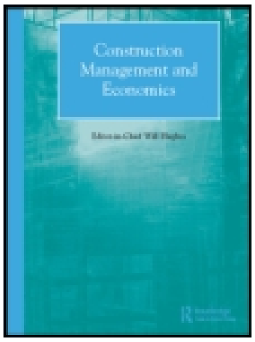

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The development of an expert system for the strategic planning of construction projects

Peter S. Brandon

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The development of an expert system for the strategic planning of construction projects

PETER S. BRANDON
Professor, Department of Civil Engineering, University of Salford, Salford, UK

The paper outlines the problems associated with cost models and the role of professional expertise. It then outlines the production of an expert system to be used at the strategic planning stage of the development process. The system was developed in collaboration between the University of Salford and The Royal Institution of Chartered Surveyors (Quantity Surveyors Division) and funded under the British Government's 'Alvey' IKBS programme.

Keywords: Expert system, strategic planning of construction projects, budgeting, procurement, time, development appraisal

Introduction

The UK construction industry has developed a series of management models over the years, largely related to financial planning, monitoring and control. Many of these models are of a mathematical or statistical nature and, in some cases, are of complex construction. Despite this growth in development an investigation of consultants and construction site offices would reveal that the use of traditional models is still the norm and there is very little likelihood of this changing within the foreseeable future. Computers are installed extensively throughout these offices but their role appears to be to make the former manual processes more efficient rather than exploit the increased potential brought by the machine.

It may be that this is inevitable because consultants are reluctant to move away from the knowledge which is familiar to them. This knowledge forms the foundation of their technique. To move into what they perceive to be unknown territory, where they lack experience, is not something they wish to do in a commercial situation. This is particularly true on large projects in a competitive environment where they can be held liable in the courts if they do not perform satisfactorily. Most consultants are expert in their own domain, that is they have a deep and proven knowledge and they are recognized as persons who can be trusted to give advice to solve real problems in that domain.

Their knowledge is often built upon a very light skeleton of information in the form of a model which they use as a simple framework or reference point (Brandon, 1984) which they embellish from their experience. For example, Martin Skitmore (1985) discovered that for certain types of building an expert would only require between 6 and 15 items of

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information at the brief stage of a project to provide a realistic estimate comparable to that of the tender figure. The expert uses his imagination, knowledge and experience to fill in the gaps and expand the information available on the project at that time. He appears to look for 'signals' coming from the client's brief, the description of the site and conversations with other consultants to 'trigger' his thought processes in a certain direction.

With traditional mathematical models it is difficult to mirror this process. It requires a knowledge of the world which cannot be captured easily within a formula or conventional computer program. The expert is merely using his model as a reference point to which he adds his wealth of experience and weaves his knowledge of external events to produce a solution.

Despite this ability the expert often produces at a later date a quite complex model to achieve the same result that he obtained with the simpler, earlier one. It could be argued that the use of the more detailed model is merely to justify and support (and possibly check) his own 'head model'. It is merely a means of externalizing his thought processes in such a way that others, notably the law courts and the other members of the design team can comprehend and satisfy themselves that due care has been shown. These more detailed models may be more about accountability than judgement.

Herein may lie the problem with the new wave of models particularly in the field of building economics. The development of statistical and operations research models has continued at a regular pace in recent years but few have found their way into current practice. Many of these techniques require the transformation of cost data within the machine in a way that is inaccessible and sometimes hidden from the user – at least without considerable effort. The 'black box' nature (Beeston, 1983) of the model, excluding as it does the judgement of the professional, means that implicitly the model must be perfect or at least as good as the consultant.

So to whom are the new models aimed? In most papers describing the new technique the target group is left undefined but by implication within the text it is the consultant. However, building projects are noted for their uniqueness and the variety of problems which they pose. It would be a very sophisticated model indeed which could cope with all the issues which in the normal course of events the consultant has to handle. If he is excluded in any way from the support information which is used, or the reasoning process adopted, then it is unlikely that he will place confidence in the model. It may be that one of the reasons for the lack of 'take-up' of statistical/operations research models within the building professions is this remoteness that the user feels from the processes by which the problem is apparently solved.

This is not meant to be an argument against the adoption of the new methods. In many cases they have improved understanding but it does appear that if they are to be implemented on a wide scale then they need to be made more transparent to their users.

It is also likely that a way will need to be found for a gradual change from traditional to newer methods. Current professional expertise is based on the data and framework of the older model. If the new version requires different data and different thinking processes, then the consultant will require much convincing before he is prepared to take a risk by employing a new concept of which he has little experience within a commercial domain. It is interesting to note that of the SERC-funded research projects investigated by Lansley (1983), the one which received most praise for speed of implementation was the one that was closest to current practice. Researchers will need to devise methods by which new models can evolve from the old if they are to expect a significant shift in model adoption.

However, there are signs of a willingness for firms to move to new methods and it may be that the advent of expert system technology has provided the vehicle by which this can be achieved.

Expert systems

Expert systems by their very nature attempt to replicate at least part of the thinking processes of experts. Indeed psychologists are using such systems as models of the brain to further their understanding of human behaviour. In addition such systems offer an explanation facility which can identify the reasoning process adopted. They are therefore reasonably 'transparent' to the user and perhaps more importantly they mirror his thinking and thereby reinforce confidence in the system. More than this most systems allow the user to interact with them and override the assumptions made enabling an imperfect model to be improved by the expertise of the expert.

In addition because expert systems can work alongside conventional computer models, using them in the same way a human would, they can be used to explain, analyse and interrogate these models without the restrictions of human brain power. They may well have therefore the ability to use and explain the newer models in a way that will gain the confidence of the user and provide a vehicle for a transformation in professional practice. This has yet to be proved but the potential appears to be there.

The application of expert systems

The problem is that expert systems are in their infancy and paradoxically, bearing in mind the above discussion, they need to be introduced in a manner and in a domain which will not alienate the user and cause a crisis of confidence. Small incremental steps in which careful attention is given to the user interface, appears to be the order of the day.

The choice of expertise which should be captured in an expert system is a difficult one at this stage of their development. It appears that most success in expert system application is gained in areas involving a fairly low level of human judgement, e.g. the purchase of airline tickets or the diagnosis of faults, where clear procedures exist to identify the source. Domains where rules and regulations exist are favoured by many expert system builders. However, much professional expertise is of a creative or interpretive kind, very often based on experience. Figure 1 shows a diagrammatic view of the shift that occurs in professional development away from 'text book' knowledge and general theories towards knowledge gained from experience. By its very nature the latter is not made explicit to the same degree and is therefore more difficult to capture. The situation is aggravated in the management problems in which many professionals are involved. As Blanning (1984) states, 'it is an area where the goals, the possible action of managers, and the relationship between management decisions and their consequences are not easily made explicit'.

In the construction field, expert system builders have discovered problems even where the domain appears at first sight to be well constrained. The developers (Harris and Wijesundera, 1986) of a system to select plant for high-rise construction identified nine main factors determining the choice of plant, but stated for eight of these factors: 'no definite rules governing the weighting of each of these variables could be ascertained; the final decision

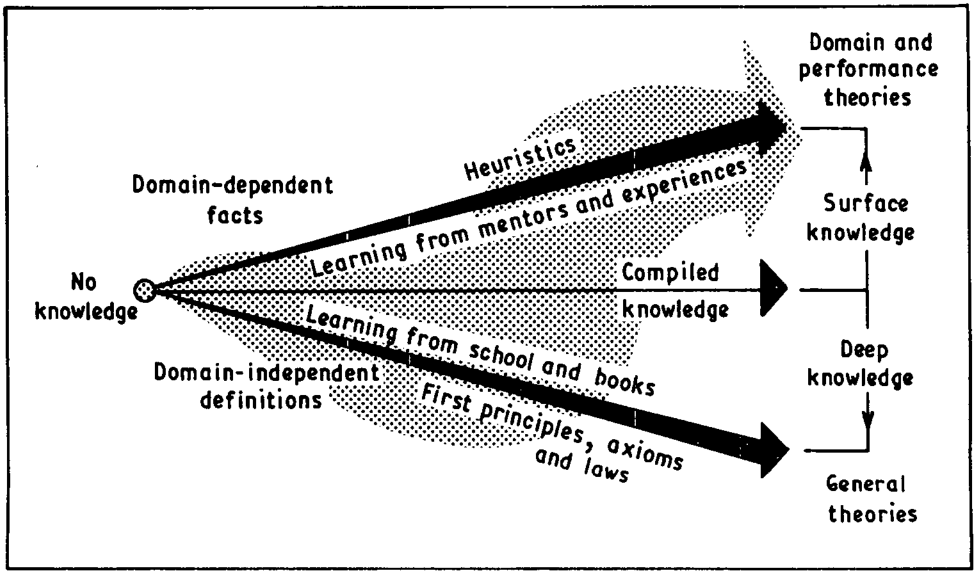


Fig. 1. General pattern of professional development (Harmon and King, 1985)

being an unknown combination of each variable depending on the people making the decision and their past experiences'. They concluded that

> while the potential of the technique for capturing knowledge in a readily usable form has been encouraging, the complexities of rule encodement required of the computer programs would presently limit the application to well-defined knowledge areas . . . the selection of construction equipment being largely based on uncertain and intuitive knowledge allowed only broad rules of thumb to be formulated. Further development of this particular application is therefore unlikely to gain authentic support, until more output data and production information appertaining to plant and labour resources have been evaluated and more generally applied by practitioners in their planning and estimating processes.

The RICS 'Alvey' project

It was similar views to these which influenced the choice of subject matter for a major grant of £200 000 awarded by the UK Alvey Directorate to the Royal Institution of Chartered Surveyors in collaboration with The University of Salford. The purpose of the grant was to increase the awareness of expert systems within the construction industry and was made to the Quantity Surveying Division of the RICS whose members had played a leading role in implementing computer technology within their profession. The Alvey Directorate was inaugurated by the British Government to combat the Japanese 5th Generation Project. Funds totalling £350 million were provided with a further £150 million to look at various aspects of computer technology including IKBS systems.

The management of the project involved a research group (comprising two knowledge engineers and a quantity surveyor) directed by a research director, and a steering committee chaired by a practitioner incorporating three members of the RICS Quantity Surveyors

Division. In addition a Project Manager from the RICS undertook the liaison with the Alvey Directorate and general matters of administration. A 'User Group' of 12 leading practices was formed from members of the Quantity Surveying Division of the RICS whose firms were active in computer-based methods. This user group, together with other personnel within the firms represented, provided the knowledge upon which the expert systems were based.

Approach

The research was originally intended to be in two distinct stages. Stage 1 was to develop a simple pilot expert system which would allow all those involved in the project to become familiar with the new technology and to firm up the brief for Stage 2 based on this experience. Stage 2 was expected to develop one or more expert systems which would form a datum and which would eventually be able to be developed into a commercial product.

In practice it was found possible to follow through on the work commenced in Stage 1 and combine both stages together to provide the working system described later.

Subject choice

In determining the choice of subject for the expert system these four key criteria were used:

(1) It should be in a subject area which involved judgement since this was central to the role of the profession.

(2) It should be in an area of importance in professional decision making since many of the current 'toy' demonstrator systems in the construction industry related to peripheral activities and did not prove useful to practitioners.

(3) It should be in an area which could provide the foundation for future development.

(4) It should be in an area in which quantity surveyors had the knowledge but where that knowledge is relatively scarce.

After considering these issues it was agreed to design a system for the strategic planning of a construction project prior to formal design. Major commitments to cost, quality and time are made at this stage which have an effect throughout the development process.

The expert system was designed therefore to play the 'lead consultant' role for a commercial client considering the decision to build.

Accepted limitations

In order to achieve maximum awareness within the constrained time and resources available it was agreed to accept the following limitations:

(1) The system would be developed on an IBM PC AT – the most popular machine available in quantity surveying offices.

(2) An expert system shell would be employed and after some market research SAVOIR was chosen.

(3) Only one building type would be considered and 'offices' were chosen as most practices would have some experience of this type of building. However, half of the developed system relates to a wider range of building type and the other half has the potential to be adapted.

(4) The system would be used by the quantity surveying profession – this would avoid problems of technical vocabulary and procedures.

In fact the target user was defined still further to a member of the generalist middle management of a quantity surveying firm who has the knowledge of the basic principles behind the techniques but not the specialist or detailed knowledge of the building type, i.e. administrative buildings. These assumptions with regard to the user enabled the knowledge base to be constrained within acceptable limits for the 18 month contract.

The subject

The major issues to be faced in the strategic planning of a project were broken down into four components, each of which was developed into a single module before integration at a later stage:

(1) *Financial budget.* How much money will I have to spend to get the kind of office block I require and what standard of building will I get for my money?

(2) *Procurement.* What will be the most appropriate method of arranging the individual responsibilities of the design and construction teams in order to achieve the building on time and within the flexibility required by the client?

(3) *Time.* What is a reasonable time for undertaking the feasibility, design and construction activities, taking account of project particulars and constraints?

(4) *Development appraisal.* What is the profitability of the scheme likely to be and/or how much time can I afford to spend on the site etc.?

Each of these facets of strategic thinking is linked to the others (see Fig. 2). It was an important feature of the final system that all four modules were interlinked. This has been achieved by a common database into which are placed the answers to questions input by the user together with the assumptions and recommendations derived within the machine.

The expert system problem

Each of the four modules represents a different type of expert system problem:

(1) *Financial budget.* This is an 'intelligent front end' to a conventional estimating model.

(2) *Procurement.* This is a diagnostic problem which takes the client's needs (symptoms), identifies the problem (diagnosis) and suggests a suitable approach (remedy).

(3) *Time.* This is a planning problem involving the establishment of critical activities to determine the overall time of the project.

(4) *Development appraisal.* This program interacts with a conventional valuation model and provides additional knowledge as to certain input values.

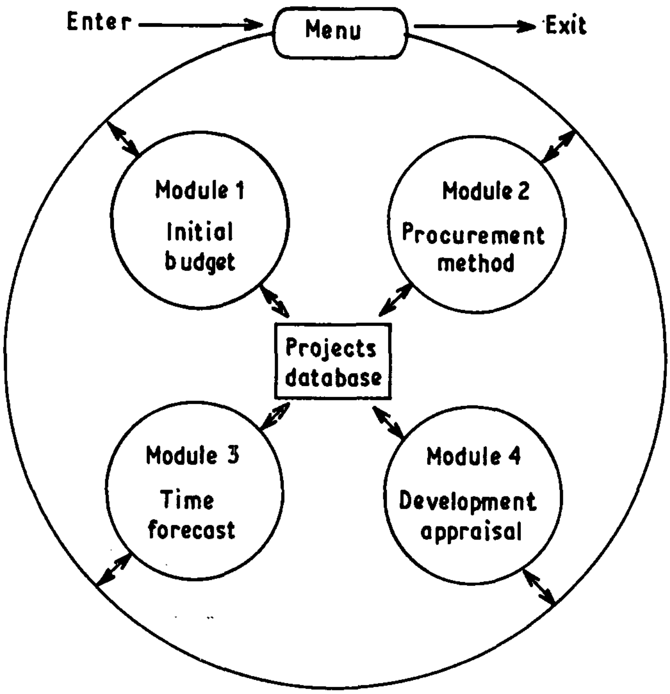


Fig. 2. Conceptual framework for dialogue with an expert system for strategic project planning

Knowledge acquisition

The research team used a traditional interviewing technique to obtain the knowledge held by experts. Initial interviews explored the general approach taken by the consultant and this was followed by more detailed elicitation of the particular issues identified. The method adopted followed that of Attarwala and Basden (1985) to guide knowledge from the experts – the latter author being a member of the research team. Although elicitation might start with trying to establish heuristics, this was then followed by trying to seek the understanding which lay behind them. This meant that context-free understanding was separated from problem-solving context, and reduced some of the difficulties normally found in building expert systems. It also enabled links between items of knowledge to be made which were not possible at the more general level.

Multiple experts were used in both acquisition and validation. Six firms were selected for the development of each module. These six were divided into two, one group to act as knowledge providers and the other to act as independent validators. During the interview stages for acquisition an inference net was constructed for each piece of knowledge (see Fig. 3) and this provided a check for the provider and subsequently the validator. This 'paper-modelling' of the knowledge proved invaluable and eventually formed the basis of the knowledge base record.

Where disagreements between experts occurred the different views were represented in the

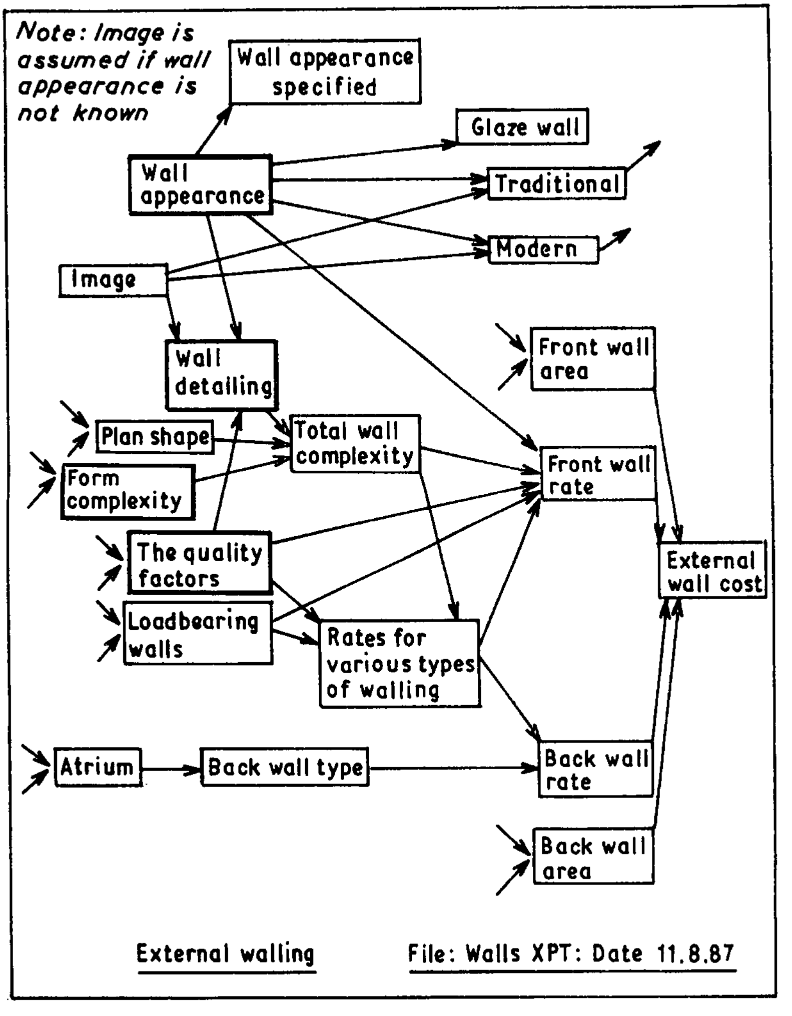


Fig. 3. Inference net diagram

inference net format and exposed for public debate. This enabled many of the apparently conflicting assumptions to be remedied.

Prototyping vs. formal specification

A mixture of prototyping and formal specifiation was used. However, the prototyping was structured into distinct stages and the specification was such that it could change during the project if necessary. The stages can be summarized as skeleton, demonstration, working, usable and commercial systems. This is not a strict procedure but helps to keep the client informed about what to expect. Interesting expert system features were staggered in their delivery so that progress was tangible throughout the project. This kept the experts interested and maintained motivation over the 18 months.

The formal specification that we have found advantageous is not that of a detailed program or data specification, but concerning such things as objectives, roles, users and benefits. These have a strong influence on the format of the knowledge and how the research team will work with the client, experts and users. However, even here, flexibility is required. As an example, the objective of the procurement module changed after the demonstration stage. It was found that expertise in this area related to the expert's personal experience of what would inevitably be a limited number of projects. It was difficult to aggregate this experience to achieve a consensus. The objective moved therefore from an advisory system to providing a 'sounding board' for the expert's ideas.

The software

Although the system was developed using SAVOIR on an IBM PC AT other software was also used.

(1) PASCAL to write approximately 40 external subroutines to perform tasks for which SAVOIR is not well suited and to perform special input/output.
(2) SIDEKICK, as a memory-resident editor (this allowed the research team to run the system until we found a fault, then immediately investigate it and make changes to the source code, without terminating the run or stopping to make copious notes).
(3) GEMDRAW to draw the inference net diagrams.
(4) WORDSTAR to write the reports.

SAVOIR, PASCAL and SIDEKICK worked very well but GEMDRAW was found to be slow.

Description of the system

Initial budget module

The purpose of this module was to take the kind of information conveyed in a client's brief and convert this into an assumed specification and quantity of building and from this information determine the likely building cost.

In conventional practice the process is as illustrated in Fig. 4.

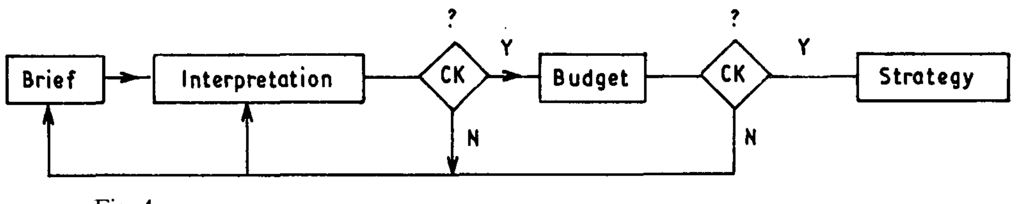
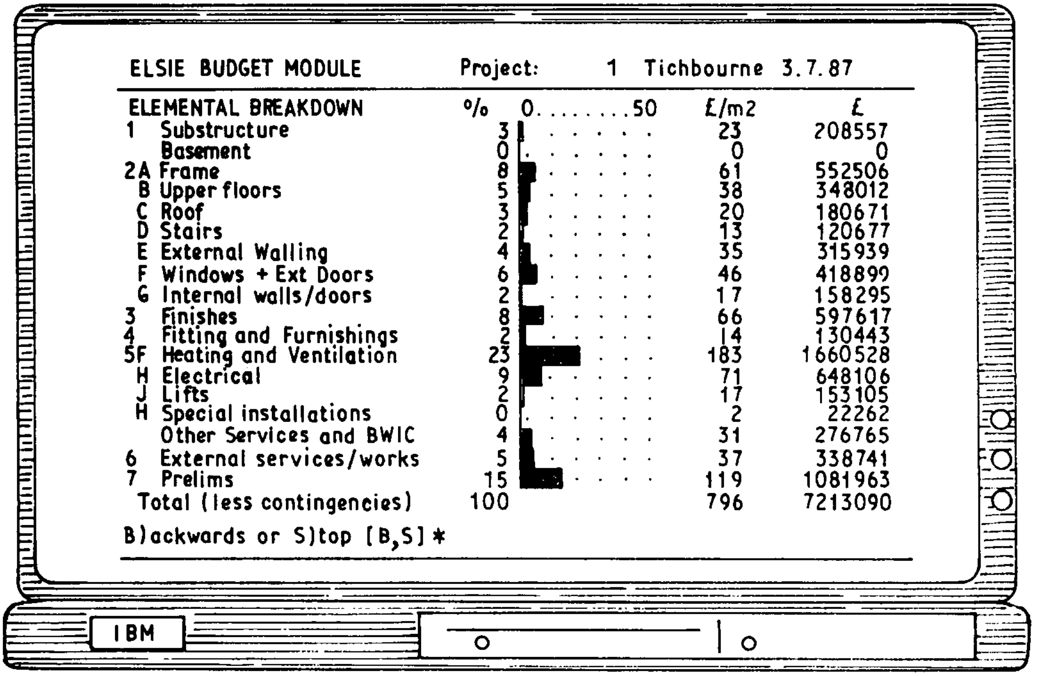


Fig. 4.

There are many programs which take a design team's interpretation, input by the user, and then calculate the budget. In this expert system the aim was to use the knowledge of the expert, encapsulated in the machine, to undertake the interpretation and refine the brief, and then calculate the budget. The user answers approximately 25 questions on the kind of office block he wishes to build together with information on the site, function, etc. From these answers the machine gathers an indication of quality, form and size which allows it to derive a reasonable specification for the building. Since the number of combinations of specification and form are for practical purposes infinite, the user can challenge and interact with the program. There are some 1500 variables used in the module and the user can go back and change up to 150 of these to undertake 'what-if' calculations, i.e. if I change the specification of 'x' what will be the effect on the cost/m^2 or total cost. In addition the user can provide his own data base of cost information.

After the consultation he can receive a number of reports including a summary of elemental costs (see Fig. 5).



ELSIE BUDGET MODULE Project: 1 Tichbourne 3.7.87

ELEMENTAL BREAKDOWN	%	0........50	£/m2	£
1 Substructure	3		23	208557
Basement	0		0	0
2A Frame	8		61	552506
B Upper floors	5		38	348012
C Roof	3		20	180671
D Stairs	2		13	120677
E External Walling	4		35	315939
F Windows + Ext Doors	6		46	418899
G Internal walls/doors	2		17	158295
3 Finishes	8		66	597617
4 Fitting and Furnishings	2		14	130443
5F Heating and Ventilation	23		183	1660528
H Electrical	9		71	648106
J Lifts	2		17	153105
H Special installations	0		2	22262
Other Services and BWIC	4		31	276765
6 External services/works	5		37	338741
7 Prelims	15		119	1081963
Total (less contingencies)	100		796	7213090

B)ackwards or S)top [B,S] *

Fig. 5. Example of elemental cost breakdown

He can then receive approximately a 20-page report on the assumptions made by the machine (see example in Fig. 6) which he can then review before undertaking his 'what-if' calculations.

The program was validated informally amongst the group of experts and more formally against a data set of over 40 projects. Since then it has been used commercially on a great number of administrative buildings. It has performed well and in some cases has proved to be more reliable than the experts who provided the original estimate.

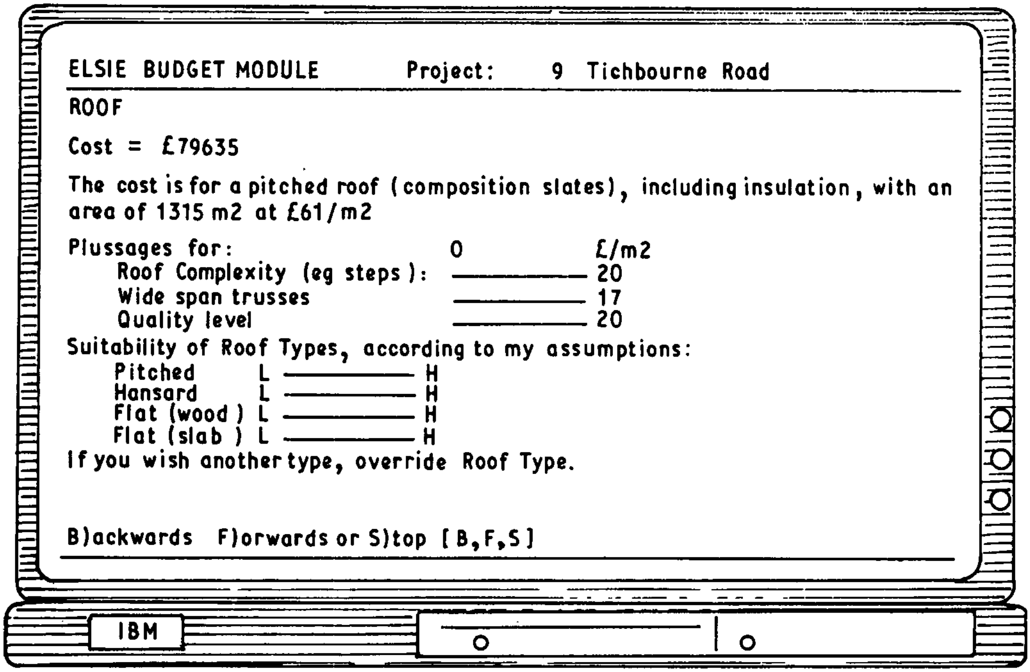


Fig. 6. Example of assumptions report – roof

Procurement module

In this module the machine determines from the client's requirements (in terms of such matters as building quality, size and time) what would be a sensible contractual relationship between the various parties to the development process as defined by five major strategies in common use in the UK construction industry, i.e.:

(1) conventional (i.e. design, tender, construct)
(2) two-stage tendering
(3) management contracting
(4) construction management
(5) design and build.

It combines a series of probabilistic answers to select from the five and rank them in order. The final screen suggests whether a particular method is likely to be appropriate or not and categorizes each under suitable headings (see Fig. 7).

It is then possible to investigate the machine's 'reasoning' by calling up the explanation facility which will give the arguments for (shown by + signs; the stronger the argument the more plusses are awarded) or against (shown by the – signs in a similar way). Figure 8 provides an example of such a screen and it can be seen that further explanation can be provided by calling up one of the numbers in brackets.

In addition it is possible to undertake sensitivity analysis on any of the answers originally given.

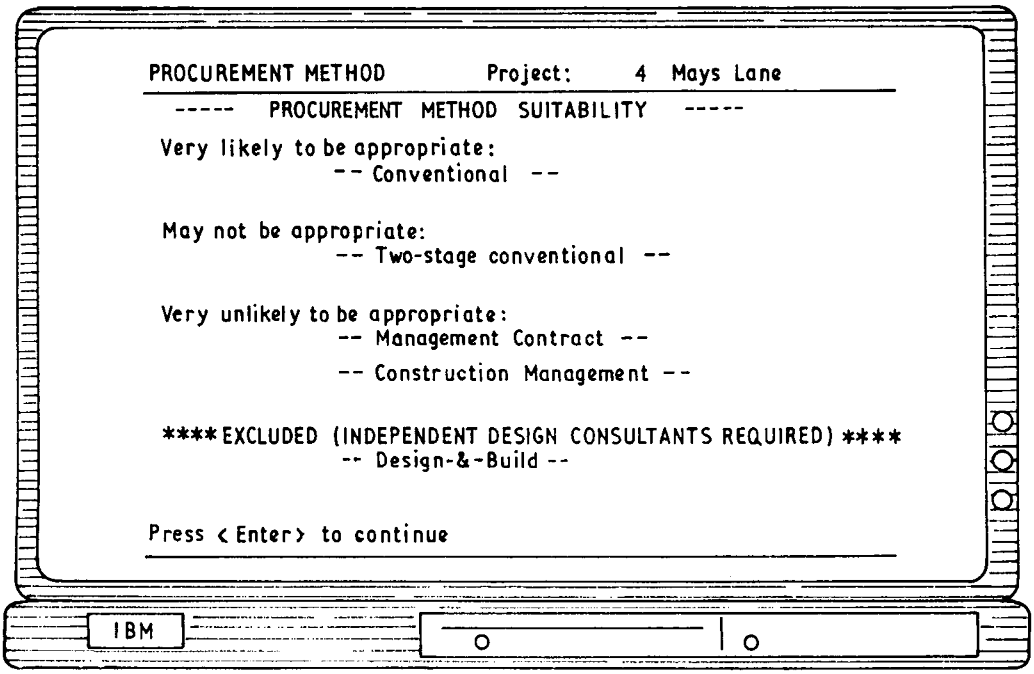


Fig. 7. Procurement – results screen

The program has worked reasonably well, although the research team are concerned that the nature of the knowledge base is not robust. No formal weighting of the variables contained in the system can be found and experts differ on their view of which procurement method is most suitable in a particular set of circumstances. The knowledge cannot be validated objectively because it is not possible to build a project under exactly the same circumstances with the same people time and time again. The only method of validation that was reasonable, bearing in mind the personal nature of the user's experience, was to try and achieve a consensus. This was achieved but the research team feel that the program should only be used in a decision support category as a 'sounding board' for the expert's ideas.

Time

A key feature in any development strategy is a forecast of the time for development. This module takes the rather scant information available at the brief stage and attempts to give guidance as to what is a reasonable period for up to three phases:

Phase 1 Feasibility (from inception to start of design)
Phase 2 Design and procurement (from start of design to start on site)
Phase 3 Construction and commissioning (from start on site to handover)

The program works on the basis of critical activities alone and selects a 'reasonable' time period together with an indication of the variability that can be expected.

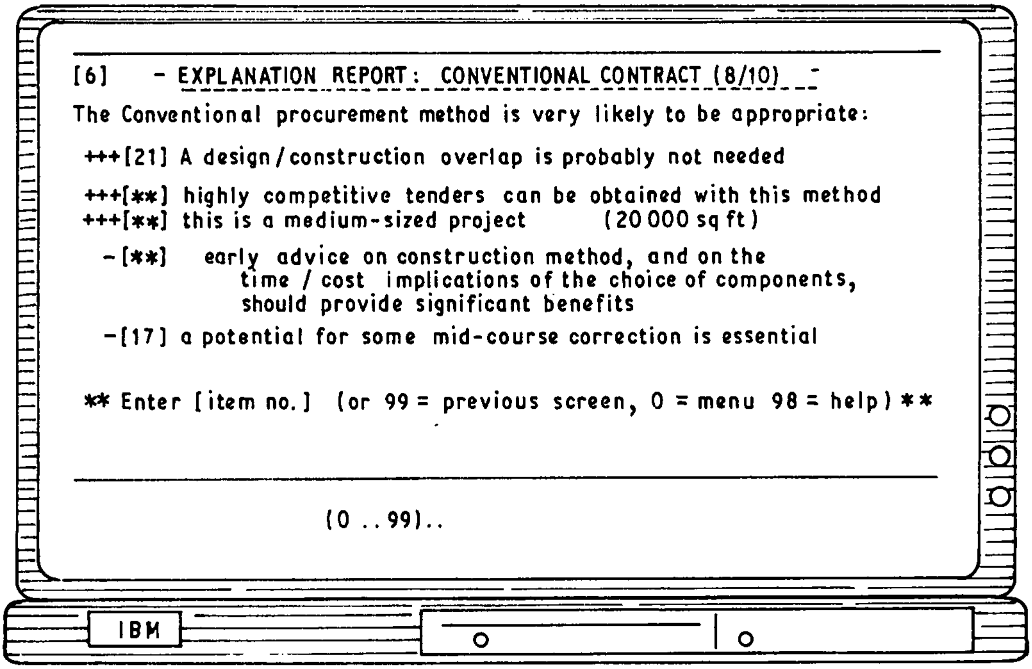


Fig. 8. Procurement – explanation facilities

At the end of the consultation, approximately an 8-page report gives an explanation for the advice given and the user can undertake sensitivity analysis on any of the answers given. Summary reports in bar chart form can also be provided (see Fig. 9).

The program has its own coarse procurement selection process which only needs to be run if 'Time' is selected first. If 'Procurement' has already been investigated then the results will be fed directly through to the 'Time' module. This master–slave relationship has had to be developed between all modules to avoid confusion in the data base.

Development appraisal

A conventional (in UK terms) residual valuation technique was employed to gather up information used in the other modules together with inputs by the user to discover the profitability of the scheme (as perceived at brief stage) or the value of residual land value, rent, yield or building cost. The localized nature of rent and yield values did not enable this knowledge to be gathered in the time available for such a universal program. The knowledge included is largely associated with fees and the cost of various procurement methods. Various reports can be obtained after a question run including a breakdown of finance costs, a theoretical cash flow for construction, gross development costs, etc. Up to five rental zones can be accommodated and sensitivity analysis is available on all major variables. It provides information for a more substantial DCF calculation at a later date, when more detail is available, but this is not incorporated at the present time.

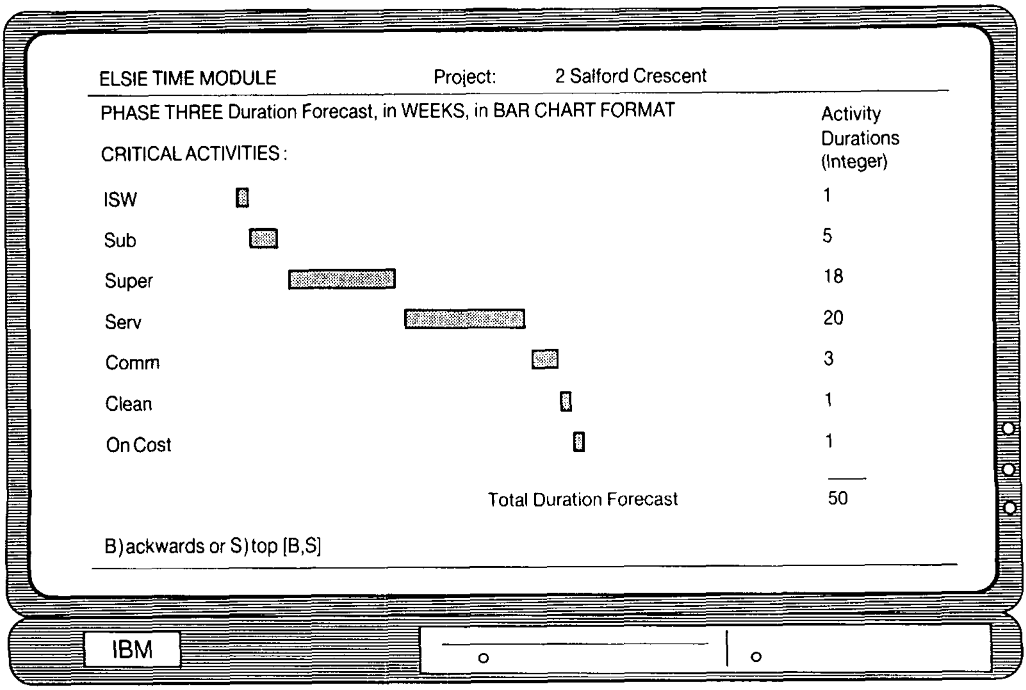


Fig. 9. Time – summary report

This module was included in order to provide a complete strategic planning system but does not include sophisticated knowledge-based routines.

Performance of developed system

The program has been developed for commercial application using funds provided by the RICS and some 40 member firms. Well over 200 systems have been sold and are in active use. The evidence that we have gathered so far, suggests the following:

(1) The Financial Budget Module gives as reliable an answer as the expert providing the user has a good knowledge of general construction and estimating. An experienced user can guide the system to account for unusual circumstances related to a specific project and this gives it great flexibility. Many firms report an accuracy of between plus or minus 5% which is remarkable for this stage of the project.

(2) The Financial Budget Module is more consistent, is more transparent and provides better explanation than the expert at this early design stage. It contains some 1500 rules and is therefore a very complex program.

(3) The Time Module provides a reasonable forecast for the limited information that is

available at this early design stage. It is, however, more explicit in its advice compared to the expert.

(4) The Procurement Module provides sensible answers but because the knowledge is so personalized it can only provide a check on the expert's thinking.

(5) The Development Appraisal Module has only a limited amount of knowledge within it. Its main purpose is to take the decisions made in other modules and bring them together to test profitability. Much of the information, e.g. on rents and yields, still has to be input by the user because it is too local to be captured in this universal program.

(6) The 50-page printed report provided after each consultation with the system is considered to be a considerable bonus for having used the machine. Firms word process the reports to suit their own needs in order to provide rapid reports for their clients.

Output and benefits

The research has produced a system that is now being sold to all members of the design/development team. A hardback report on the research (Brandon *et al.*, 1988) has been published by the RICS (QS Division) and is available from Imaginar Systems, 41 Leslie Hough Way, Salford University Business Park, Salford M6 6AJ (Tel.: 061–745 8767). A company is being set up to sell, maintain and develop the system. Packages for other building types have now been developed.

Many presentations and demonstrations have been given, both in the UK and abroad, and a general awareness of the potential for expert systems has been established. Future work will include the development of further modules for other building types in order to expand the scope of the system. Much of the knowledge and approach taken is common to all buildings and it is hoped that this will assist the speed at which further units can be added.

There is a general consensus from the Alvey Directorate, the RICS and the research team that this has been a most successful study. The product is now being used in commercial applications across the UK and achieving great success. We have reports of users winning competitions against other firms because of the improved output, and a very warm reception from building clients who are able to explore many possibilities before they finalize their brief. Indeed some clients are suggesting to their consultants that they should buy the product.

The benefits of the system are seen as:

(1) a sharing of expertise to enhance the skills of the profession;
(2) an improvement of expertise particularly within small firms;
(3) a speeding up of and improvement of quality in the early decision-making process;
(4) an increased consistency in decision making;
(5) an improvement in the speed of learning with regard to the strategic planning of projects for junior staff.
(6) a formalization of expertise which will provide a foundation for further knowledge acquisition and testing;
(7) an increase in productivity. An afternoon of consultation with the machine could take several days if undertaken manually. Clients claim an increase in productivity by at least a factor of 10.

The success of this research has given considerable encouragement to the development of expert systems within the UK construction industry and already other developments are underway. At the University of Salford, there are at least seven systems being developed at the present time, representing an investment of over US$2 million.

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Note: A full hardback report on the research entitled 'Expert Systems! The Strategic Planning of Construction Projects' is available from Imaginar Systems, 41 Leslie Hough Way, Salford University Business Park, Salford M6 6AJ, UK, price £30.