The JCT Povey Lecture

Design, Procurement and IT:
Rolling back the frontiers of construction management?

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Introduction

On Wednesday 12 October 2005 the JCT Povey Lecture was given by Professor Peter Brandon, Director of Strategic Programme for the School of Construction and Property Management at the University of Salford and Vice-Chairman of the RICS Research Foundation. His lecture, entitled, 'Design, Procurement and IT: Rolling back the frontiers of construction management?' was presented at the Jarvis Hall, Royal Institute of British Architects, London.

The JCT Povey Lecture is an annual event at which an eminent person is invited to give his/her thoughts on significant matters that are relevant to the construction and property industry.

The JCT Povey Lecture was inaugurated in 2003 as a public acknowledgement and tribute to Philip Povey who served the Joint Contracts Tribunal for over 50 years.

Biographical Details

Philip John Povey – Barrister – commenced in construction as a legal adviser to the NFBTE, now the Construction Confederation, in 1951. At the same time he began to assist the Joint Secretaries of the Joint Contracts Tribunal (the JCT).

Philip first became Director of Legal Services at the Confederation and then its Director General. He later became the first Secretary-General of the restructured Joint Contracts Tribunal Limited in 1998.

Philip's work for the JCT became well known through the publication of JCT Standard Forms of Contract, which in time found their way to many parts of the world. He had a keen mind, which steered him around what he viewed as the less important or parochial issues for which the industry seems to have a particular attraction and enabled him to get to the core of a problem and to resolve it. He was an extremely skilful draftsman who invariably managed to satisfy the demands of many disparate, often competing, bodies.

Although there were committees, working parties and individuals that provided valuable input, it was Philip who shouldered the burden of writing the text.

He retired from the JCT at the end of 1999 but died suddenly only 18 months later, in 2001.

Design, Procurement and IT: Rolling back the frontiers of construction management?

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Introduction

More than any other topic, the nature of procurement has become the focus of attention in the UK and in a growing number of other countries. It has appeared to dominate industry agendas for research and innovation and it is at the heart of the Latham report on ‘Constructing the Team’ (Latham, 1994) and in the Egan Report (Egan, 1998) the concern has been the fragmentation of the design and construction team, the creation of silos of information and knowledge (which are often defended by the designated professional institutions) and the creation of an adversarial environment which is harmful to the process of achieving the desired objectives of the project. The increasing complexity of large scale buildings has meant that complex contracts have been devised to make sure a multitude of actors in the process know where they stand in terms of liability, and a blame culture has developed. Partnering, alliancing and other methods have been devised to try and overcome these problems. While these relatively new approaches seem to have some advantages, other approaches to major advances in design and procurement appears to have been missed.

For example, whilst recognising these difficulties, the potential use of technology to aid the solution to the problem has been sidelined and the advances seen in other industries have not been seen in construction. All sorts of reasons have been given for this including the ‘special nature and uniqueness’ of construction, the nature of the workforce and the high capital investment required. However, it is not clear that any of these reasons are valid or would have been tolerated in other industries. Yes, there are some things that are different, but are these fatal to revolutionising the industry?

The management issue

The answer to improving performance has been seen as largely a need to improve management. In practice this has tended to mean that what we need is more of it! To manage is defined as ‘*to exert and control the use of*’ or *‘to contrive or arrange, succeed or accomplish, especially with difficulty’*. The result of the ‘more is beautiful’ approach has been the creation of an exotic labyrinth of regulations, contracts, policies, insurances and management tools which are all used by managers to accomplish what they are expected to achieve. Much of the energy of the management activity is spent dealing with the interfaces between disciplines and specialists and making sure that accountability is foremost in everyone’s mind. Whilst this has some plus sides it also has the negative impact of people fighting their own corner and increasing their own management personnel in order to make sure that the rules and regulations are covered. Managers beget managers! This in turn leads to fossilisation of the process and it is only the enlightened few, who may hold special positions of power, who are able and willing to persevere, break out from the impasse, reflect, and really examine what *could be* and what *should be* done to improve the situation.

The knowledge issue

The traditional management activity is supported by a wealth of knowledge and when there are many specialisms engaged then it is a major part of the management process to ensure that the transfer of knowledge and its maintenance within the project is undertaken in an effective and efficient manner. Knowledge is at the heart of the integration and understanding of the management process. One of the problems in the traditional construction industry has been the gradual entropy in the integrity and completeness of knowledge through the development process leading to clashes between design proposals, litigation among participants and lack of an information legacy for future analysis resulting in a breakdown of understanding of intent and a record of what happened.

For example, a thin and simplified slice through the tendering and cost control process reveals a number of interfaces:-

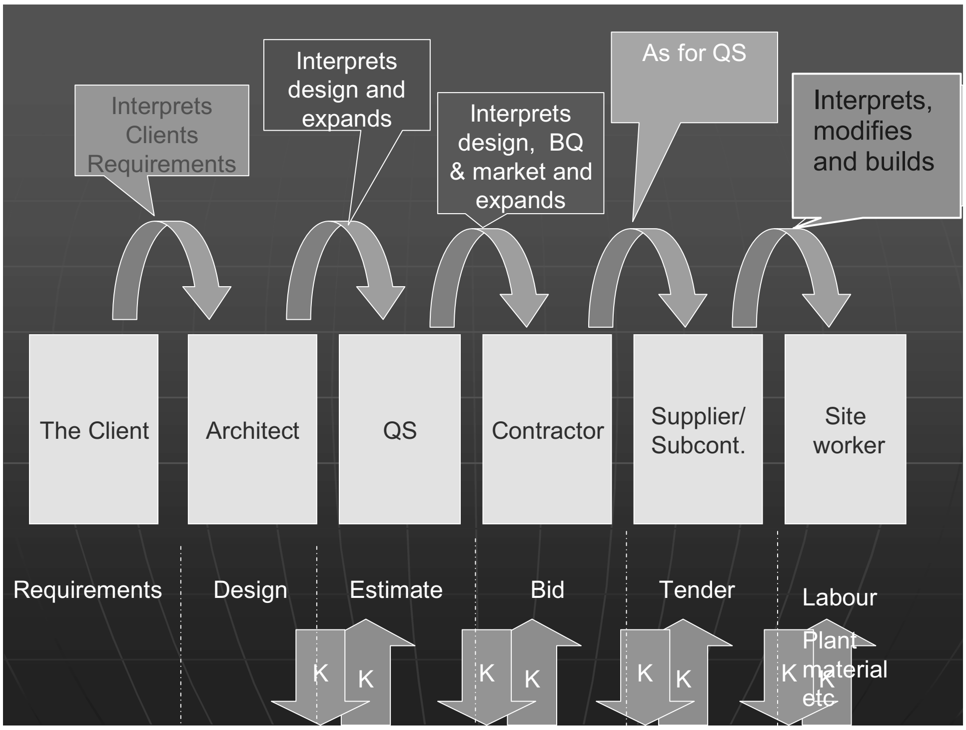

Figure 1: Knowledge transfer and enhancement through the design/manufacture process

The above diagram shows just a few of the hundreds of interfaces that occur in such a process. At each stage the person or function which is next in line interprets what has gone before and then because of his or her particular knowledge and skill will enhance the information available and use it for their own purposes of communicating to the person next in line. At each abstraction from one person to the next there is selectivity in what is carried forward and therefore there is a breakdown in the knowledge transfer. There is also an aspect of adaptation in the knowledge as information is added or changed to aid the next step in the process. Some knowledge is lost, some is gained. In order to understand the scope of what is communicated, regulations have been developed such as the Standard Method of Measurement or Standard Building Contract to make clear, up to a point, what has been done. It is also a process engaging several media including visual, textual and physical modelling each of which has strengths and weaknesses. At the start, the knowledge about objectives and strategic aims is strong, whereas at the end it is the knowledge about detailed construction or manufacture which is dominant and the original intent and objectives are lost in the detail.

For many years the process has been honed to suit the limitations of human brains and limbs. Because we cannot assimilate masses of detailed information we use simplified models; because we cannot compute quickly we use rules of thumb and limit the number of items we measure; because we find the information complex we simplify and allow for this in our contract documents. This process of simplification and limited transfer of knowledge is at the root of the growth in management as a discipline. Someone has to organise and control and check that there is compliance and there is communication and there is assessment of the consequences. To aid the management function process models have been created (Process Protocol: www.processprotocol.com) which are well established and sometimes standardised for the industry.

The following diagram illustrates through simplified processes for cost control how different models might be used over time:-

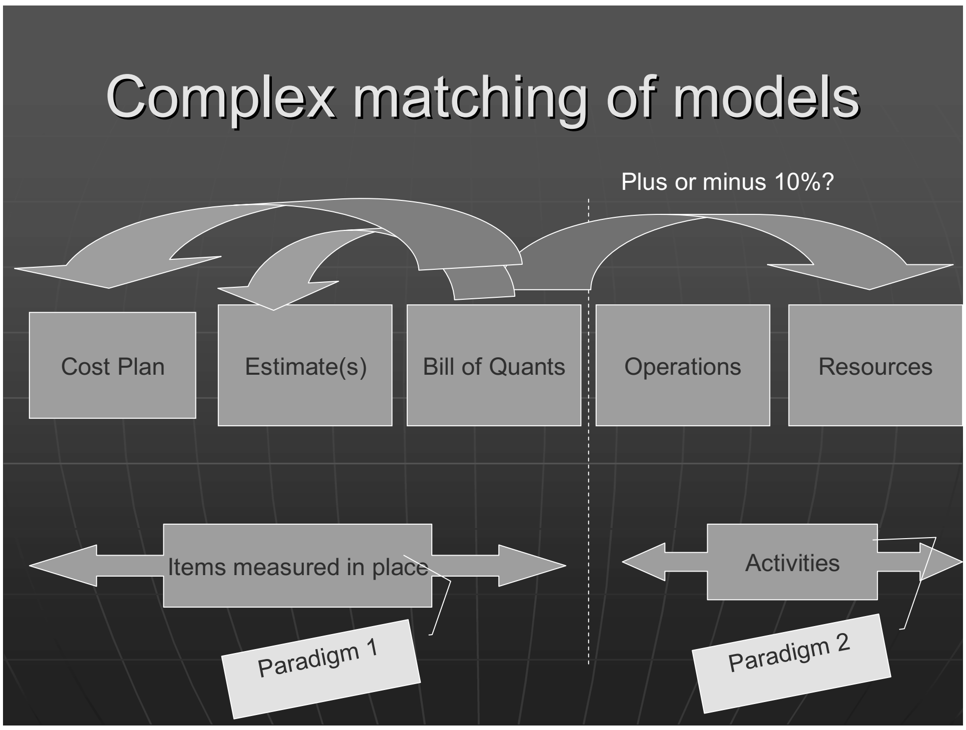

Figure 2: The Complex matching of models through the design/construction process.

In this case there are two paradigms within which the models operate. The first is related to the Bill of Quantities and the second is related to the resources used on site. The BQ provides the data for the cost plan and estimates and is based on items measured ‘in place’ in the building. In other words it ignores major aspects of process even though they may be crucial to the building of the end product. The second relates to the manner in which the building is built and the resources required, BUT, and it is a big but, it often has as its reference point the BQ estimate provided at tender even though this may ignore major aspects of process. There is some evidence that contractors build to the original tender figure and this has undue influence on what the building actually costs to build. This may be a contributory reason to the plus or minus ten per cent figure often suggested for the accuracy of the Bill of Quantities – perhaps the percentage should be much higher!

As the process of design and construction takes place then it is possible to observe a careful matching of models each trying to assess what the next model might provide in terms of information. Management uses a considerable amount of energy in trying to control and achieve success in this and many other areas. It is a major overhead.

Can the future be better?

One of the pre-occupations of this age is the desire to see into the future. This is understandable because the speed of change is so great that if you do not prepare then you begin to lose out in some way. This is particularly true of organisations and the concept of the 'learning organisation' (Senge P, 1990) to prepare for change is now an established metaphor for this preparatory process. We need to learn in advance in order that when change occurs we have the tools and culture to adapt to its requirements.

This has been taken a stage further with foresight studies where the scientific and technological base of whole countries has been marshalled to examine future possibilities and to prepare a research agenda to match. Over thirty countries have undertaken such exercises over the past thirty years and many have found it enormously helpful. In many cases it has been the process that the organisers have claimed has been the great benefit. To get several hundred influential experts to engage in such a process begins to change the culture of an industry or country towards a desire for self improvement.

Within such foresight exercises there has often been sector groups looking at the needs and possibilities for major industries and of course construction, being one of the major manufacturing industries of the world, has received due attention. Flanagan R and Jewell C (2003) summarise the results of such exercises (See Table 1). Some aspects of such a comparison need to be interpreted because, for example, Information Technology may be assumed by some countries to be embedded in all the various aspects and therefore it does not necessarily require to be shown as a separate item. However, it is, of course, a major issue. Likewise the improvements in process, whether design, manufacture, assembly or occupation can be found within many of the assumptions made about where improvements will occur.

	Australia	Canada	Finland	France	Germany	Ireland	Singapore	Sweden	UK	USA
Globalisation	Yes	Yes							Yes	
Innovation/R&D		Yes		Yes	Yes			Yes		
Exports/competitiveness	Yes					Yes	Yes		Yes	Yes
Construction and production processes			Yes		Yes			Yes		Yes
Integration – processes & people					Yes		Yes		Yes	
IT	Yes	Yes	Yes		Yes	Yes		Yes		
Repair & maintenance - existing stock				Yes		Yes			Yes	
Procurement and project delivery	Yes									
Service provider			Yes							Yes
People/workplace/ Culture	Yes	Yes				Yes	Yes	Yes	Yes	
New technologies		Yes			Yes	Yes		Yes	Yes	Yes
Environment/whole life/sustainability	Yes	Yes	Yes	Yes					Yes	Yes
Urban/city development		Yes		Yes						
Governance – codes & standards		Yes								Yes
End-user demands		Yes		Yes						

Table 1: Comparison of Foresight issues from various countries (Flanagan and Jewel)

This kind of exploration is healthy for any discipline and reveals the maturity of the industry in terms of its realisation of, and the willingness to, change. It can be argued that once a corporate view takes hold, caused by sufficient people seeking and adopting the new view, that change can be rapid and revolutionary. It may be that construction is reaching such a point when it comes to the adoption of Information Technology and process improvement.

It is, of course, possible to have an over abundance of technical solutions but without change occurring. In the early days of information technology the term *'solutions in search of a problem'* was often used. By this it was meant that the technology was advancing so fast that it was outstripping the ability of society to assimilate it in a meaningful way. Often its use was lost on the community it was meant to benefit, or worse, the creator had designed something which genuinely had no use for the foreseeable future. In the former case it is critical that society has some vision of what it wants to achieve in order for it to take advantage of the new tools. To do this it needs a vision.

One dictionary definition of vision is '*Intelligent Foresight'*. In this sense, then, the intelligence gathered from industry, academe and other sources can be used to give an insight into the future. The difference between 'foresight' and 'forecasting' is that forecasting attempts to predict the future (whether it is events, technological advances or expected dates for occurrence) whereas foresight tries to provide guidelines for policy makers about the directions they should follow. In one case (forecasting) the industry asks *"how do I respond to these events?"* knowing they are powerless to do anything about them and in the other (foresight) the industry asks *"what do I need to achieve these goals?"* It is the difference between saying the future is inevitable and we just have to predict what will happen and on the other hand saying we can influence the future, we are not just helpless bystanders.

One of the most recent foresight studies and undertaken by the author is the Construction 2020 Vision arranged through the Commonwealth Research Centre in

Construction Innovation based in Brisbane, Australia, involving all the major organisations and professions in the Property and Construction industries. Several hundred people attended workshops and completed questionnaires in which they identified their vision for an improved Australian Construction industry. The final summary report of these deliberations launched in the Australian Houses of Parliament in June 2004 (Hampson K and Brandon P, 2004) reveals the integrated nature of the aspirations of the industry. Figure 3 shows the broad outline of the nine visions or themes distilled from all the responses made. On one axis it can be seen that it is the ‘environment’ in which construction takes place which is the key issue. (Environment here means *the complex of social and cultural conditions affecting the nature of an individual or community).* These include the needs of the workforce, a sustainable environment, responding to clients’ needs, an improved business environment and research and development. On the other axis are the technologies which might well aid the improvement in the environments identified such as process issues and those related to information and communication technologies. On one axis the values which people need to address are defined and on the other the tools to help meet those aspirations. The strength of relationship does of course vary between the two according to the ability of the tool to respond.

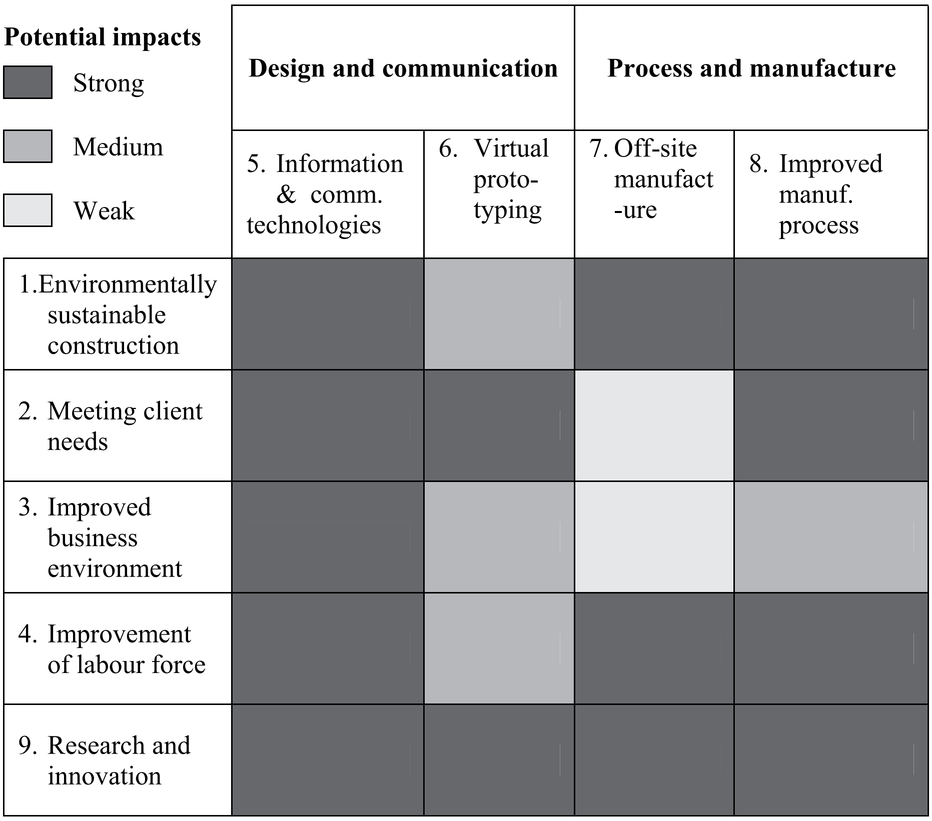

Figure 3: Construction 2020 Visions and themes for the Australian Construction Industry (Hampson K and Brandon P, 2004)

What is interesting in this study is that it is not the technologies which dominate. In fact, in the analysis of responses it was the improved business environment and environmentally sustainable construction which headed the list. The technologies, although considered important, were seen as a means by which the other issues could be achieved. In other words, it was the people issues which were really considered to be important, whether it was now (as in the case of the business environment) or in the future (as in the case of sustainable development). At root it was the feeling that management was something that had to be addressed and that management should feel responsible for existing problems (largely to do with people) and new possibilities and directions.

This suggests that visions of the future as expressed in peoples' aspirations are more about quality of life and the values people hold rather than mere technological advance. However, it was also recognised that the real potential for change to achieve these ends is held within the new technologies and more specifically the information technologies. This was also more evident, as has been the experience of a number of studies, when people are asked to look into the longer term future rather than the short and medium term. In the short term people consider the problems they face today but as the horizon gets longer so they shift to considering the values they hold about which there is often a greater consensus. What we see is a shift to values the more we leave the baggage of the present behind.

So where do we look for this major change to happen which can revolutionise our industry and lead to approaches which reflect these values?

The Tipping Point

Malcolm Gladwell (2001) in his international best seller entitled 'The Tipping Point' identifies a phenomenon whereby an activity or a technology suddenly emulates the kind of behaviour that we see when we talk of an epidemic in medical terms. It is a significant point in time when there is a dramatic moment when everything can change at once. The situation moves from incremental to revolutionary change in what appears to the observer a very short space of time. Gladwell attempts to identify three characteristics of this phenomenon. Firstly, contagiousness - where the concept or idea suddenly becomes the accepted wisdom and produces a new paradigm which the vast majority follow. Secondly, a period where little causes can have big effects and thirdly, where change happens not gradually but at one dramatic moment. He applies this to many instances where social behaviour becomes revolutionary but the same can also be said of technology.

It was the introduction of the personal computer which suddenly made the power of that computing machine available to the masses. This in turn led to changes in communications and the way people undertook many of their normal activities whether it be leisure, or communication with friends or purchasing travel tickets or discovering knowledge. The world changed in the space of less than one working lifetime to something quite new. Partly it was contagious as the word was passed on as to what this technology could do for the everyday life of people and once imparted it was difficult to stop. Partly it was the fact that a relatively small but significant piece of software, the internet, enabled people to access knowledge and interact with it through the machine at their office or their home. Partly it was the dramatic possibilities (a vision) which were seen suddenly by so many that helped to create a critical mass of activity which brought the investment, intellectual capital and imagination to produce the information infrastructure we have today. Of course, there were many factors which aided and abetted the change but viewed from a distance these major drivers created an epidemic in human behaviour which still continues today.

The Tipping Point for IT in Construction

So what happened to the Construction Industry and the application of Information Technology? Here is an industry which appears ripe for reaping the rewards of improved communication. It requires vast stores of inter-disciplinary knowledge; it can be aided enormously by visual imaging of a finished product and the simulation of performance when at the present time the cost of physical prototyping is just too prohibitive. It needs masses of information to be exchanged, manipulated and stored and therefore there seems to be a prima facie case to be made.

The recent short term forecasts for when the industry might get its act together e.g. when its supply chain will come 'on-line' have all proved much too optimistic. There have been significant mini epidemics, for example when contractors of all sizes suddenly found the benefit of the mobile phone to communicate in a geographically distant and often dirty and noisy environment. The industry was one of the first to take this technology on board in a big way. But what about the big changes where collaborative working in design, manufacture and operation are seen and exercised through a virtual model for the benefit of all stakeholders in the process: where remote sensing and control allows machines to manage and direct activity in what are often dirty and hazardous environments: where ordering and purchasing all resources can be done electronically: where it is possible to try before you buy and know what you are going to get and why. The industry is sometimes described as the world's largest but this great industry appears to be locked into its craft technology which in principle has not changed for millennia. The management of large projects has become more complex, certainly so have some of the structures which are now designed (Gehry F, 2002) and in many cases they could not be built except for the support of computer technology. However, the wide scale adoption of the machine to harness its power in a way that can be seen already in, say, the aircraft industry, is just not in place despite the excellent aspirations and investment made by enlightened clients such as British Airports Authority. Where there is movement it comes from collaboration between individuals such as the way in which the Frank Gehry Partnership has worked with Dassault Systems to adapt software originally designed for aircraft design to meet the aspirations of one of the world's great architects. It is interesting to see that it was another industry that provided what was needed to achieve a new free form structure which has excited the world.

These breakthroughs are relatively minor outbreaks of a benign driver which pave the way for what might be. The epidemic is still to come. There are signs that mass breakout is possible soon and there are many conferences which identify the work of some of the 'thought leaders' in the field. These conferences address what is happening, what might happen, what should happen and what should definitely not happen! Although the term 'thought leader' seems to have Orwellian overtones it does capture one important aspect. It identifies the power of thought and the imagination to provide visions of the possible. This aids the first ingredient of the 'tipping point', that of contagion. So what of the other two ingredients? If we can identify little causes which can have big effects then we may be well on the way to radical change. A view of the industrial/social world we live in would provide us with the following trends which coming together might provide the spark for ingredient number two. As with all epidemics it is impossible to predict but somewhere in this soup of ideas and developments lurks a minor change which could revolutionise the way the construction industry works.

- **Convergence:** The last decade has seen a massive change in digital technologies which has seen all forms of media whether it be visual imagery, radio, television, audio, personal computers or telephone communications all come together in one digital representation. Mobile phones today now have the capacity to bring most of these aspects together. It does not end there. Society across the world is changing and despite resistance in some quarters there is much more sharing of knowledge leading to a common or converging viewpoint which may in the long run lead to globalisation of values. The seduction by western values is seen by many to be one of the downsides of such open access which is controlled by a few. Will the construction industry come together in a way we have never seen before?
- **Connectivity:** Alongside the convergence through technologies has been the vast increase in communication and the access we have in the developed world to all forms of information. We can now be 'connected' anytime any place anywhere and with the development of ambient computing this is going to extend still further. With connectivity comes contact, access and the inability to hold on to and protect specialist information for more than a short period. The hold of the professions and their 'fortresses of knowledge' protected by their examination systems and barriers to entry begins to disappear and boundaries between knowledge disappear. Connectivity allows us to change quickly and for the 'virus' of change to move through the population unfettered, unleashing a contagion of ideas which can tip us into a new and unknown situation.
- **Culture:** As the technologies converge and connectivity allows the spread of the contagious idea then it needs a receptive culture within which it is easy to 'breed'. The present generation of university leavers are the first cohort of graduates who have been through the complete school system where information technology was an integral part of the curriculum from the very first year of entry into education. To them it is the norm whereas to previous generations it had to be learnt and absorbed and systems had to be re-learnt to embrace change. The information technological change is now endemic in society as a whole and it is even stranger to be outside it than to be in it.
- **Creativity:** Do computers release creativity or constrain it? In past generations the need to standardise and formalise in order to use the machine was prevalent. Now this is changing as the nature of the machine becomes more flexible and adaptive. There is still a long way to go and the culture has changed so that there is mutual give and take between machine and user to which both are becoming more accustomed. The games industry is a leading example where the users speak the language and seldom seem to have to read any rule book before they can participate at a high level. This natural take up needs to extend to industries like construction.
- **Content improvement:** As the content of what is provided through the technology improves so it is more likely that more people will want to use it. When that content of knowledge or access becomes indispensable for normal living then the technology also becomes indispensable. In the developed

nations we are getting close to this situation as our financial, employment, consumerism etc is being built around electronic processing. For the construction industry we have some way to go but the industry is a laggard in the race towards electronic business and falls sharply behind transport, banking and other sectors.

- **Collaborative working:** When the stakeholders need to work together for maximum efficiency and they are geographically separated then the drive for integrated communication and sharing becomes paramount (JCT is such an example). In addition, the real benefits often arise when the stakeholders work together and it is just not possible for one organisation to act alone. The benefits of airline booking of tickets would not be as successful if each company developed its own system which could not speak to the others. Where the benefit is of this nature it may be necessary for Government or a major player in the software industry to take the lead. There must also be willingness for all parties to work together in pre-competitive research to establish the platform.
- **Content:** With the growing developments in the hard technologies comes an increased impetus to provide the content for users to find the technology even more useful. The entertainment industry has been one of the first to realise the potential for extra services and education is following close behind, often using the same technology. It has been argued that the distribution networks required for the content may create a monopoly of knowledge, not unlike the half a dozen or so global film distributors who control the films made available to us for general viewing. This could be dangerous as we then leave the access to knowledge and the values that the knowledge conveys in the hands of a few.
- **Cost reduction:** As quickly as a new refinement to the technology takes hold then an improved version is produced. This highly competitive market creates a leapfrogging effect which sometimes leaves the purchaser bewildered and unable to invest without substantial risk. However, the overall impact is for more computing power to become available to each individual which in turn enables him or her to do more for the same cost and in some cases to be more flexible in their use of the technology, thus removing some of the barriers to use.
- **Common Standards:** This may be a temporary factor in the tipping point agenda. The technology is moving so fast that the hurdles we see now to inter-operability are likely to disappear and the issue will become unimportant. However, for the time being the move towards standards for inter-operability such as the Industry Foundation Classes (IFCs) is opening the opportunity to exchange information and to integrate processes together. This in turn allows the collaborative working around a single model which has long been the holy grail of the IT model builders.

We may well find within the above list that key activity which will tip the balance and bring the construction industry to the fore in e-business. It is likely to be a combination of many of the above but just one new development could well take us into a new digital craftsmanship to replace the old.

If this is about to happen, and many think the time is ripe, then we need to consider future possibilities and what it might be like to live in this new world. What will be the advantages and the pitfalls?

The future Information Technologies

If we take the information technology developments we can see how harnessing the technology coupled with an understanding of science to aid in imagination, manufacture and use has produced significant developments. If we link this with the idea of '*direction*' then we move into what will form the next research agenda.
The European Fifth Framework project called 'ROADCON' ('Strategic RTD Roadmap for ICTs (Information and Communication Technologies) in Construction', 2001), in which Salford University and others were responsible for developing the IT vision attempting to identify where we are now in terms of IT and the roadmap of where we should be going i.e. the vision and direction. This is a summary of what was listed:-

Applications*:*
- *Current:* These are dedicated to specific engineering functions and project/building life cycle stages.
- *Future:* Total life cycle appraisal supported by user-friendly functional applications and persistent data ensuring holistic decision making.

Products and Components
- *Current:* Have little 'added value' to the building operation.
- *Future:* A mixture of high and low value components acting intelligently.

Knowledge re-use:
- *Current*: Experience and previous solutions are available in personal and departmental archives but new solutions are regularly re-invented in every project.
- *Future*: Relies on industry wide sharing of experiences and fundamental understanding of complex systems interacting at all levels.

Information access:
- *Current:* Company and project data available via LANs and web based technologies.
- *Future:* Ambient access provided, anytime, anywhere, by industry wide communications infrastructure, distributed and embedded systems, ambient intelligence and mobile computing.

Project Information and Communication technologies:
- *Current:* Based on ICTs which augment the creation and sharing of human-interpretable information.
- *Future:* Based on model based ICT enabling context awareness, automation, simulation and visualisation based on computer interpretable data.

Nature of technology:
- *Current:* Invasive technology where the user has to adapt to proven and emerging technologies.
- *Future:* Technology is human-centred based around design and build paradigms promoted by ICTs that enhance the social condition of individuals in the society.

Data Exchange:

- *Current:* Available at file level between different applications and companies based mainly on proprietary formats at low semantic level.
- *Future:* Flexible inter-operability between heterogeneous ICT systems which allows seamless interaction between all stakeholders.

Processes:

- *Current:* Business processes are driven by lowest cost but there is a growing awareness of customer perceived value which is not supported by prevailing business models.
- *Future:* Performance driven process assuring compliance with clients' requirements and emphasis on customer perceived value.

Collaborative teams:

- *Current:* Teamwork between distributed experts in participating companies is supported by web-enabled document management systems in 'project web sites'.
- *Future:* Virtual teams combine distributed competences via global collaboration environments that support cultural, linguistic, social and legal transparency.

Systems Flexibility:

- *Current:* ICTs require customisation to meet the varying needs of users and has to be tailor-made for new situations requiring manual maintenance, configuration and support.
- *Future:* Adaptive systems are created which learn from their own use and user behaviour, and are able to adapt to new situations without manual maintenance, configuration and support.

The above list suggests where technological development might take place to overcome some of the difficulties we face today and provide a working environment which is more finely attuned to the needs of human beings. It is no accident that most of these activities relate to aiding and potentially replacing aspects of the management role. The reason for this is that the process is now so complex that it needs to be streamlined and it is the next stage in the automation of the business process. Whereas management was once unassailable as a leading discipline in its own right the new technologies now place it in the position of merely support to those who are the creators and those who are the builders of products although no doubt these will be threatened in due course.

This is a return to the position adopted three centuries ago where it was the creator or the designer who also maintained the management function.

Where are we now?

In readiness for the 'Tipping Point' for construction a number of research agencies have been exploring the ways in which the technologies centred on the computer can be harnessed for the benefit of the construction process. At Salford we have been developing many systems such as:-

- Knowledge based systems which could provide advice on traditional practices of cost forecasting, procurement path, development appraisal and time estimation at the very early stages of commissioning of projects based on very limited data. These have been developed since 1986 and have been found by industry to out perform human beings at that stage of the process and sometimes beyond. These became commercial projects and have sold many hundreds of licences.

- Integrated object oriented systems (since 1990) which provide the building blocks to further development into fully integrated computer systems and data bases supporting the whole design and construction process.
- Virtual environments (since 1994) where design and evaluation could take place in 'real time' across national and other geographical boundaries with the target to produce a 'cockpit' where progress and information was available to all rather like that of a car or plane. The introduction of virtual reality enhanced the potential of these activities.

Most have been taken to prototype level at least and have been used 'in anger' on real projects. All were developed with the help of firms and organisations. This work continues to flourish at the leading edge of the technologies but as industry catches up so the emphasis and content has changed. (It is also worth noting that parallel to these developments were a series of management studies which aided the introduction and use of such models).

In terms of industry a large number of leading firms are now using such technologies to enable them to undertake projects which would be almost impossible without them. Perhaps the leader in the field, largely because of the nature and complexity of the design and materials used, was the firm of the leading architect Frank Gehry in the United States. Gehry wanted to combine his skills as sculptor/designer with the new materials that were coming on the market and his partner Jim Glymph decided that the only way to achieve this was to harness the tools available in other industries such as the aircraft and automobile industries. Working with a software package called CATIA originally developed for the French aircraft industry by Dassault systems they created an advanced 3D model of their intended construction which was used for a variety of purposes including understanding the design, manufacturing direct from the model, cost forecasting, management, setting out and maintenance of the design as built. It also included acoustic and other evaluations in due course.

The first attempt at this approach was for the Barcelona Olympics in 1992 where Gehry was invited to create a sculpture of a fish. He had nine months to complete the project and he agreed to do it providing planning and other constraints were eased, no external management was engaged, it would be built round the 3D computer model and paper drawings were not required. These requests were agreed and the large steel structure was completed on time and cost. The management and control were placed back in the hands of the designer through the technology.

Jim Glymph, Gehry's senior partner responsible for the management and procurement issues in the firm says of the process adopted with the fish sculpture:-

'..in construction, you know, there's been a tradition built up about paper and a paper process, an approval process that is very complicated. We didn't sacrifice any quality control procedures, we clearly did not sacrifice any management. We just eliminated management where it was not necessary, which was most places. The fish sculpture was a fairly easy, steel structure, metal skin, it's not like the other buildings we are doing now…but the big road block is still management.'

The success of this venture some 13 years ago encouraged the firm to take a similar approach to other projects of a more complex nature. Subsequently the Experience Music Project in Seattle, The Guggenheim Museum in Bilbao, The Walt Disney Concert Hall in LA and the Stata Centre at MIT, Boston have been developed (among others), demonstrating the benefit of this approach.

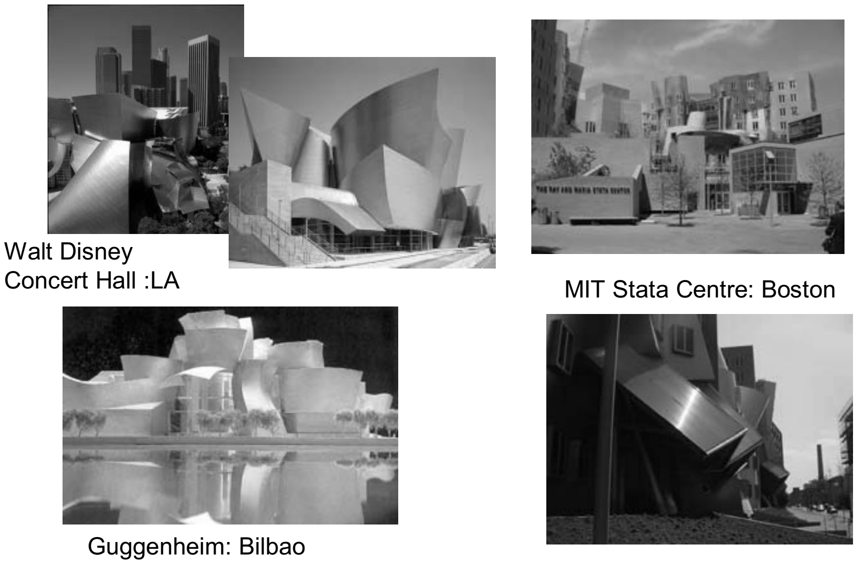

Figure 4: Examples of the Gehry buildings

On many of these projects the fabricator worked closely with the designer to achieve the designer's objectives using the computer as the intermediary to create, test and evaluate what was being suggested. As Jim Glymph said "the Project Manager had to stand aside to allow this direct communication and development to take place, he was not needed'.

On the Stata Centre in Boston the contractor, Skanska, was working with the 3D model throughout the process. It was used for evaluation as design developed; it provided the output for the fabricator to automatically manufacture the steelwork and tiles to very demanding tolerances; it aided a link by laser input from the physical models to the computer models and from the computer models to setting out on site; it recorded progress and laser feedback allowed the model to be adjusted for working tolerances on site thus allowing the manufacturing process of the frame and cladding to be amended; it connected the management programme to the 3D model. The problem the contractor had was in finding the right people who could handle the new processes and in fact they hand picked their team and did not appoint anyone over 30 to the project except the project manager because they thought that older staff might bring the baggage of past systems with them. This needed a totally new approach.

What is evident in these projects is that the number of interfaces which need to be managed is severely reduced and consequently the level of management required to control the interface problem is also reduced. It also reveals the beginning of a direct link to the Supply Chain through the model (in this case the fabricator) whereby some of the design function, the paper drawing intermediary, the cost function, the manufacture, the feedback and adaptation of the model as construction takes place, are all subjugated to the machine and its technician support.

This does not mean that all the work is undertaken by the machine. Gehry himself still models using physical artefacts which are then laser input into the machine and then tested and sometimes output again as physical models. Where appropriate, however, the process is smoothed and the possibilities for misunderstanding and error, particularly in communication, are reduced. At Salford we are beginning to work with Gehry Associates to study what has been done so far and what potential areas there are for future development.

The interest at the moment is to see whether the benefits of the virtual project environment used on a particular type of sophisticated scheme has application to the wider range of more standard projects. At first glance, apart from the present start up costs (and they will come down with volume sales), there appears to be a prima face case for pursuing this approach. The evidence seems to suggest that:-

- The design is better understood and the design integrity is moving towards that achieved in the aircraft industry
- The process of building can be simulated and better understood
- Management is reduced because the number of managed interfaces decreases
- The contractual arrangements are simplified but with the client taking a larger risk. (I would comment that although at the moment the majority of clients are shedding risk, the Partnering movement is really about clients taking more risk although it is seldom portrayed this way). The supply chain is engaged with the process through the model and particularly in automated manufacture
- Aspects of the cost function can be automated
- Site layout and control can be improved leading to improved tolerances and a move towards higher quality standards.
- The need for paper drawings is reduced although traditional processes such as regulatory control often demand drawings even though they do not provide the level of information of the 3D model.

These are powerful advances which begin to change the roles, and the power bases of many of the project participants including the client. There are still specialisms within the project but they are now much more in the control of the designer because he can evaluate inputs and test alternatives in a way that has not been possible before, particularly for complex structures. Whereas the shift in the last half century has been away from the designer as lead consultant, now we see a reversal and a possible return to the arrangement of two centuries ago albeit with different tools. It is not yet clear what this might mean in terms of the contractual arrangements and how this might be reflected in the procurement process.

Management could be one of the disciplines which begin to decline as a separate profession and the role once again becomes the province of the designer. In some of the projects undertaken at Salford such as DIVERCITY (an EU funded project with a number of EU participants) (www.e-divercity.com) it became clear that it was possible for any member of the design team to work in real time and investigate and try options using virtual environments evaluating and seeing what were the impact and performance. These included site layout, acoustic properties, spatial layout etc, all undertaken through a single model operating across national boundaries and which could be controlled from any geographical site.

Knowledge management is at the root of this change as the person who has access and the ability to manipulate knowledge is the person who will ultimately be the person with the status and strength to control.

How far can we go with knowledge transfer to the machine?

As you might expect with a subject which is still in its infancy the understanding of knowledge management has changed over the past twenty years since the above case was developed. Snowden (2002) identifies three 'ages' of knowledge management. These he suggests are:

- First age (prior to 1995): Information for decision support where the focus is on the appropriate structuring and flow of information to decision-makers and the computerisation of major business applications leading to a technology enabled revolution dominated by the perceived efficiencies of process engineering. However, this 'age' stuttered to an end when organisations recognised that that they might have achieved efficiencies at the cost of effectiveness. For example they had laid off people with experience and natural talents of which they had been unaware and these attributes were lost to the organisation.
- Second age (after 1995): The popularisation of the SECI model (Nonaka I and Takeuchi H, 1995), with its focus on the movement of knowledge between 'tacit and explicit knowledge states' through the four processes of socialisation, externalisation, combination and internalisation. Previously Polanyi (1974) had seen tacit and explicit knowledge as different but inseparable aspects of knowledge, the de facto use of the SECI model was dualistic, rather than dialectical. The work of Nonaka and Takeuchi was seeking to contrast a claimed Japanese idea of oneness with a rational, analytical and Cartesian western tradition within the context of innovation in manufacturing processes where tacit knowledge is rendered explicit to *the degree necessary to enable that process to take place.* It did not follow that all the knowledge in the designers' heads should or could have been made explicit.
- Third age (emerging): It appears that some of the basic concepts underpinning knowledge management are being challenged to a point where we grow beyond managing knowledge as a thing to also managing knowledge as a flow. This is based on three heuristics namely: *Knowledge can only be volunteered – it cannot be conscripted; we can always know more than we can tell and we will always tell more than we can write down; and we only know what we need to know when we need to know it.* It is recognition of the limitations of the second stage but not the abandonment of its practice. (To take an example of a contract, it tries to convey an appropriate level of knowledge to satisfy the agreement between the parties. However it is also clear from litigation that the knowledge contained in the contract documents is not complete and can sometimes be challenged in the courts. We can never demand or capture all the knowledge in the minds of the participants so we allow practice and rules and regulations to determine our understanding of what was intended. It is never complete.)

Increasingly academics and others are seeing the importance of context to the process of knowledge management and this raises the issue of culture (Snowden, 2002). By recognising the situation in which knowledge is used and disseminated and how that impacts on both the knowledge delivered and the process chosen, a more fundamental understanding of what is involved in knowledge management and its complexity begins to be addressed.

In fact it is the complexity of the problem which underlies most of the problems found in the construction industry and any other complex system. A bespoke artefact built on a unique site in a unique location with a virtual design and construction team which is geographically separated and with major interfaces between specialised knowledge is bound to create difficulties. For many years it is remarkable that this has been able to be managed largely through the knowledge in the heads of the personnel involved and in their representations in terms of physical models, 2 dimensional drawings and text.[1] However, the knowledge that human beings bring to complex problems can be severely underestimated, as the following example shows.

A Case study in knowledge capture for procurement

At the end of the 1980s a team at the University of Salford, led by the author, were invited to join with the Royal Institution of Chartered Surveyors, under the UK Government 'Alvey' initiative, to produce a knowledge based system which could act as a demonstrator to the construction industry as to what these systems could do. It was a successful partnership with the RICS firms providing the expertise of the market and the academics providing the skill and expertise on the technical base. The aim was to provide an advisory system which provided information on budget, time forecast, development appraisal and procurement path at the beginning of a construction project before formal design began to take place. It proved to be very successful and eventually produced a product 'The Lead Consultant' suite of programmes which was sold extensively in the UK and was also bought by seven countries who were exploring similar programmes, even though the knowledge related to the UK. Other programmes followed and in tests undertaken by several firms the programmes even outperformed experts in the field.

However, at the start, one of the modules appeared to be the best suited for this type of application of 'expert systems' as they were then called (a misnomer if ever there was one). The procurement module appeared to have the best chance of success because similar programmes in medical diagnosis had been written which were able to take the symptoms of a disease, analyse them and then suggest a diagnosis and treatment. On the face of it the Procurement Module had similar aims. The symptoms were the clients' requirements, the analysis was the skill of the design team in determining what this meant in terms of the most appropriate way to build (the diagnosis) and the treatment and prognosis was the suggested procurement path and the actions which then followed. The programme was asked to suggest a particular procurement path from the information it had received from the user and to select from five main possibilities (Conventional, Two Stage Conventional, Management Contracting, Construction Management and Contractor Design and Build). It then provided the arguments for the choice or recommendation it had made.

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[1] For a fuller discussion on complexity see Bertolsen S, Construction as a Complex System, Bertolsen S, Complexity - Construction in a new Perspective and Bertolsen S and Koskela L. Avoiding and Managing Chaos in Projects, all presented at the 11th Annual Conference in the International Group for Lean Construction, Blacksburg VA, August 2003.

The way in which the programme was developed used the ‘Client Centred Approach to KBS’ (Basden *et al.,* 1995) broadly as follows:

- The context for the system was determined
- Knowledge was ‘engineered’ from experts in the field
- The knowledge was represented in inference net diagrams and then programmed into the computer
- The results were tested against the experts’ expectations
- If acceptable the programme was accepted and if not the knowledge was refined to produce an improved solution.
- The interface with the user was refined to make it sensitive to the manner in which the user operated and interpreted the programme. This included developing an innovative explanatory program which provided the strength of argument for the recommendation determined by the machine.

(For a fuller description of the approach and the Procurement Module see Brandon *et al.,* 1988.)

The process and subsequent programme revealed many of the inadequacies of capturing knowledge in a machine with the tools that were available then and the processes adopted. The key lessons were as follows:

- Experts could identify the ingredients to the solution i.e. the information needed to make a selection, but they found it almost impossible to weight the value of the information in numerical terms (probabilities) when bringing information together to determine a solution. In real life they did it intuitively but they rarely articulated the process they went through. Although the research team developed tools to try and overcome the problem of how to determine the probabilities, in the end it came down to trial and error with a massive number of combinations which could not be exhaustively tested.
- The use of the results was too dependent on personal experience. If the user had good experience and skill in say Management Contracting then he or she would have bias towards this approach. In fact, it would be dangerous to suggest some types of procurement to a person who did not have the experience or skill to implement. Personal knowledge and skill might be paramount.
- The knowledge was transient and at the whim of the market. Halfway through the creation of the Knowledge Based System one of the firm of experts discovered, through a completely independent study undertaken for another purpose, that the market was penalising management contracting at that time by a factor of nearly twenty per cent.
- The other eleven expert firms had not undertaken such a study and were still working on another set of assumptions. It changed the whole nature of the weighting of the knowledge base and it is likely that it has fluctuated widely in the twenty years since.

The positive side of the process was that it did make clear the main issues and the resulting program did provide a sounding board for the experts’ own intuitive assessment. This was considered of value to the surveyors who eventually used the package. However, it did also identify the problems with developing complex, knowledge rich computer based information systems.

Difficulties with knowledge

The Procurement Case study outlined above demonstrates many of these problematic issues. The knowledge based system tried to gather knowledge together for a complex decision-making process harnessing the power of the computer to process the knowledge to emulate the human thought processes through heuristics. It found that the knowledge required for this problem was not absolute but was emerging – it was responsive to the flow of information in other external agencies.

The consultants found it almost impossible to distil the complexity of the various pieces of knowledge into a form which truly reflected their own tacit knowledge and the intuitive processes which they normally brought to bear on solving the problem. In other words, the knowledge representations available (and several were tried) were not natural repositories for the kind of knowledge required. However, with hindsight, it did recognise some of the aspects of the third generation knowledge management systems which suggest that we only know what we need to know, and that we will always tell more than we write down.

Consequently, all the modules in the 'Lead Consultant' suite of systems needed to be used by those who had a working knowledge of conventional practice so they could also bring this tacit knowledge to bear on the problem being presented by the machine and the user. To go outside this experience was dangerous. Nevertheless, within reasonable parameters the programme in the right hands was able to produce sensible solutions to the clients' needs and also provide a framework within which the growing knowledge process throughout the project could be placed and checked. In addition, in several cases it was used as a check on experts and was able to pinpoint errors in their assumptions or calculations.

Knowledge support for the management function

The above discussion has provided a review of some of the key issues with regard to capturing knowledge within a computer for the purposes of providing support for management. The reason has been to show that although it is recognised that computer support will be an essential ingredient of management systems in the future there is still a long way to go to achieve the automation that would be so helpful in making knowledge capture and use a reality.

It is right and proper to focus at this stage of development on the cultural issues relating to knowledge which underpins the management function. The recent work undertaken at Loughborough University in the Partners in Innovation Project (CI 39/3/709) identifies the specific features of knowledge production in the construction industry, investigates and documents the main challenges and examines the different approaches and the skills required to implement such systems. This was also developed into a training tool as an appropriate approach for small and medium sized enterprises (see http://www.knowledgemanagement.uk.net). It is interesting to note that while the authors recognise the importance of information technology to knowledge management they focussed on the need for the firm to see the importance of knowledge within the organisation and how this can be harnessed for the improvement of future performance. They consider this to be an important first step and an essential component of the internal culture which will allow performance to be enhanced.

Issues for the future

In any discussion of matters relating to Information and Management we need to remind ourselves of some basic terms. *Data* can be described in the computing context as 'a group of one or more characters representing basic elements of information that can be processed or produced by a computer'; *information* is a general term for any data that have been recorded, classified, organised, related or interpreted within a certain context so that meaning is apparent; and *knowledge* is a general term for the aggregation of facts, principles and other information which is characteristic of human intelligence' (Dictionary of Science and Technology, Academic Press, 1991). The shift from data and information to knowledge is a shift from something which is recorded to something which is placed into context to add meaning, to something upon which we can bestow the concept of intelligence as experienced by human beings. The application of the concept of knowledge is therefore a shift from something which is inert but has the power to be useful to something which can be rationalised and made active to assist or undertake decision-making. For example, contracts by their very nature, place data and information into a context which enhances the knowledge of the parties concerned. The drawings, the specification and the quantities do not exist in isolation but within an overall context described by the contract. It is this context which is one of the most difficult things to capture in text or indeed within the media employed by computer programs. The complexity is enormous but what computer programs can do is provide visual information and deep knowledge which can allow exploration which hitherto was hidden or unavailable to the parties concerned. It is when the computer begins to 'make' decisions that problems arise.

Knowledge is sometimes described as the sum or range of what has been perceived, discovered or inferred. In computer programming the line of code which provided the most powerful contribution to the concept of knowledge within a machine was and probably still is, IF…..THEN. In general terms it means that IF a certain set of circumstances exist THEN another action can be taken, conclusions drawn or meaning inferred. Examples include:

- IF these circumstances exist in a certain form (perhaps a gathering together of facts) THEN this meaning can be inferred.
- IF these probabilities exist and combine in a predefined way THEN this further calculation should be undertaken.
- IF the results of previous actions result in this particular threshold being reached THEN take the following action.

This concept allows a machine to draw conclusions, determines what and when decisions can and should be made (either internally to the machine or externally); provide explanation for its reasoning (e.g. it took this action because these circumstances exist); and to make judgements which are based on incomplete or fuzzy information. Even with advanced computer languages and knowledge representations this simple statement has enormous influence even if it is sometimes expressed in different ways

(Of course in many areas of building procurement there are rules of this kind to take account of differing circumstances and differing aspirations of the parties concerned. They appear in rules for measurement and contracts and specifications. The difference is that Information and Communication Technologies have the potential to use such rules on a much bigger scale and without necessarily making explicit what rules have been adopted or gaining agreement of what they might be).

Knowledge within the Information Technology context is based on such IF…THEN statements and they reflect partially the reasoning of human beings in their own human intelligent systems. However, human intelligence is placed within a rich context of experience in which value systems play a large part. Before humans make a decision they call on a wide variety of experiences which include emotions, education, social inter-action and discipline which is brought to bear on the problem in hand. The simple IF…..THEN cannot cope with the enormous variation and combination of these experiences and consequently almost any result which involves a value judgement requires additional human intervention. The problem here is that often we bring the value judgement to bear into our decision-making intuitively without recognising that we are doing it. In a machine this can be captured in a heuristic in which the user is unaware of the judgement being made. It then gets used by others and a single judgement gets embedded in many programs. In construction design this might be about, for example, gender issues (number of women workers assumed), aesthetic issues (the value placed on space and form), construction issues (related to issues of health and safety) or in estimating terms (the performance of the market).

These matters are extremely important because as we allow the machine to make more of our judgements so we delegate a view of the world which is specific to the author of the program (even though this may be the result of a concerted effort) and which reflects a particular set of values. By their nature these values are not challengeable unless everyone is aware that they exist and that it is possible to understand their representation and change them. Democracy is much more difficult when the values are enshrined in a machine.

Values

At the heart of values are the belief systems to which we hold. These in turn arise from or are created by the culture in which we live. In democratic societies, at least, these are partially enshrined in the legislation and regulation which the people have determined to represent those values. Whilst in past times these matters were largely stable and often confined by national or other boundaries, this is not so true today. The internet and other technologies do not recognise such boundaries and can pose a threat to those who hold strong beliefs. We are moving into a period when values are becoming a key issue in development and world politics as globalisation begins to be the mantra of the many. When the EU calls for greater harmonisation it often means a harmonising of what are perceived to be (Western?) European values How far this will extend in the future is not clear but there are fears in many parts of the globe that other civilisations are being seduced into Western values. Our contractual arrangements are merely one small aspect of how we capture our view of the world and the values which we feel should be established.

When we consider the research agenda for industries the question of values is often forgotten in our desire to improve the systems and technologies with which we work. When the Australian community in the Construction 2020 study calls for a better business environment, what is it calling for? Does it mean 'more profits for all' and if so does this mean that someone else will suffer? Does it mean a fairer distribution of risk, in which case who wins and who loses, assuming the present system is unsatisfactory. Does it mean that those with technology win and those without lose? It is a very complex issue but one that is fundamental to the well-being of the people we seek to serve. Our research cannot be undertaken, and a new tool produced, without considering whether people want it, whether it has negative as well as positive contributions to make or whether it supports or undermines the values of the society in which it is to be used.

These matters are critical in the information sciences. Knowledge is not neutral; it empowers some and can disempower others. At the same time the technologies used to convey knowledge use models, which by definition, are not fully representative of the object or system they try to represent. They represent the item but they do not convey it in its entirety. We are moving to the creation of a virtual world where we aim to create reality within a machine. As we move in this direction we begin to touch on some very key and sensitive issues. How do we really know that this new world truly reflects our own? Even if it does – are we interpreting it in the right way? In the real world it only affects a small number of individuals and changes can be made and the model adapted. Computer models on the other hand are designed to be used time and time again by many people who do not necessarily communicate with each other. Mistakes become fossilized and values become frozen to the point where an oppressive tool may have been created.

The author, as a programmer, many years ago became concerned by some of the knowledge he was placing in some computer programmes. As stated earlier in several programming languages the expression 'IF….THEN' was common. IF a certain set of circumstances existed THEN a certain action was taken. At the time we were writing into the programme well recognised techniques and best practice but what if our knowledge increased or society did not want to implement that action when that set of circumstances occurred? This concern resulted in an article in the technical press attempting to articulate the problem (Brandon P, 1981).

In a simple program the assumptions could be changed but not before many had used it or still continued to use it. In a complex program the piece of knowledge became embedded so deep that it was often impossible to find it and extract it and change it. It became part of the system and it was almost impossible to detect the manner in which it influenced the full model or program.

This became even more acute when Knowledge Based Systems came into being. We captured the knowledge of 'experts' and we made that available to those who were less expert. The knowledge of the expert and to some extent his or her value system was now built into the model. We tried to devise ways round this by designating some knowledge as stable (but who says so) and some as unstable and therefore made more explicit and easy to change. This can work in relatively small systems dealing with focussed applications but the trend is towards integrated systems and greater ‘intelligence’ for the machine. In ‘intelligent machines’ we will be leaving more of the decision making to the machine. What algorithms will the machine use and how many of these will represent values? When we begin to have ‘conversation’ with the machine how do we know what mechanisms it is using to guide us towards a particular solution?

This is but one example of where technology is taking us into the value systems arena; although some would argue that we have been there for some time. These are not trivial matters. As we allow machines to intrude on our privacy and on our decision-making are we going to be constantly challenging its reasoning powers as we do in debate and conversation? How will we get all of us to ‘buy in’ to what it is doing when the users are not a coherent homogenous group who can exercise some kind of democratic power? We are already talking about ‘jacking in’ computers direct into the brain. This raises even greater questions about at which point the brain leaves being human and becomes a machine and who provides its value system, man or machine?

This must seem like science fiction to some but it is coming upon us fast. In our research we must ask the question about what we are creating and how this really ties in with the aspirations of our fellow human kind to have a reasonable quality of life. There should come a point when every piece of research but particularly research in terms of knowledge and processes should require a set of questions to be asked about how it impacts upon the society which it seeks to serve.

Concluding remarks

This paper has attempted to explore some of the issues regarding the information revolution and the role of management in construction projects. The last three decades have seen some significant changes in the external environment within which construction takes place but none so much as the revolution in computer technologies. Whilst other industries have embraced these technologies, construction has found itself slow to adapt and consequently it is now often seen as a backward industry, finding it difficult to recruit the best people and to maintain its status as a major contributor to the quality of life of the citizens it serves. It is remarkable what it has achieved through centuries of refinement. Its ability to put together teams to construct some of the most complex artefacts designed by man at short notice and to control the processes to achieve a product acceptable to its clientele is no mean feat. Its contract procedures and systems are some of the most complex available but the question is whether they need to be with the technology which is now available.

Researchers have tried to pave the way for advancement and many of the new tools and initiatives coming onto the market have their origins in universities and research establishments. The focus of research is often dictated by fashion, external developments and the funding agencies. The following figure shows the focus over the past three decades.

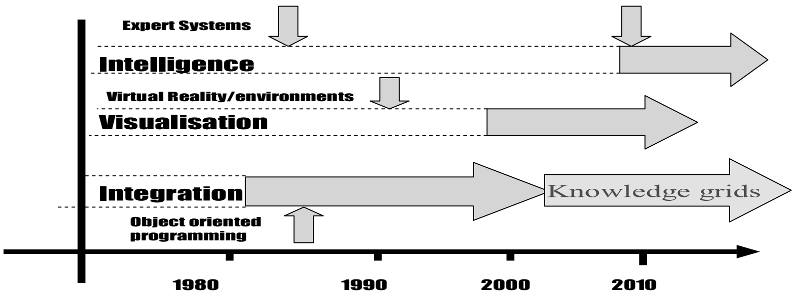

Figure 5: Research themes for IT in construction

For a while in the late 1980s the question of knowledge was key with the Japanese 5th Generation Project driving a world agenda. However the technology was not sufficiently advanced to drive through to many commercial systems. To really tackle the knowledge question and to manage it in complex systems requires an integration of all the systems which go to make up the total project and its management. The focus therefore shifted towards integration as the main theme with object programming providing mechanisms for the reuse of knowledge and its storage and manipulation. However, much or our everyday knowledge comes from what we see and therefore visualisation became the main focus in this decade, led by the computer games industry, but lately with a major advance in technologies through knowledge grids. These grids allow computers to work together to provide the knowledge support required for complex problems. The programs do not reside in one place. Gradually these changes are moving together towards the holy grail for computing personnel, the emulation and extension of human intelligence. As the power of the machine and the access to knowledge supported by automated 'agents' in the system continues to develop then more and more of what we classified as the management function will be taken by the machine. Special expertise of some professions, particularly those with a numerical base has already been eaten into by the drive in technology. The softer issues of management will follow.

It raises many questions about the role of machines vis a vis the human brain. To what extent are we prepared to allow machines to assimilate our knowledge and use it on our behalf? We do not have in place mechanisms for dealing with the nature of knowledge in a machine as we do for human knowledge. Humans can be challenged by a variety of mechanisms and this testing is embedded in our social structures. These matters relating to machine intelligence may be the most serious issues that humankind has to face over the coming century for it pervades every aspect of our decision making processes from going to war to bioengineering, from space travel to building a new construct in a city centre, from the use of the earths scarce resources to the use of DNA maps to determine tendencies in human behaviour. The delegation of management to a machine is not something we should take lightly for its impact will determine the quality of life we have for generations to come.

Whether these approaches result in the tipping point is unknown. It is likely that it is the combination of scientific method, scenario planning and a response to values which will provide the changes that will see construction move in a way which has been seen by many industries. These issues around construction are now reaching a crescendo of movement which seems to suggest that this point is near and we need to consider what part each of us should play.

In conclusion, scientific research underpins our understanding of the future and provides material for our visions; forward looks and visions allow us to provide scenarios in which we can mould events and seek to match the aspirations of society; values underpin all that we do and unless these are part of the foregoing processes then we may be undermining the very progress we are trying to achieve. Values should dominate if the tipping point is to provide us with a technological base which will be human centred and serve humankind and our industry well.

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