UNRAVELLING THE VALUE CHAIN IN CONSTRUCTION

Brian Atkin[1]

ABSTRACT

A study of project processes and information integration has been carried out on ten building projects in the UK, France, Germany and Sweden. This paper summarises the findings and includes comment on the projects and the resultant models of the design and construction process. Functional models of the process were produced, using a computer based IDEFØ tool to show information flows, participants, organisations and IT use. The models were verified and presented in as uniform an approach as possible, using a generic model of the process. Analysis was performed on the models, including checks for consistency and process integrity. The findings indicate that, *inter alia*, IT use is significantly affected by the attitude of the client and the IT capability and orientation of the 'constructor'. Moreover, it is essential to have all members of the project team within the operational 'loop'. Integration is about bringing people and organisations closer together. The generic model has been subsequently developed in line with the best practice elements of each project, changes in construction practices and out of sector best practice in design and production. The result is a new project generic process model that could form a blueprint for subsequent projects. This research will continue, by modelling and costing different project scenarios so that non-value added activities can be isolated and eliminated.

KEY WORDS

Process modelling, functional modelling, design, supply chain, value chain, IT.

1 Professor of Construction Management and Economics, The Royal Institute of Technology, Drottning Kristinas väg 30, SE-100 44 Stockholm, Sweden; email. brian@recm.kth.se

INTRODUCTION

Efforts to improve the supply chain in construction are the subject of numerous initiatives within industry in many countries. The potential for process improvement to deliver real savings in cost and time is not lost on the construction industry's clients. Moreover, the prospect of greater consistency in the process, leading to a more certain outcome has raised expectations. Application of lean production principles to the supply chain is beginning to show benefits in terms of time, cost and quality improvement.

Just how much improvement is possible will depend on the extent to which the value stream can be identified and manipulated to deliver against client demands. In the absence of this, piecemeal initiatives will produce sub-optimal results. Tinkering with a part of the process without understanding the remainder will not result in serious improvement.

An alternative—and the one covered in this paper—is to model the entire process for a project down to a fairly detailed level. Opponents will simply say that it is too complex a task to be performed and that, besides, all projects are unique. Research has shown that even across different countries (for example, France, Germany, Sweden and the UK) there is too much similarity for this matter to be ignored. Detailed modelling of the supply chain, in terms of information flows, participants within the process and the tools they use to communicate—especially IT—has already provided many useful insights (Karhu et al. 1997). A better understanding of how organisations interact at the project level has emerged and will lead to some remedying of long standing failures. Even so, more has to be done to deliver the order of savings in cost and time that have become enshrined in various national initiatives (see for example, post-Latham actions in the UK and the new national Swedish programme, *Competitive Building*).

Preliminary research had shown how even the most basic actions are prone to failure because of information that is not communicated when it is needed, in the form that it is needed and to the people who need it. This merely confirms the problem, but does not necessarily provide firm answers. Further examination suggests, however, that the entire infrastructure for delivering a project has to be taken into account. There are simply too many factors and influences that are being ignored. In this respect, the research is attempting to establish a generic model of the infrastructure for managing the human resources and IT on a project.

This paper describes the findings to date and discusses the next steps for effecting improvement, drawing on the analysis of ten construction projects across four countries.

DIFFERENT LIFE STAGES IN DESIGN AND CONSTRUCTION

All stages in the building life cycle were considered—see below. Comparison was made on the basis of this generic model, taking account of different procurement strategies, and the extent to which information flow was IT enabled. All ten projects were believed to reflect good to high use of IT.

The following stages were mapped.

1. Inception
2. Briefing
3. Feasibility
4. Concept design
5. Scheme design
6. Detail design
7. Tender documentation
8. Estimating and tendering
9. Evaluation of tenders
10. Off-site fabrication/prefabrication
11. Delivery/logistics
12. Production/assembly
13. Testing, commissioning and hand-over
14. Operations/facilities management
15. Re-use/demolition

METHOD OF STUDY

It was considered that all observable information flows should be regarded as necessary to the projects in question, but that an audit of every piece of information was outside the scope of this project.

Project co-ordinators were interviewed on the project sites or in their offices in order to obtain a complete (or as near complete) picture of the information flows, their frequency and the kind of IT being used. Each project was visited, on average for two days: first, to get the general impression of information flows and IT use, and second, to make detailed notes and to refine the analysis. Further days were spent in preparing and validating the resultant information models.

Interviews began by considering the extent to which the list of generic stages applied to the project. The tool used to assist in the analysis and the subsequent presentation of the ten project process models is IDEFØ. This is used to document activities, their relationships and their associated inputs, controls, outputs and mechanisms (ICOMs). This was supported by computer software, AIØ WIN. This is based on the US IDEFØ Federal Information Processing Standard for function modelling.

The basic notation of IDEFØ has been modified for the purpose of this study to aid clarity in the analysis and presentation of information. Input and outputs are shown as normal, that is, as the actual flows into and out of activities. Controls and mechanisms have, as far as possible, been simplified such that the various participants, organisations and authorities that have any bearing on the process are represented as controls; mechanisms remain to cover mostly IT elements and other tools.

PROJECTS

Six of the ten projects are briefly described below.

Out-of-town shopping mall. This is one of the largest building projects currently being undertaken in northern Europe and is being procured under a modified design and build arrangement. The architect was novated to the construction manager during the latter stages of design. It is a fast track project, with a large body of design staff and has faced a number of tests, not least a difficult planning approval. Local sensitivities have been a major factor and constraint for what is held to be the last major project of its kind in the region.

Speculative housing. Innovations in practice, as well as in the use of IT, are reflected in this case study, the design and construction of a medium sized housing project. A striking feature of this project is that of a single source of responsibility under the control of a developer-builder. The adoption of an innovative procurement method took the place of practices that were long considered in need of change. A good example of this was where management of the supply chain had to be completely overhauled. Suppliers became partners in the process and, as such, were given electronic access to the project database. This innovation enabled the project team to eliminate many non-value added activities that otherwise characterise much of traditional procurement.

Office complex built to support the client's expansion into financial services. The design commission was won in competition for a scheme that, subsequently, changed significantly. Whilst the client could be regarded as highly informed or expert, that appears to be true only in the case of its core business. The client was inexperienced and unsure of requirements. This necessitated a close interaction between the design team and the client. Changes very late in the day were a common feature of this project. The architect was novated to a management contractor during the later stages of design.

Public-private partnership detention centre that was the first of its kind involving the use of so many innovative approaches. Major projects can create many challenges. Complexity and a novel form of procurement were just two challenges facing the project team on this large building project as part of a public—private partnership. Add to this a diverse and culturally varied project team and one has the makings of a very demanding project. Perhaps for these reasons, effort was concentrated more on integrating people into effective teams than achieving a high level of IT use.

Microchip manufacturing facility is a major project with a *hands on* client and is based on a management contract. Very high levels of services were required, with extensive clean room technology. The project commenced in November 1996 and has suffered a slight setback through the current economic problems in south east Asia. Work on the site was, in fact, suspended between during the first quarter of 1998. Completion is scheduled for early 1999. The project is welcomed locally as it is expected to provide high levels of employment within the area.

Headquarters building, car park and related facilities for a car manufacturer which is let as four separate contracts. The headquarters building, a 40,000m^2 development, was the subject of an internationally invited design competition. Considerable effort was expended up-front during the competition phase, which provided the basis for the subsequent design commission. The client novated the contract to a developer, with the intention of leasing back the development on completion. The contractor that took over the design and build contract re-let the consultancy contracts, although the developer retained the original consultants in an advisory role. The project reflects a very demanding brief and client and one where the physical location of the project has caused some difficulties. Procedures are highly detailed and somewhat complex. The design commission is a joint venture with partners from two countries.

PROJECTS' USE OF IT

Out-of-town shopping mall. This project's greatest achievement is probably its control over a large and intensive work programme, involving a large number of people and organisations. The construction manager's use of an in house developed system of information, cost and change management, amongst other features, ensures that information flows are controlled and directed to those who need them. This is an information management application on a large scale, with impressive savings demonstrated already in the use of IT over traditional means for communication and the transmission of drawings etc. No organisation is allowed to fall outside the IT sphere or regime. This means that even the smallest of contractors and specialists has to fall into line and enable information flow to be fully electronic. There may well be criticisms of the narrow focus of this IT supported process, but whatever it is the word focus is highly pertinent. IT is used to get on top of a large problem and reduce it to more manageable proportions.

On the downside, the project suffers from what appears to be too protracted a design phase, where information is developed very incrementally and where some inputs (especially those in relation to constructability) appear late in the day. A final impression is of a project that appears to be trying hard to keep up. IT is making sure that, at the very least, the process sticks to the schedule.

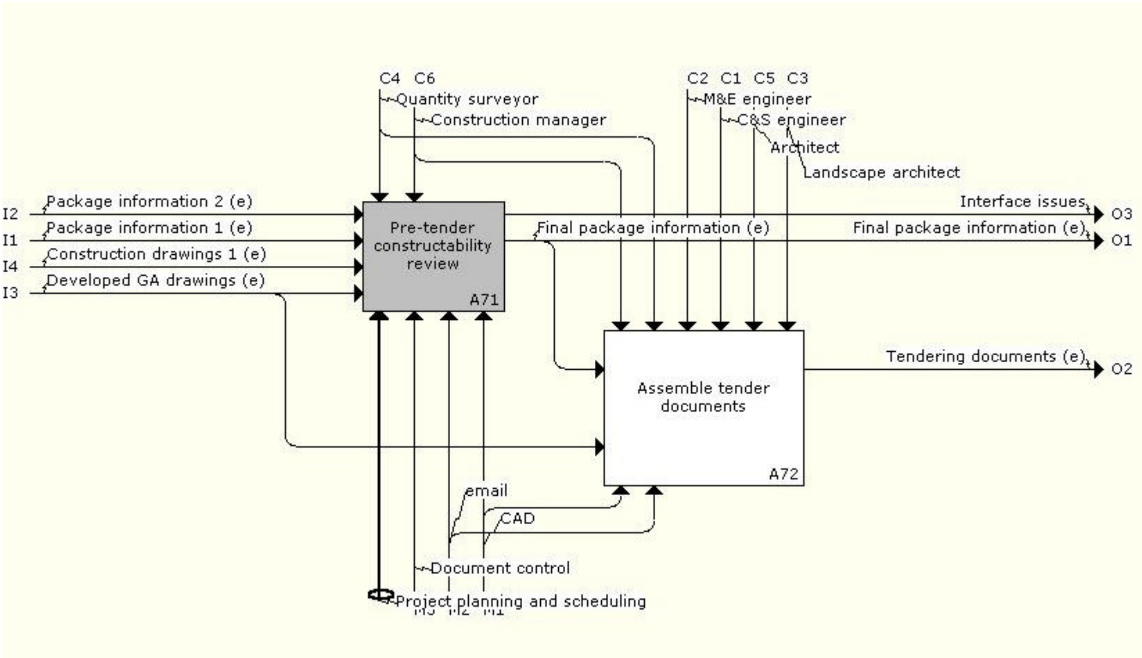

Figure 1: Constructability studies are vital, but should not be late in the day
(the letter (e) after the name of a flow indicates that it is electronic)

Speculative housing. This project exemplifies the concept of integration through a re-engineered process that used significant IT to achieve lower production costs against tighter time-scales. Indeed, the project team was able to boast substantial reductions in programme time when compared with more traditional procurement, including its own previous work.

In overall terms, this developer-builder claims a near 50% reduction in time spent on design today, compared with earlier projects. Particular gains arose from the ability to make changes to the design once only and his ability to communicate them rapidly to those affected. CAD is a key technology for the developer-builder and one that is being used to build object oriented models embodying information about the process. The intention is that these can ultimately be evolved into product models serving the wider needs of the project team, manufacturers, suppliers, the client and end users.

During the project's design, checks for consistency in detailing and clash avoidance—especially in the area of engineering services—also meant that prefabricated components could be manufactured in the knowledge that few problems would arise on site. This latter aspect was important since the time spent on site had been compressed to the point where there could be little tolerance for delays caused by errors and inconsistencies. Bringing manufacturers and major suppliers into the project during the earliest of stages helped to co-ordinate work to the extent that the goal of zero errors in component delivery and assembly is now within reach. Comparison of the use of IT against the earlier manual process showed that quality, reliability, accessibility and re-usability of information was significantly better.

In many respects, this project has moved a long way towards the ideal of making construction more like a manufacturing process. By applying IT to a re-engineered process, the developer-builder has been able to make the kind of progress in integrating project information that would be extremely difficult under more traditional procurement. Despite the enormous gains on this project, the developer-builder is intent on extracting further gains as part of a culture of continuous improvement.

Office complex. The client has relied heavily on the architect's plan of work and IT support for it. Where pressure has come from the client, this has tended to be in responding to changes to the design. The experience of not having the QS as part of the design 'loop' has meant that progress in evolving, developing and refining the design has been impaired to some extent.

Lack of real pressure for IT use on the part of the client and 'constructor' has meant that more reliance has been placed upon the architect's own preferences in regard to the use of IT. This does not necessarily imply a great or innovative use of the technology. Indeed, there are elements of the process where streamlining of working practices could have been achieved had the client and rest of the project team been more IT aware. IT use has supported control of documentation generally and the production of design information in particular.

Public-private partnership detention centre. Whilst IT was present in many forms—desk top PCs, email and database management—there was little linking and sharing of information. Nevertheless, the project was viewed as a success, against a tight time-scale, strict budgetary control and a demanding client. The nature of the project, in particular its intended use, meant that security was an important factor weighing on the project team. The imposition of rigorous procedures, designed to ensure confidentiality and security on what was a politically sensitive project, meant that IT presented too great a risk for the project team.

Limited electronic exchange did take place between various parties, for instance amongst the designers and with the client body, but even these did not amount to a significant attempt to integrate information on a project wide basis. The demands of the project were probably thought to be enough without having to cope with the uncertainty of IT. Even so, the opportunity to enforce better communications between the various actors through, for example, project wide email and drawing exchanges were passed up. Project team members were acutely aware of the penalty for failure on the project and so anything that was unproven was unlikely to be adopted. Given that the project was the first to bring the consortium together, there was arguably no obvious basis upon which to implement an information management strategy.

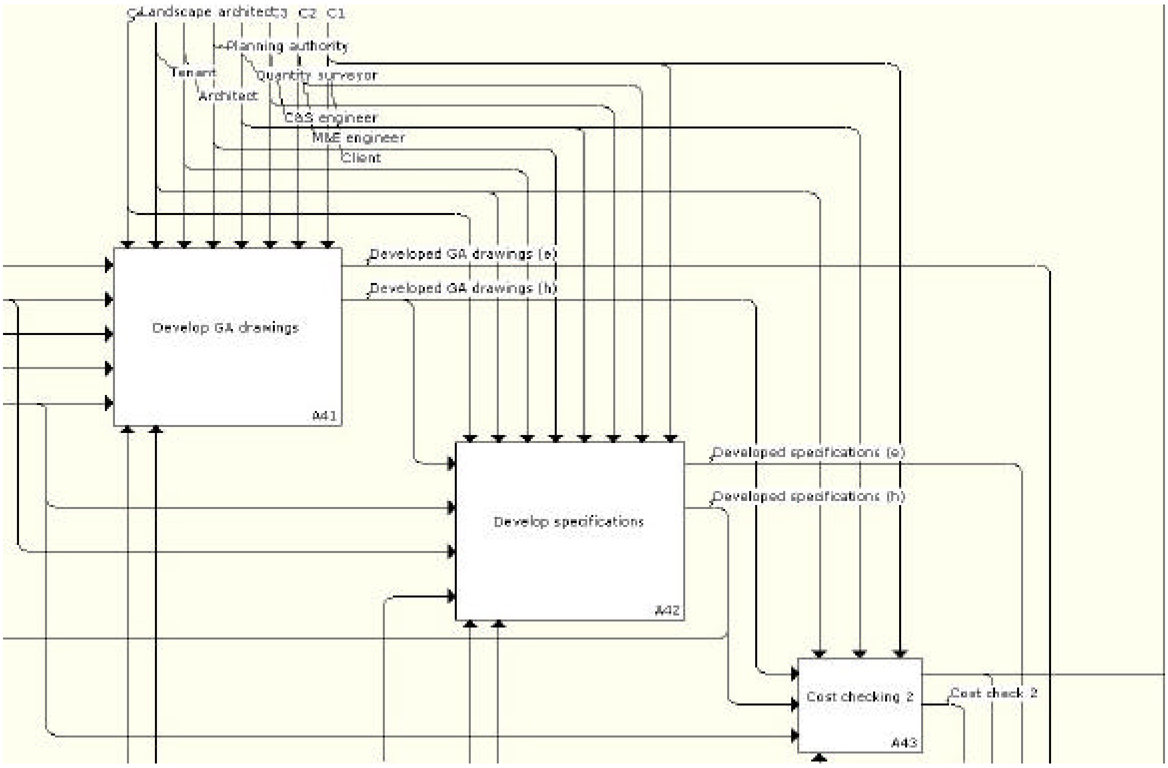

Figure 2: Quantity surveying cost checking function impairs the free flow of information

IT was used in many different ways, but most were in supporting the disparate working practices of the various participants. As a means for exchanging information, IT was rejected for the reasons given above. The co-location of project team members helped team building, but did not necessarily make for an efficient process. Meeting deadlines and working within budgets are not conclusive proof of an efficient and cost effective process. Concentrating attention through the actions of project personnel may not represent the most efficient use of human resources, but it can get the job done. The fundamental issue is therefore one of whether or not IT is necessary for integrating the project team. On the face of it, there is no evidence to support this contention. However, there is no evidence either that efforts to integrate project information would have compromised time, quality or security.

Microchip manufacturing facility. Activities on this project were planned with IT in mind. All drawings were produced on CAD and all documents shared electronically between members of the design team. The client's retained architect, management contractor and the designer each maintained their own servers and LANs for security purposes. All operated with up to date versions of office automation tools and CAD software to ensure compatibility. Limited access was available to areas of all three servers to ease distribution of information. Drawings and specifications were uploaded to the management contractor’s server for onward distribution to suppliers and trades contractors (typically on disk). There was, similarly, a transfer area on the design architect's server where drawings were uploaded for distribution. Hard copy documents were still provided in addition to electronic versions.

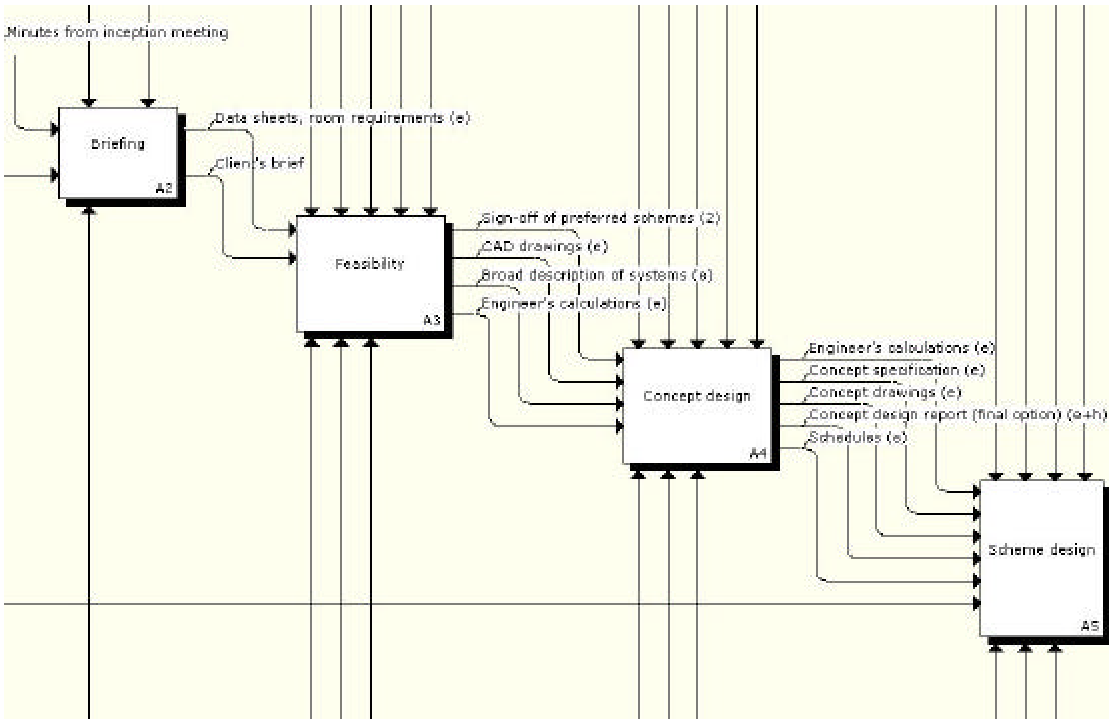

Figure 3: A strong degree of information integration between stages

Internet email was essential to ensuring connectivity with the client (in south east Asia) and other consultants located in North America and elsewhere in Europe. The architect maintained connectivity with head office through an ISDN link to the WAN. Security of data was paramount, with extensive virus checking of all information received electronically.

Headquarters building, car park and related facilities. The project office was based in one country, using the software and CAD facilities available there, and the project was sited in another country. ISDN links were established to the site in order to exchange data with the local design partner and other members of the design team. This was also used to send drawings to a print shop near the site. Data exchange was accomplished by internet email and attachments through the ISDN connection. Internal email in the main design office was automatically forwarded to the external system if the project manager was at the site.

90% of the design and electronic document generation on the project took place at the design office which had both space and resources. The site office was, on the other hand, very small during the initial phases of the project and connectivity was maintained through a modem link to a laptop computer. Later, the site was connected to a LAN in a new office in the same town as the site.

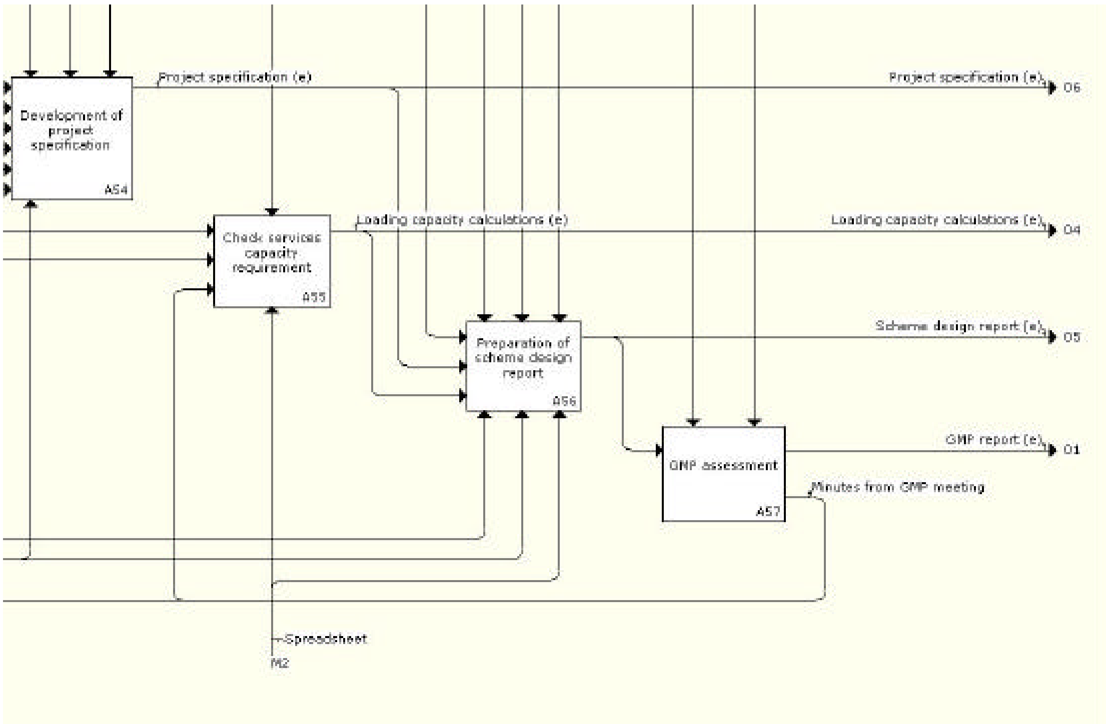

Figure 4: Even at a very detailed level there can be good integration

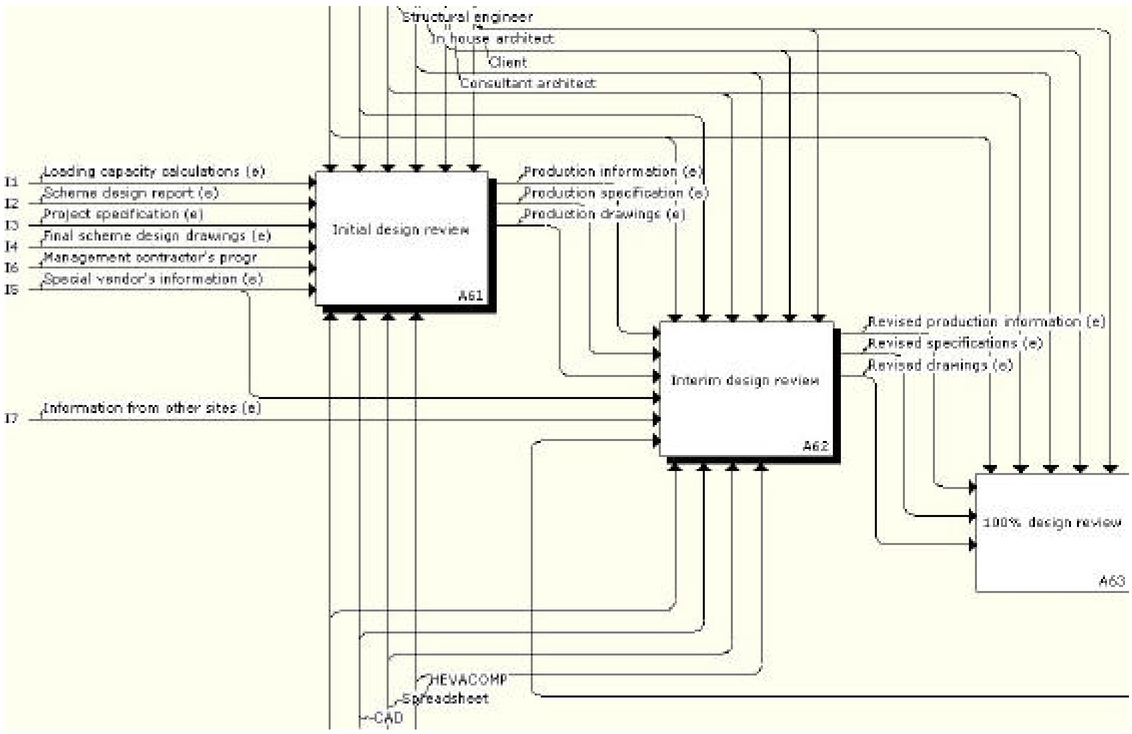

Figure 5: Focused involvement of the client and team in design reviews

MAIN FINDINGS

There are several findings that are significant overall and that warrant separate discussion.

1. *Design is largely a process of progressive and iterative development of information and detail used to describe the building—the traditional distinctions between the different stages have become blurred. There is good reason to question the several traditional stages that constitute 'development of the design'. Collapsing three stages into two looks sensible and is feasible*.

   Procedures are generally geared to plans of work that are not closely aligned to the objectives and demands of the particular projects on which they are applied. When interviewing project managers and co-ordinators, it became clear that their thinking was framed in terms of the established plan of work. This might seem self evident, but the implications are that innovative methods can be shoehorned into an inappropriate plan of work. What could appear to be complicated and carefully detailed procedural elements within the models might well be more a consequence of an ineffective plan than a necessary problem solving function. Allowing the design to develop through the several traditional stages can mean that time is not spent productively enough. More time should be allocated to the earlier stages in the process.

2. *Quantity surveyors—by no means a rare breed—are not properly integrated into the process. QSs must be able to interface electronically. There is the potential for delays and bottlenecks, because they are still requiring paper based information. Their physical dislocation from the rest of the design team also means that they cannot contribute efficiently to the evolving design. Concurrent working is not possible. It is a classic case of reaction, as opposed to proaction*.

   The QS can be too easily left outside the loop of close interaction between the design disciplines. One reason for this is that the external (client's consultant) QS is not used in a way that actively supports such interaction. The consequence is that the QS exercises a limited role. This has to be contrasted to a situation where an in house QS (i.e. one working with the designer) or value engineer could contribute proactively to the search for a better value for money solution. The role of external QSs is, in contrast, rather more about cost minimisation and, therefore, considers only part of the value equation.

3. *The degree of IT use and, therefore, integration is influenced by the extent to which the client and 'constructor' see IT as an important factor in achieving project success. Everyone in the value chain must be connected through IT if success is to be assured*.

   This is borne out by all projects to a greater or lesser extent. The shopping mall development illustrates what can happen when the 'constructor' ensures that everyone is locked into the system. Savings in cost and time can be substantial. The attitude is one of no exceptions. Even the smallest firm can have no reason for failing to implement effective IT. No one is allowed to hinder the smooth, electronic flow of information. Significant time and cost savings are demonstrated from this approach to IT use.

4. *IT is being used to support innovative methods of procurement and technology procurement. The highest degree of project information integration is where there is a single source of responsibility for the project.*

   Integrated project information is also greatest when there is a physical distance between the participants, for instance when they are located in different regions. IT use is generally lowest where project teams are co-located. This working arrangement has benefits for team building, but tends to mitigate against co-ordination of information and can succeed in building paper bureaucracies.

Many examples of good practice exist and are noted mostly by the seamlessness that results from an IT enabled process. There is, however, real danger in that what appears to be a good use of IT might be little more than the reinforcement of a practice that adds little value for the client. Faster information is not necessarily better information.

Specific examples of good practice include:

- electronic, seamless transfer of design information, where printing of drawings and specifications is a final action on the part of the recipient (as required);
- consolidated summary documentation (in the form of reports) *spun off* as statements of the outcome of a given stage; and
- integration of design disciplines through the use of CAD in a way that allows near concurrent working.

GENERIC PROCESS MODEL

Elements of best practice within the ten projects, which are consistent with changes for the better in the industry, have been identified and are presented as part of a generic process model. Of these changes, *managing client's requirements*, *integrating design and construction as a single process*, *value chain management* and *total project management* are major factors in achieving project success.

The search for best practice has been extended beyond construction to other industrial sectors where lessons can be learned for improving the overall process. The generic process model is, therefore, more than just a basic distillation of ten projects. It could be used for benchmarking performance and as a blueprint for future projects that can be adapted to suit the needs of individual clients.

Within UK construction are several current initiatives aimed at process improvement. These include the Agile Construction Initiative (Bath 1998), Prescott-Egan construction taskforce (Building 1998) and *The Agenda for Change* by The Construction Round Table (CRT 1998). All three aim to reduce cost and time dramatically, whilst raising quality and certainty, and are strongly client focused. Improvement is sought in three areas:

1. design of the building or facility;
2. delivery of the building or facility; and
3. trading environment.

Design of the building or facility

- Understanding and measuring the customer's needs.

- Using design techniques and processes that address those needs.
- Identifying and managing the risks.
- Achieving predicted design performance.
- Benefiting from proven standardisation.
- Measuring customer satisfaction on the outcome.
- Continuous and sustained improvement in design.

Delivery of the building or facility

- Adopting the most efficient construction processes.
- Establishing integrated project teams.
- Eliminating waste and achieving zero defects.
- Shifting the emphasis from construction to production.
- Investing in people and their skills.
- Eliminating accidents.
- Measuring and publishing performance.

Trading environment

- Value base sourcing of suppliers and specialists.
- Collaboration with suppliers and specialists.
- Building strong relationships with suppliers and clients.
- Creating a culture of certainty.
- Simplified commercial stream (for payments).
- Measuring performance in the value chain.

In order to achieve the above and as a reflection of the elements of best practice distilled from the ten projects, it is necessary to redefine the life cycle stages. This has produced a sequence that is markedly different to that adopted as the basis for modelling the ten projects. This has occurred for two reasons. First, many activities performed on the projects do not fit comfortably within the original stages, since they attempt to deal with the unique circumstances of a client and/or a constructor-driven process. Second, the original generic stages do not adequately reflect the emerging structural changes outlined above. For these reasons it has been thought necessary to reconsider the entire process.

PROPOSED NEW GENERIC STAGES

Analysis of elements of best practice and their application to construction has produced the following stages for a generic process model.

1. Project initiation
2. Project definition
3. Outline design
4. Advance works procurement

5. Detailed design
6. General works procurement
7. Production
8. Facilities management

This reduced set falls naturally out of the project analyses and includes all the value adding aspects of current process improvement initiatives and traditional plans of work. However, it differs in several respects, not least in its use of terminology that is intended to avoid potentially misleading assumptions about what is or is not included. Perhaps the main differences are in reflecting the concurrent and iterative nature of design and its overlap with construction. The proposed generic model also attempts to align more with a process that is client-driven and for which the ultimate deliverable—the building or facility—is just the beginning of the next phase in the business cycle. Whether or not this proposal becomes the generic process model depends largely on the extent to which identified changes within the construction industry are seen as threats or opportunities.

These new generic stages are drawn without either controls or mechanisms. Overlaying the latter, as has been the practice on the ten projects, leads to a cluttered and confusing picture. It is unnecessary to show all lower level inputs, outputs, controls and mechanisms at the top level. The amount of detail should be consistent with the level at which the model is viewed.

These stages are now described with reference to the model itself. Flows of information are not marked as electronic in the way that they were in the earlier examples, since all are deemed to be so.

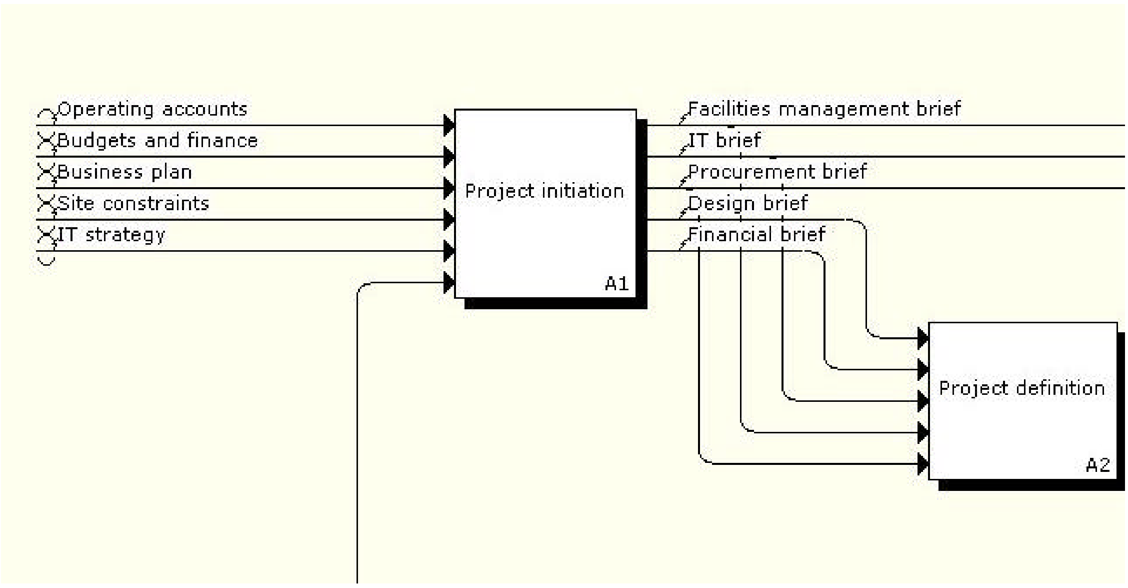

Figure 6: First two stages of the new generic process

Project initiation (A1) portrays the earliest stages of a project's life where the decision is made to proceed with the idea of a building as a possible solution to the client's needs. From the definition of client's needs, project objectives give rise to briefing. This is often regarded as a single outcome activity, that is, a singular briefing document is produced. Research has revealed how best practice in briefing, both within the construction sector and within manufacturing, considers several different, but interrelated documents. There is the design brief, which will be used, *inter alia*, to express the architectural, engineering and functional requirements of the project. But there are at least three other briefs. Of these, the financial brief is more than a cost plan under the traditional system, since it embodies a breadth of information that is used to set the project on a sound financial footing. Implicit in this is a life cycle appraisal approach to cost planning. Instead of life cycle considerations being added to a capital cost planning approach, they become the dominant feature.

Two other briefing documents are produced at this stage which inform later critical stages in the process. The procurement brief sets out, *inter alia*, the actions, requirements and time-scale for organising contracts and buying work packages. The facilities management brief ensures that matters essential to the successful functioning and enjoyment of the building are brought to the fore and do not become an afterthought. With the growth of public-private partnership projects, it has become clear that the management of the building or facility is a priority concern and one that directly affects funding prospects. Little in the way of technical IT solutions are used or, indeed, needed here. Office automation tools and an effective communications infrastructure will ensure that more order is put into the process.

Project definition (A2) is where the form of the project emerges. The first part attempts to produce a design concept that feeds off the design brief. The overall design approach, models and sketches are used to establish proof of the concept. Other primary inputs are the remaining briefs. From this stage emerges a workable design, complete with cost limits and time constraints, i.e. a focus on a design having clear quality, cost and time objectives. Within this stage, separate consideration is given to the several facets of design: architectural, structural engineering, environmental, geotechnical and landscaping. This is also where we see the close interaction of a design value for money function. Life cycle appraisal becomes part of the overall design discipline. It effectively replaces the traditional, external quantity surveying function that ordinarily delays the iterative, convergent development of the design. This is an opportunity for the design discipline itself to achieve greater value for money. This is why there should be a value engineering input. In practice, this could be QSs with particular aptitude towards design economics. Additionally, they will need experience of constructability issues.

The now recognised role of the planning supervisor is brought into establishing proof of the concept. This contribution is integral with that of the value engineer and the design discipline overall. It will also begin the process of ensuring the elimination of accidents. Proof of concept is also where the first applications of value engineering occur—this is something that should be a continuous feature of the design phase. Moreover, it should be design-driven, not left to external disciplines to impose cost and quality cutting exercises.

IT use within project definition is largely a matter of graphics-based systems, (CAD) and GIS. Office automation tools provide the support for most other activities, within an IT infrastructure that enhances communication across the project team.

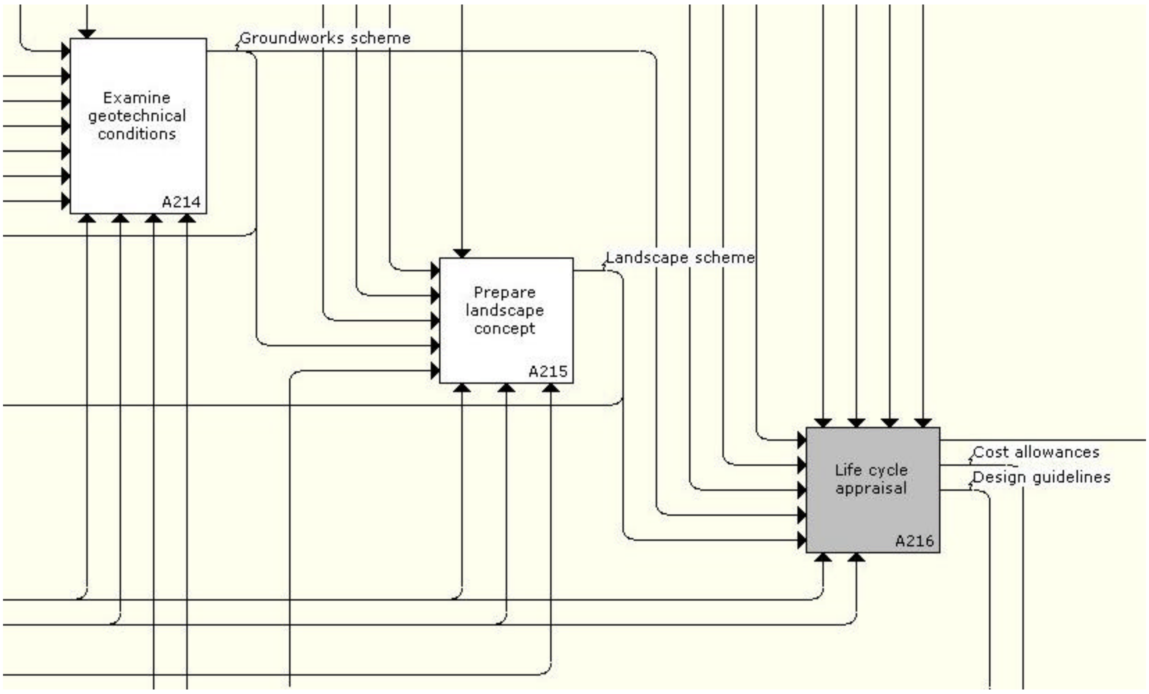

Figure 7: Life cycle appraisal effectively replaces plain cost planning/checking

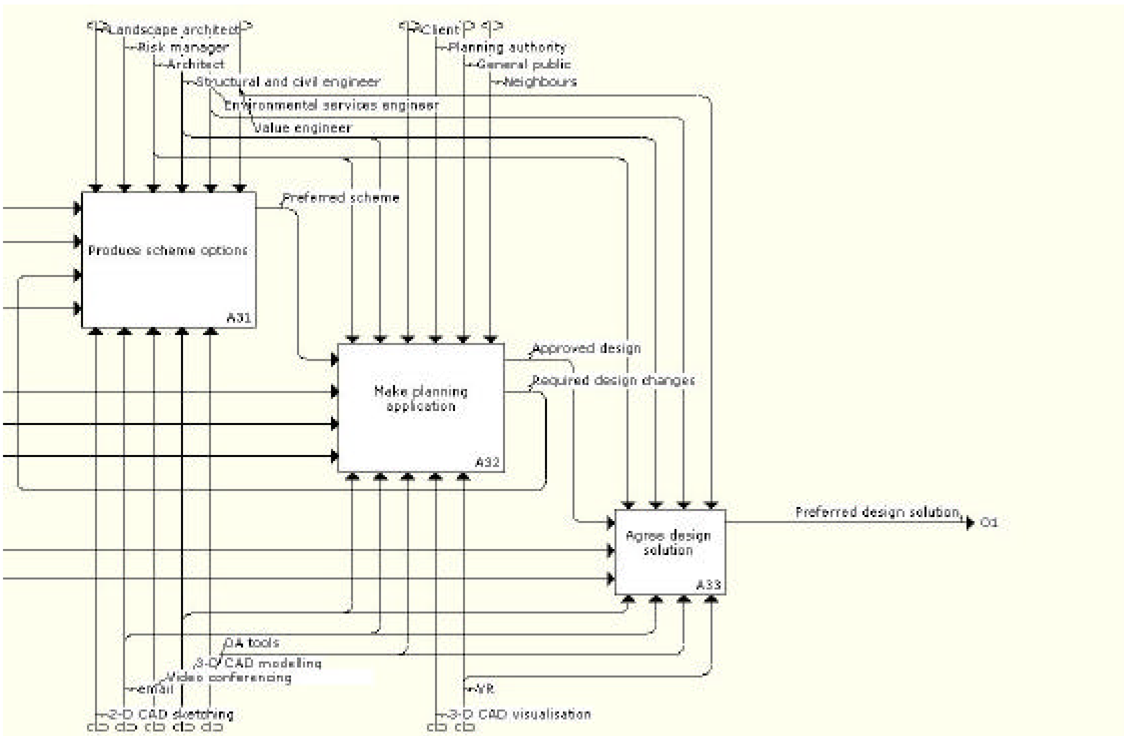

Figure 8: Using a range of existing IT to establish the concept

Outline design (A3) is where various design options are explored and from which a single, preferred scheme emerges to form the planning application. Beyond this point a single design scheme can be adopted as the preferred design solution. Throughout this stage are many hidden iterations supported by IT in the form of CAD and other means for understanding how the design will manifest in practice.

Advance works procurement (A4) deals with the need to commence some parts of the detail design in advance of the generality and which may be the subject of the work of specialist contractors or suppliers. The procurement of such specialist services will have been identified within the procurement brief and arrangements made to negotiate or tender these works. At the operational level, the aim must be to ensure that any external designers do not fall outside the loop of IT use. They must be properly integrated if information is to flow seamlessly. The essence of this stage is that preliminary design will occur in a number of areas. This is referred to by some practitioners as *technology clusters* and is reflective of the need to concentrate on major elements of the building having strong connections and for which design and production must be largely concurrent. Five technology clusters are identified here: *frame*, *envelope*, *engineering services*, *groundworks* and *fit out*. IT support is largely the same as in previous stages, that is 3-D and 2-D CAD, office automation tools and a communications infrastructure.

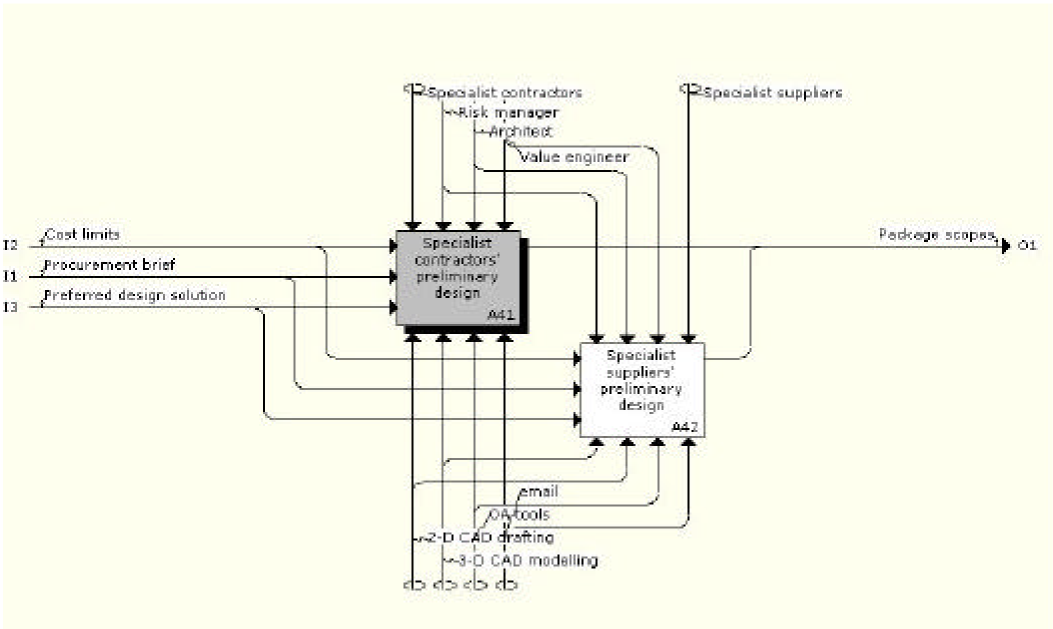

Figure 9: Specialists must be fully integrated into the process

Detailed design (A5) draws on developed package scopes alongside the preferred design solution to produce design details. Interface issues are identified and resolved here and a final detail design emerges. This stage is essentially the same as that within the traditional process, except that it integrates the final stages of specialist contractor design with the generality of detail design. As in other stages, there is no differentiation between drawings and specifications. Electronic means have the capability of allowing different forms of abstraction or representation of a design than has traditionally been the case with paper. In other words, the move is away from seeing CAD as a means for simply automating the production of paper drawings and the use of dedicated specification writers. IT use is, therefore, broadly the same as in previous stages.

General works procurement (A6) covers what were originally three stages: *tender documentation*, *estimating and tendering* and *evaluation of tenders*. This stage is intended to accommodate the remainder of work packages, although the same basic arrangement could be used for the procurement of specialist works. This could be achieved by linking the procurement brief and preferred design solution outputs from earlier stages to this stage and providing a feedback to advance works procurement. Graphics-based systems are used in the bid package preparation stage, alongside office automation tools and the communications infrastructure which supports the complete effort.

Production (A7) recognises the trend towards shifting more of the production off site to factory controlled conditions. Fabrication allows the often long and complex process of off site production to be properly integrated into the totality of the project. It requires a more proactive approach on the part of the project team than has hitherto been the tradition. This stage emphasises also the need to secure evidence of compliance with the specification and other control instruments. Indeed, control over this phase in the overall process will become even more important in future. IT integration is vital. Other aspects of this stage include assembly and commission. These cover the delivery, materials handling, component fixing and the finishing and commissioning of the works. In other words, they are a sequence of activities aimed at ensuring a fully functioning and certifiable building or facility, complete with supporting documentation. This latter aspect is only really likely to be managed successfully if there exists a comprehensive IT infrastructure. Documentation that signifies compliance and provides the means for effecting a smooth transition to occupation are emphasised here.

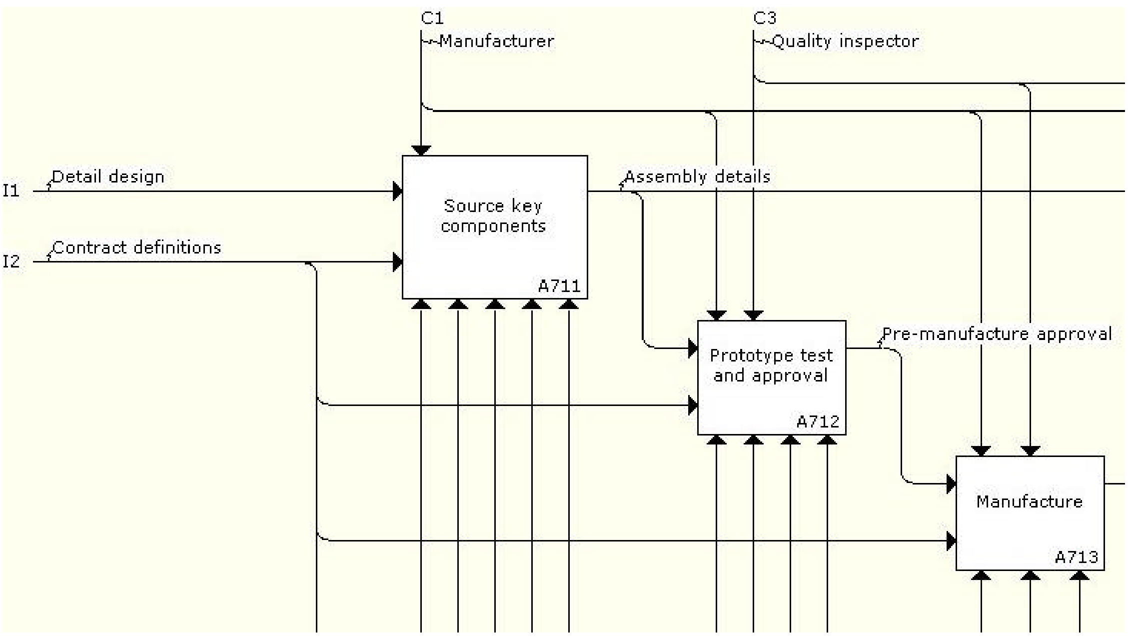

Figure 10: Off-site fabrication is a key activity

Facility management (A8) completes the process and provides the basis for a new phase in which the actual demands placed on the building by the client and users can be converted into plans for changes to the building. This stage links directly back to project initiation. Successful development of the design in an electronic form will enable live CAD models to be transferred to the managers of the building or facility without the need for paper drawings. The facilities management brief has the potential to ensure that successful management of the facility is more by design than chance.

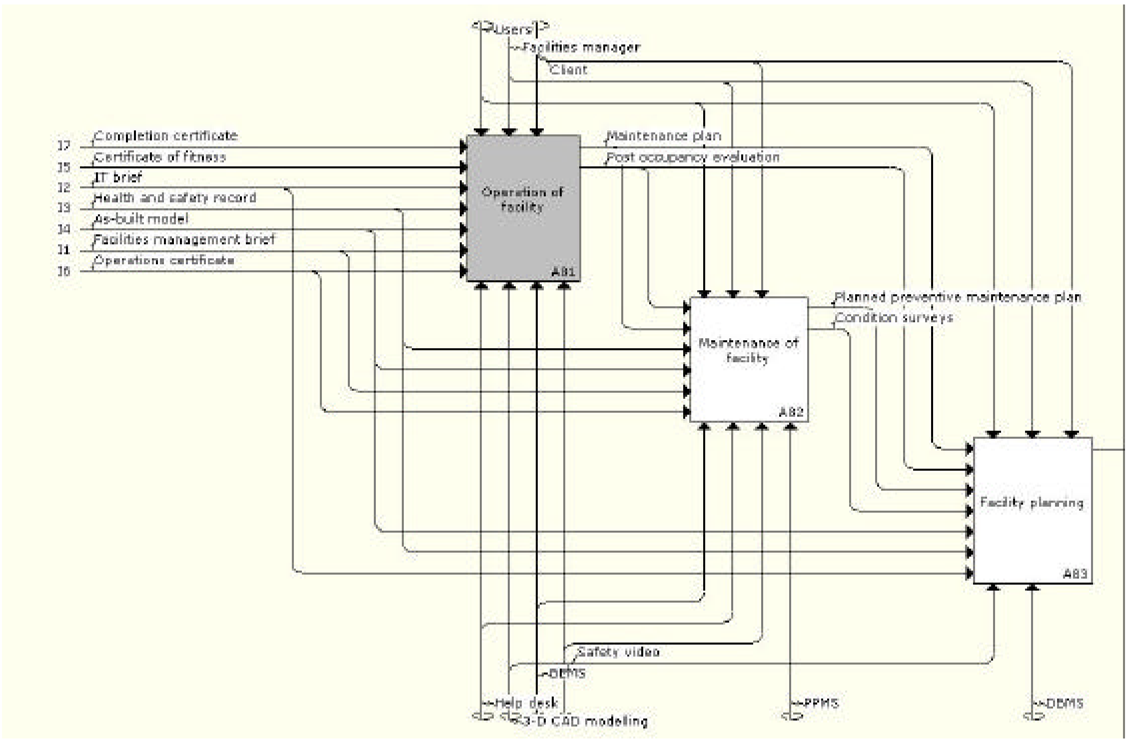

Figure 11: Retaining the design model of the building to support FM

NEXT STEPS

Each of the projects has been analysed and presented using a functional modelling tool. The tool has been used to compile a generic process model. This same tool can also be used to capture process time and resource costs for activities, resources and products.

The initial benefits of using the tool are in organising, modelling and analysing projects As-Is functions and their dependencies. In the next phase of the research, the tool will be used to:

- identify value added functions, that is both essential and non-essential non-value added functions;
- track and analyse the cost of the project's activities with automated activity based costing;
- model the project's To-Be functions and their dependencies, from which new strategies for performing those functions can be implemented.

The expectation is that different project scenarios can be modelled and costed so that optimal value pathways can be found through the project.

CONCLUSIONS

The research reflected in this paper is a partial account of attempts to re-engineer the design and construction process along the line that has added value as its objective. Armed with base information as to how real projects perform and a blueprint for a new project generic model, the research effort will concentrate on refining the process through feedback from live situations. In this respect, IT will be sure to play an increasing role, though not one that will involve more than proven tools and techniques many of which are low in cost.

REFERENCES

Bath (1998). *The Agile Construction Initiative*. University of Bath, UK, see web site at http://www.bath.ac.uk/Departments/Management/research/agile/home.htm accessed on 15 July 1998.

Building (1998). "Rethinking Construction." News report, *Building*, 17 July 1998, p8, comment on the launch of the UK government-construction client task force.

Construction Round Table (1998). *The Agenda for change*. The Construction Round Table, BRE, Watford, UK, 6pp.

Karhu, V., Keitilä, M., and Lahdenperä, P. (1997). *Construction process model: generic present-state systematisation by IDEFØ*. VTT, Espoo, Finland, 190 pp.