orders and distribution to customers are possible. Each individual supplier is, as a result, able to offer better customer services and redefine the boundaries of the company's area of operations.

Most construction enterprises seem only to be examining IT as a means of improving internal productivity. Governments, professional institutions and groups of enterprises may have more opportunities to examine external productivity. RICS provides a further example of how this can be done in the form of the Building Cost Information Service. This system is a central database of price information supplied by subscribing members who are all able to exploit the shared data to improve their individual productivity. The external productivity of all surveying enterprises is thereby improved and it could be argued that the better quality of data also improves their competitiveness. The Royal Institution of British Architects (RIBA) is offering a similar form of use of IT through the RIBACAD system (Ray-Jones, 1990) library of standard architectural details. This has obvious benefits to external productivity but does not improve external competitiveness.

There are many isolated and individual examples of enterprises and projects where IT is being used for small improvements in internal productivity. Where construction organizations appear to be failing to exploit IT strategically is for their internal or external competitiveness. Few appear to be able to offer a new or improved service by virtue of their IT use and even fewer to consider new ways of managing and organizing themselves or to develop new businesses. From this it can be concluded that on the basis of IT being a strategic weapon, the construction sector falls short of having fully arrived in the IT era.

IT: Needed in our economic context

The sectors where IT appears to have made most dramatic impact are where other major forces for change also exist. Some examples of these are quoted (Earl, 1989) at both the macro and the micro levels. At the macro level, for example, the deregulation of airline and financial services, the need for global survival in automobile manufacture and textiles, and the structural changes that are affecting retailing are all quoted as forces which are leading some organizations in some sectors in some countries to use IT as a strategic response.

In construction, the emerging economic context is also dynamic, such that the strategic exploitation of IT may be appropriate. This lack of stability is evident at the organizational, national and international levels. Organizationally, there have been sufficient criticisms of industry practice (Higgin and Jessop, 1975; RICS, 1979; Construction Industry Development Board, 1988) and responses suggested (British Property Federation, 1983) that structural change within industries of a fundamental nature may be imminent. As clients' demands for quality and convenience continue to increase, an industry which has traditionally been conservative is realizing the need for innovation in many respects. The possibility of this happening has been discussed by many commentators and by the industry itself (Ball, 1988; Centre for Strategic Studies, 1988; Chow, 1990). IT may be an important strategic tool by which organizations can respond to such changes.

Nationally, the construction industries of different countries are constantly moving through different stages of development and maturity that reflect the economies of which they are a part. In Singapore, the domestic industry has proved very successful in rapidly providing mass public housing for a large proportion of its population, infrastructural works and a modern business city. Having done so, the excess capacity that now exists is having to be rapidly reorientated to the maintenance and retrofitting sectors and to construction exports.

The economic context at the international level is similarly dynamic, particularly with the coming of the common Western European market and the general internationalization of construction. The trends in these fields are giving great impetus to construction firms to seek ways and means of improving their productivity and competitiveness and to develop new businesses. The international dimension will be an important force behind IT applications in construction (Hasegawa, 1988).

The economic context of construction is thus highly volatile and this is an attractive situation for the potential strategic use of IT. Many procedural changes are likely that will be able to be designed with IT in mind, new markets and business opportunities are going to be encouraged and IT could play an important part in the securing of these. On the basis of this proposition, then, construction appears well placed to enter the IT era.

IT: Affects all functions and levels of management

A further symptom of an organization having entered the IT era is stated as the technology having permeated all functions and levels within an organization. Early uses of DP were restricted to distinct DP departments and for specific number-crunching applications. Organizations that have more fully embraced IT are now in a situation of having a range of hardware and software technologies being used by a diverse range of groups of people and for a variety of different tasks and activities.

In construction this is far from the case. The majority of construction organizations still appear to have IT being used by IT specialists or for discrete applications and it would seem only by staff at the technical levels. This situation has been borne out by the different studies referred to earlier (Chow, 1989; Peat Marwick McLintock, 1990). Both observed that IT is still restricted to administrative functions of an accounting nature or for highly specific and technical functions within the construction disciplines.

On this basis, it must be concluded that the construction sector is a long way from having entered the IT era and that a significant change is needed in the variety of levels of management that are using the technology and the diversity of functions to which it is being applied. For this to be possible will require all construction organizations to reconsider their size, organizational structure, recruitment policy and their education and training activities in the light of their requirements in the IT era.

IT: A revolution in management information systems

IT is embracing a range of technologies that are being applied to a range of existing and new techniques and processes. A sector could be described as more fully having entered the IT era if it is exploiting a range of technologies for a range of existing and new applications. The examples of soft technologies quoted by Earl (1989) include expert systems and decision support systems and of hard technologies, teleconferencing and executive management information systems.

Knowledge-based (expert) systems technology has been successfully applied in many application areas such as diagnostic work, but has not been sufficiently developed to be able to represent and dynamically manipulate knowledge about spatial objects that are temporal in nature as is the case with built-forms. The construction knowledge domain is also very large, complex and tends to evolve during a construction project. There is also a need to include existing, incompatible systems, which requires the integration of conventional databases and applications software with knowledge-based reasoning (Howard *et al.*, 1989).

In this regard, there appears to be an implementation gap. There are many new initiatives and completed research projects that have led to the development of expert systems and other information systems tools for construction which have not been applied or incorporated into industry practice. Part of the reason for this must be the inability of construction organizations to be sufficiently flexible and far-sighted in their willingness to embrace technological improvement. A change of attitude by construction organizations would appear to be necessary.

IT: Involves many stakeholders

Earl (1989) refers to seven different categories of stakeholders in IT. These are (1) government through regulations and policies, (2) business users through their information needs and standards they demand, (3) IT manufacturers through their technology and standards they set, (4) customers and suppliers through networking and integrating arrangements, (5) consumers through their expectations and behaviour, (6) competitors through their use of new products in new markets and new businesses and (7) employers through any union agreements and their job satisfaction. Construction organizations are in many ways more diverse and complex in their range and interrelationships. A picture of the relationship between IT stakeholders for the construction sector may look more like that in Fig. 3.

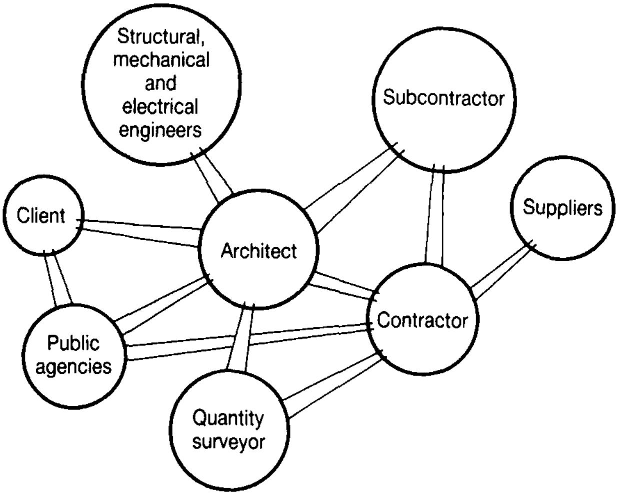

Fig. 3. Construction IT stakeholders.

A consideration of IT stakeholders is important for two reasons. The diversity of stakeholders that are involved with IT in a sector may indicate how well the IT era has been embraced but could equally be seen as an obstacle for more extensive IT use not having been achieved. Stakeholders are also important to IT government planning. A sector may enter the IT era either through its own commercial pressures, because of the planning and direction of the industry itself or through direction of economic policy makers and implementors. Central planning and direction may sometimes be necessary as an extra push to support the movements taking place in an industry or could be used to speed up the process. This is particularly important in construction where the diversity and complexity of stakeholders is such that this may in itself restrict the extent to which strategic use is made of IT. If central planning and direction is to be followed, it is important that all stakeholders are considered by implementation plans and even that they are involved and consulted during the process of drawing up plans.

IT: Technology matters do matter

It is easy to get carried away with technological developments and always assume that the next stage of technological improvement will remove all of the inadequacies of the current stage. It is also tempting currently to assume that incompatibility problems between parts of an industry will be overcome as technology improves, although in construction the extent of this problem could be very significant (Peat Marwick McLintock, 1990). The other factor with regard to technology is that, ultimately, for a sector to enter the IT era, the right sort of technology must be owned by a sufficiently large number of the organizations that participate in it. There are signs that in construction this is beginning to happen (Chow, 1989).

There is a general problem here that construction organizations need to embrace all types of technology more fully to retain their competitive positions. This point is illustrated by Tatum (1988) in relation to US contractors exploiting technology to retain competitiveness with regard to Japanese competitors.

IT: Management makes the difference

The final proposition for the IT era is perhaps the most important of all and also the most likely reason for us concluding that construction has not yet fully embraced it. IT continues to be thought of as a technological issue to be handled by technologists. One of the most important ways in which IT differs from DP is in its need to be managed.

A report by Kearney (1984), a member of a firm of management consultants, identified the most important management factors as top management support, degree of IT awareness by management, level of IT investment and degree of Board level IT direction. It concluded that it was factors such as these that distinguished the leaders in successful strategic IT exploitation from the rest.

In construction organizations, because of the predominance of SMEs, because of the poor management skills found generally in the industry and because IT continues to be treated as a technological issue, the strategic exploitation of IT has been much less successful. The remedy may lie more in improvements in the education of managers rather than the employment and training of technologists.

Problems of IT implementation in construction

The propositions outlined above can be taken as the principal ways in which the IT era can be distinguished from the DP era. However, it is necessary to consider the issue in greater detail and to identify what would be required to ensure further movement from one to the other. Before doing this, it is pertinent to review the current problem of IT implementation in the construction sector by considering the design and construction stages of a typical project.

The most important issue in the implementation of IT, which distinguishes construction from other sectors, is the integration problem, i.e. how to exchange information among different designers and also between designers, clients and contractors. This problem has been the subject of study of national level projects in Finland (Bjork, 1985) and other Nordic countries, but is far from being resolved. A relatively easy approach to solving this problem would be for all participants to use the same information systems and share their central database. It is also now becoming technically feasible to exchange data between dissimilar systems, and therefore the use of the same information system is not imperative, though it is desirable.

Information used at the design stage is diverse and includes details of the emerging design of a building. To illustrate the obstacles to the strategic use of IT and the limitations of current approaches, the emerging design is used as an example. The discussion of the construction stage concentrates on the integration problem as well as the impact of various forms of IT application.

Design

Architectural design is very much an intuitive activity with the creative abilities of the architect playing an important part. The architect needs to confer with the client, engineers, contractors and maintenance managers. These communications, which should take place frequently, are at present limited to a few meetings to resolve major design or construction problems, and rarely to discuss perceived maintenance problems. The proponents of the current CAD-systems believe that the use of CAD will resolve these problems, indeed assuming that the integration problem addressed above can also be resolved satisfactorily.

The current CAD-systems are design aids which allow predefined components or parts to be assembled, in two or three dimensions. As such, these are well-suited for engineering design activities such as electrical circuits (assembly of transistors, resistors, capacitors, etc.) or mechanical systems (assembly of gears, rack and pinion, pistons, etc.). The only components in building design that have some standard sizes are doors and windows and, to some extent, panels for external cladding and internal partitions. Architectural design is not, and will not be in the immediate future, a process of assembly of parts. An architect, and other members of the design team, views a building as a three-dimensional object, a spatial concept; however, a builder perceives it as an assemblage of walls, beams, floors, and so on. The current CAD-systems are therefore not suited to the early, sketch design stage, a stage where most strategic design decisions – possibly leading to as much as 80% of the total cost commitment on the project – are made. Current CAD-systems are mainly useful as drafting tools, at the detailed design stage, for generating production information or working drawings. The upper-end of CAD-systems (based on mini-computers) are also useful for visualization, i.e. viewing the building outline in three dimensions mainly for aesthetic appraisal done by architects at the early design stage. Considering the capital investment, not many architectural firms can afford this facility.

The drawings, produced manually or on a CAD-system, are used exactly in the same form in later stages. CAD-systems used in engineering design are different: information from a CAD data file can be fed into a Numerical-Control machine for production operations. The use of a CAD-system does not, at the present time, provide any benefits at later stages in the construction process. It only provides savings in drafting manpower. Architects' offices, in many countries around the world, have recognized this. Indeed, drawings are far more portable on computer diskettes than on standard blueprints. With electronic data interchange (EDI), even the exchange of disks will not be necessary; files can be transferred over telephone lines from one office to another. It must again be noted that we are simply talking about transporting drawings from the architect to, say, the structural engineer, or to the government agency responsible for building control, the Building Control Division (BCD), for approval. This will no doubt speed up the process of transporting files, but the use of CAD-systems neither speeds up the structural engineer's work (unless the CAD-data file can be read directly into structural analysis programs – 'integration problem') nor the BCD's work (unless the BCD have programs for automatic checking of drawings, which requires design intelligence). The structural engineer has to generate the data needed for analysis and design, and feed this into the computer. It should be noted that if changes were made to drawings at this stage, the engineer would have to go through the same tedious process once again. The drawings are also subject to the engineer's (mis)-interpretation.

The above example illustrates quite clearly the problems in using current CAD-systems. If we consider the other design aspects – the mechanical and electrical system, and so on – the current use of IT in construction is only the tip of the iceberg. We must also remember that information about the emerging design is only one part of the information used by the design team overall, and therefore only one part of the overall scope for IT application.

Construction

At the construction stage, there are again many enterprises involved who may potentially use IT for a wide range of activities. One of these activities is the translation of the design into a constructed building, and to follow our example through we can examine the problem of implementing a design at the construction stage.

The final working drawings and corresponding specifications for materials and components are given to the main contractor for construction on-site. This information, be it on computer diskettes or on paper, is still subject to the contractor's own interpretation, which, all too often, becomes misinterpretation. Two of the main activities of construction operations – project activity planning and resource planning – do not fully benefit from current IT tools. The scheduling of construction activities can be done using advanced software known as project management systems, widely available for use on PCs. The information needed for this has to be generated from drawings. Once again the data in a CAD-file is of no use. This, however, does not diminish the merits of project management software as stand-alone systems and the benefits they provide in planning and controlling construction activities. None the less, IT has yet to solve the communication gap between designers and contractors.

Cashflow planning, progress payments and claims, payrolls, accounting and all matters related to money transactions put a heavy burden on the contractor's offices. Excellent proprietary programs are available for all aspects of the contractor's office management, some of which even claim to integrate these with project planning. A number of these tasks can also be carried out using general productivity tools such as database management systems and spreadsheet programs. Project management systems have the ability to do basic resource planning, and the office management programs are now available in very much integrated forms. However, all of these systems are really only productivity tools that can only be used to improve the internal productivity of an organization rather than strategically affecting competitiveness.

The variety and sophistication of software available for the post-tender stages of construction projects makes one wonder about the possible reasons for contracting firms not using this technology. Indeed, the variety may cause selection problems and, in order to use sophisticated software, contractors may require training and other support services from vendors. But the real problems lie with the nature of the contracting process itself. The large number of subcontractors working for the main contractor would require that all of them either use the same project management system, or use systems which can communicate with one another. This is a far cry from the factory production of engineering artefacts which are on an assembly line, where every operation can be controlled. It would require a highly interactive system operating all contractors' and subcontractors' resource and activity planning programs in a network. This may be technically feasible, but will it ever be a reality?

This again illustrates the specific integration problem faced in construction and the difficulty we have in strategically using IT.

Other prerequisites

Considering the difficulties discussed above and the fact that each construction project is unique, in the near future IT is likely to remain a supportive (and not critical) technology, it will be used for small productivity gains (and not for strategic advantage over competitors), it will be used for low-level activities (and not by higher management) and it will not be used by all participants and stakeholders in the construction process. To move well beyond the DP era and harness the critical and strategic advantages of IT would require a tremendous amount of inertia to be overcome because all participants work interdependently and many interactively and recursively (Higgin and Jessop, 1975).

For example, during the pre-tender stage, the architect, engineers, client and cost advisers share and exchange information and data which evolves as design progresses. Unless the IT tools used by these participants can communicate and interact with each other, one cannot expect any single party to independently invest in IT which cannot provide benefits beyond small productivity gains, unless other parties do likewise. There are other problems to be resolved apart from the compatibility and communication among dissimilar systems. The current tools and procedures were developed to exchange 'data' among the participants and not necessarily 'useful information'. Thus, they require further development to be suitable for use in construction, especially during the early stages of the design process. The construction industry is very different from other sectors and the approach to, and the tools for, IT application will have to be carefully planned and developed. The fragmented nature of the industry and that of the entire decision-making process is the root cause of the lack of productivity and competitiveness, and its impact on the US industry, for example, is described by Howard *et al.* (1989). Technology, in particular IT, may provide the necessary competitive advantages and change the structure of the profession. The basis of competition is shifting to a greater emphasis on technology, but construction enterprises need new strategies to compete (Tatum, 1988). Design decision-making requires a holistic approach, one where the interdependencies among sub-systems are analysed and resolved at the global (building systems) level without which the solution may not be the best for the client's investment. Only the new technologies using database management systems, computer graphics and vision, and knowledge-based (expert) systems have the potential to make it possible for consultants to share and exchange the information and knowledge effectively without personal meetings and without losing protected information. None the less, new attitudes to professionalism will be as much needed as the new technologies.

To obtain a strategic advantage of IT, one must reconsider traditional roles and hierarchies in the decision-making process. The construction industry operates such that each person has domains of expertise and these boundaries are rarely crossed. The decisions are rigidly taken as architectural, mechanical, electrical, cost, and so on. The decisions regarding the space, structure, services, cost, etc., are highly interactive; the change of one affects many others. The information and knowledge about the various aspects of design must therefore be shared by all decision makers. For reasons of practical difficulties of so many professional consultants meeting regularly, face to face, and perhaps of professional jealousies and protectionism, the various professions have accepted these rigid domains and limited information communication. One possible response to this may be that multidisciplinary enterprises or design-and-build contractors, who are able to internalize the integration problem, may be in a better position to exploit IT for strategic purposes (Brochner, 1990).

Current and future strategies by construction organizations

Within organizations

It seems, then, that IT is being applied by individual participants in the interests of their short-term gains or cost savings. Little attention has been paid to the overall interests of the client, let alone to the wider environmental, social or cultural context and implications. IT must be exploited and applied to cover these wider issues and in the interests of all the stakeholders, diverse as they may be. All construction organizations, from individual enterprises to professional institutions and trade associations and ultimately to national policy makers, must act to overcome these specific difficulties in construction if IT use is to become more strategic.

The professional bodies and government agencies may have important roles to play in different environments – from co-ordination to developing and maintaining data and information bases for their members. This would avoid the duplication of work and also help small to medium-sized enterprises who cannot see any justification for spending money on large databases in isolation.

External influences

All types of organizations need also to see IT become critical to their current and future activities. This can be enforced by a central agency making IT necessary to certain key activities where construction organizations interface with them. In the UK, in order to ensure that the newly introduced co-ordinated project information system is adopted by the industry, all organizations working on projects commissioned by the Property Services Agency, which is a major and critical source of public projects, are required to follow the procedures and documentation recommended by the Co-ordinating Committee for Project Information (1987). This could easily be extended to embrace IT applications of co-ordinated project information. In Singapore, the Construction Industry Development Board envisages making the submission of tenders for public sector projects in magnetic form mandatory as one of the means of making IT critical. Such approaches by a central agency may have a role in different economies, although the sort of IT use they encourage may not always be the best in the longer term.

A recently developed commercial product by an Australian software supplier called CLIENT, is designed to provide total project information management by acting as a central monitor of the status of information production and circulation between all members of the project team. As many as eight individual organizations including the architect, engineer, quantity surveyor, builder and subcontractors are required to have a dedicated terminal and modem link. All communications regarding the status of the project during its design and construction are to be made through the system and to be monitored by the client or their project manager. The terminals, modems and software used by the client and all of the participants are paid for by the client and treated as a project overhead. The system is being marketed not to architects, engineers and builders, but to clients themselves. Clients choosing to use the system are then stipulating that use of the software is compulsory to all other organizations when engagement terms are discussed. This is an example of individual private sector organizations making IT critical to the current and future activities of other enterprises.

Alternative approaches in various countries

In order to harness the strategic advantage that IT use would provide, an effort will be necessary appropriate to the local circumstances. One such approach would be for a government-led, industry-wide effort. At this level, information is being shared and communicated extensively, across professional boundaries and throughout the construction process. The strategic effect of such an effort is likely to be improvements in the external competitiveness of the industry as a whole. This is the most beneficial and broadest level at which IT strategy can be applied. Any IT development at this level would require the understanding, participation and support of all professions, enterprises and government agencies concerned. However, such a national industry-wide approach has not yet been effected in any country. A major study has been undertaken in Singapore and many of the recommendations in that report (Betts *et al.*, 1989) may apply to other developed economies and newly industrialized countries.

The approach that appears to be being followed in the UK is for strategic steps to be taken by individual professional bodies. At this level, information is being shared and systems are being developed for all subscribing members of a professional body for their individual benefit. Strategically, this is leading to improvements in the productivity of the professions but is not addressing the issue of their external competitiveness.

The Japanese approach is for strategy to be the responsibility of construction enterprises. The leading organizations have developed their activities to embrace all stages of the design and construction process, thereby internalizing the integration problem. Strategically, this is leading to improvements in the productivity and internal competitiveness of the enterprises and because of their size and strength this effectively means the external competitiveness of the industry is also improved.

In Singapore, as in many other newly industrializing and developing countries, the weakness of the professional institutions and the small size of corporate enterprises combined with the strength of the central agencies make a nationwide initiative more appropriate. In the UK, the professional demarcations are much stronger and the bodies themselves are more active. In Japan, the corporate culture makes strategic initiatives by enterprises the only feasible alternative. Each of these alternatives have implications for the form and impact that IT strategy takes and makes.

The current use of IT in construction in Singapore

Appropriateness of Singapore as an example

Singapore as a nation has already recognized the beginning of the IT era. The National IT Plan (NITP) which was launched in 1986 provides a blueprint for an action programme that calls for the exploitation of IT to develop a strong export-oriented industry. The NITP has seven interactive building blocks, namely IT Industry, IT Manpower, Information Communication Infrastructure, IT Application, Co-ordination and Collaboration, IT Culture, and Climate for Creativity and Enterprise.

EDI has become a reality with the start of TradeNet, a nationwide network for the commerce sector, in January 1989. A similar network for the health care industry, MediNet, has been developed. Other EDI networks are also being developed for the legal and financial services sectors. A civil service electronic network is at an advanced stage. While the use of EDI in construction is currently lagging behind many other sectors, the potential is considerable. The government's initiative in the develoment of the Singapore Land Data Sharing Network (SLDSN) is a step in the right direction. This will support a full range of land management solutions rather than simply automating maps. SLDSN is a good example of co-ordination and communication among three government ministries and information systems (hubs): the Ministry of Law and the Land Hub, the Ministry of Home Affairs and the People Hub, and the Ministry of Trade and Industry and the Establishment Hub.

The construction sector is taking up the challenge to work towards the success of the NITP and how the strategies proposed under the NITP can be adopted for the construction industry. Impressive individual developments in this regard include work carried out in CAD data exchange by Gruman International/Nanyang Technological Institute Centre (GINTIC), the Public Works Department's Project Management Information System, the more recent developments of BuildNet as a construction EDI network by the Construction Industry Development Board, and of the Design Support Centre as a national graphics database by the Singapore Institute of Architects. The present authors have contributed to these efforts through the development of a strategic framework for national construction IT developments (Betts *et al.*, 1989).

An excellent information communication infrastructure already exists in Singapore. IT is almost a culture within an industrial climate that is conducive to creativity and enterprise. Private companies with experience and expertise in implementing industry-wide networks are now established. In many respects, Singapore is not far behind most other developed countries in this area. It is at least level with most of the competition. Furthermore, Singapore aspires to more than just maintaining the position of others, but aims to be a highly developed and advanced economy throughout all sectors including construction. With the highly advanced state of infrastructure, training and control, Singapore is possibly in a unique position to take the lead in the strategic use of IT in all sectors of the economy, including construction. In addition, construction industry initiatives have been successful in their own right in being valuable developments to solve individual problems. However, it could be argued that the fact that they have been individual initiatives that have taken place outside of any national framework or IT plan for construction may lead to problems in the future. Such an issue is certainly being considered by construction IT strategists. There may be a problem in that all of these systems may fail to link together effectively. Any co-ordinated development of IT applications for the construction industry therefore requires a framework which takes into account the needs of the industry and its principal weakness, i.e. its fragmented character.

The framework

Participants in the construction process generate and use information which is specific to the project at hand, or obtained from the enterprises they are associated with, or available in the public domain to the industry at large. As a project develops, the information base grows very quickly. Each enterprise participating in the project depends on a large information base which it has developed over a period of time through its involvement in other similar projects. Public and private agencies and enterprises which support the industry such as material manufacturers and suppliers, the planning authority and professional institutions, provide information to the participants. Thus, within construction there are conceptually and in practice three distinct information systems. The Project Information System (PIS) is used during the planning, design and production phases, and (should be) retained throughout the life of the building. Information is drawn from an Enterprise Information System (EIS) and an Industry Information System (IIS) to develop the PIS. Thus EIS and IIS could be considered to be general information systems supporting the development of the project-specific PIS. As several enterprises participate in a construction project, the PIS has to communicate with several EIS's. Because, at present, the IIS does not necessarily have to be a unified source of information, the PIS may have to communicate with several sources of information which, in our conceptual model, represents the IIS.

Figure 4 shows the way in which these three information systems can conceptually combine within a single integrated national IT framework. It also shows the channels of communication among the PIS, EIS and IIS. All enterprises participating in a particular project have direct on-line access to the PIS. The PIS is shown as a separate system outside all other EIS's because it is not the property of any one enterprise. Traditionally, the architect's enterprise maintains the PIS but within an electronic data environment it will simultaneously reside with all participating enterprises. Indeed, it may be necessary for a new breed of construction professional called the 'database administrator' to take on the development and maintenance of the PIS. Any changes made to the project design or additional information produced will immediately be registered in the files of the PIS held by other enterprises. The PIS is conceptually shown as an independent system with which all enterprises interact. Enterprises do not normally communicate with each other except in the context of a specific project. Communication between two enterprises is therefore shown via the PIS. Enterprises may also communicate with each other directly during a project but this would lead to the PIS being amended. The PIS therefore results in greater interaction among two or more enterprises.

This framework has been presented to leading members of the Singapore construction industry representing public and private sectors and all relevant professional bodies. A broad consensus supporting such a national plan has been obtained. Singapore thus has a blueprint for strategically exploiting IT in construction as a nation. Full details of the framework are given elsewhere (Betts *et al.*, 1989).

The work in strategic planning for IT does not finish with such a framework but it could be argued that it cannot start without it. Implementation of such a framework should progress with the advancement of existing network systems and the launch of new databases. All such efforts should be made with reference to the national framework, the details of which should be further developed and defined through continuing industry-supported research.

Conclusions

From the analysis in this paper, it cannot be argued that the construction sector has entered the IT era. However, it is possible to see that by a number of criteria, this situation may

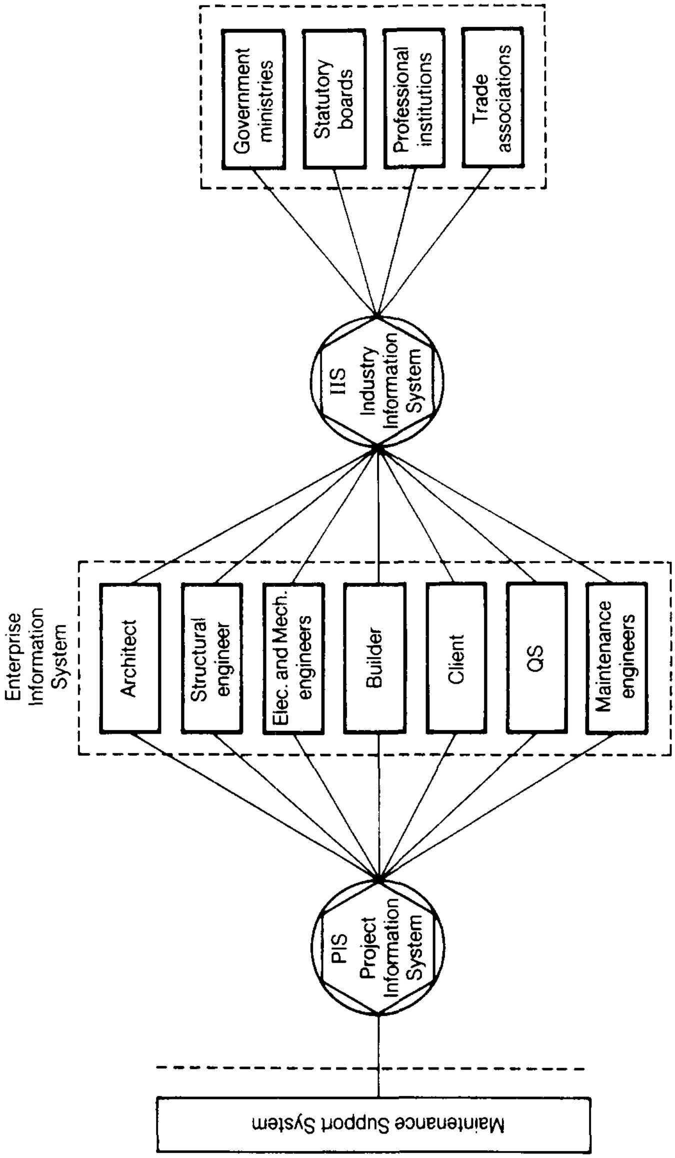

Fig. 4. An IT framework for the construction industry.

change in the future. It can be seen how some individual developments that have taken place in different parts of the world show some isolated progress towards the IT era. It is also possible to identify what change is necessary to bring the IT era closer on a broader front. This may happen through commercial pressures or through the industry itself recognizing the need for change. In some economies, it may be necessary or desirable for this process to be helped or speeded up by some form of central direction or control. The form that such direction should take can be concluded from the analysis that has been made.

There are many limitations with the current use of IT in construction. The tools that have been developed are stand-alone programs, many of which were originally intended for the engineering design/production process. Few of the tools pay due regard to the nature of the construction process and the alternative form of design approach and construction technology. Most IT products have been developed as commercial ventures for an industry that is fragmented into tightly defined roles and with short time horizons. For these and other reasons, there are few, if any, examples of the strategic use of IT at present. The implementation of the new IT, particularly those based on CAD, knowledge-based systems and robotics, will be a difficult task, because the management and dissemination of this technology in a fragmented industry requires careful and strategic planning at the industry and professional levels. The issues are not just of implementing IT as productivity tools in individual organizations and on specific tasks. For strategic competitive advantage, IT has to provide an 'environment' in which the computer functions as an intelligent tool for communication, co-ordination, book-keeping, problem solving, automation and decision making.

For IT to become a strategic weapon for construction organizations, the various enterprises and agencies should do more than only consider its contribution to internal productivity. Internal and external competitiveness will be important strategies and the role of research and development by the enterprises themselves, or through their trade associations or professional institutions, is important. Central agencies may offer financial or other incentives to such research or initiate pump-priming projects of their own.

It is essential for all levels and functions of management to embrace IT. The professional institutions may influence this issue by identifying IT awareness and management skills as an important component of continuing professional development programmes. Educational institutions must ensure that relevant courses are provided for both professional updating and for initial graduate education.

The great diversity of stakeholders in construction, many of whom do not see beyond short-term gains, is such that advancing the strategic use of IT is a difficult management problem. Alternative catalysts and primary movers are possible depending upon the local environment. The effective co-ordination of the very wide range of organizations and activities which will be necessary will require strategic frameworks and detailed tactical planning by a central agency. Such an agency will also need to consider the problems of technological matters.

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