A KNOWLEDGE BASED STRUCTURE FOR IMPLEMENTING VALUE MANAGEMENT IN THE DESIGN OF OFFICE BUILDINGS

QIPING SHEN

A THESIS SUBMITTED TO THE
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TO QIN

ABSTRACT

Value Management (VM) is an organised effort directed at analyzing the functions of systems, supplies, equipments and facilities, for the purpose of achieving the required functions at lowest overall cost, consistent with requirements for performance, including reliability, delivery, maintainability and human factors. This structured method can also be successfully used to define the scope of a project. In the UK, the awareness of the tremendous potential and benefits of applying VM to construction projects has made some clients eager to apply this technique to their projects. There are, however, a number of problems which inhibit the use of this advanced technique in the construction industry. Qualified VM specialists, for instance, are very scarce within the industry, it is often difficult to find them to undertake proper VM studies. This research therefore aimed at exploring the feasibility of building a Knowledge-Based System (KBS) to facilitate VM implementations in the design stages of a construction project. A demonstration system has been successfully developed to illustrate the facilities which would be available to potential users in a fully developed system. A method of allocating project cost against functions of the project specified by the clients has been developed, which could expedite the processes of clarifying clients' brief and ensuring good value for money by cutting unnecessary costs and enhancing required functions. The research has also explored how KBSs can be effectively applied to "open-ended" decision-making problems in which new options may be generated during each session with the system, i.e. the study considered the possibility of letting users extend and customise the knowledge base. The system has been described as a "satisfactory and very promising system" by the UK industrial specialists.

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND OF THE RESEARCH

1.1.1 The Construction Industry

The construction industry is one of the largest industries in the UK, approaching £48 billion in annual turnover, which represents 10% of the UK Gross Domestic Product ("Building IT 2000", 1990). The industry has experienced many changes in recent years, from being one employing traditional skills and techniques to one using new materials and methods in innovative ways. There was a sharp building boom between 1985 and 1990, though the industry is traditionally volatile and is highly influenced by the overall status of the economy.

Building is distinguished from other forms of construction in satisfying society's needs for shelter in the form of houses, factories, hospitals, schools, conference centres, shopping complexes and sports centres. Every building product has a life cycle, which usually includes feasibility, design, construction and occupancy (Kirk and Spreckelmeyer, 1988). The feasibility is the starting point of the cycle, during which investigation to determine the need for a project and its potential for economic and functional success is undertaken. Building design consists of producing and communicating information, which interprets the goals and objectives of the clients formulated during the feasibility stage into a set of instructions, drawings and specifications to the people who will build the project. The construction stage is the process of producing the end product, and the occupancy is concerned with the using of the end product after construction, including maintenance and rehabilitation.

As a result of technological developments, uncertain economic conditions, social pressures, and political instability, the construction industry's clients place increasing demands upon the industry in terms of the performance of the project, the capital and running costs, the time required from conception of the project to occupation, and after all the value for money of the project (Walker, 1989). Bennett (1985) also indicates this increasing demand for providing building products which satisfy clients' requirements and with relatively low overall life cycle cost. Buildings, however, are particularly complex entities involving such things as social, physical, aesthetic and environmental factors, some of which contain no reasonable way of measuring the benefit and cost (Brandon, 1984). Building problems are extremely complex and ill-defined, starting in uncertainty and trying to end up with certainty (Happold, 1986). Without proper methodologies and techniques to follow, it is very difficult for the designers to satisfy clients' requirements at lowest overall life cycle cost.

A commonly-used approach towards the above problem is the utilisation of the cost planning and control techniques, of which the elemental cost analysis is an integral component. This approach has been used in the UK for many years and has made an outstanding contribution to the study, forecasting and control of building costs. There are however several basic limitations which inhibit its further developments:

(1) A complete system of cost planning and control at the design stage consists of: a) establishment of the clients' brief, b) investigation of a satisfactory solution, c) cost control of the development of the design. Unfortunately, according to Ferry and Brandon (1980), the amount of time and effort spent by the cost planner on each of

these three aspects is usually in inverse proportion to their relative importance, often being almost entirely concentrated on the third aspect.

(2) By definition, a building element is that part of a building which always performs the same functions irrespective of building type and specifications. Because of the interdependency and indivisibility of some building elements which may combine several functions, nobody has yet produced a set of elements each of which performs a single function and can be easily cost-related (Ferry and Brandon, 1980). This means that it is not possible to compare the cost performance of the same element on two different buildings, nor to compare two different technical solutions concerning one element within one building.

(3) Since the manipulated elemental costs are not really data in any scientific sense, which may bear no relation to fact, it would be a waste of time and money to use sophisticated methods to manipulate inaccurate data. As Ferry and Brandon (1980) stated, such processing is worse than useless, because the processed results are more likely to be accepted by the clients as reliable information and therefore large risks are more likely to be introduced to the unfortunate users.

1.1.2 Value Management in the UK Construction Industry

Value Management (VM) as a methodology can make valuable contributions towards a better solution to the problems facing the designers. VM, which is also known as Value Engineering (VE) and Value Analysis (VA), is an organised effort directed at analyzing the functions of systems, supplies, equipments and facilities, for the purpose of achieving the required functions at lowest overall cost, consistent with requirements for performance, including reliability, delivery, maintainability and human factors. It has been widely used in the USA, and has made a significant contribution to the provision of cost savings and enhancement of performance in various areas. Based on the results obtained from many construction projects, a 5-20 % reduction in initial and follow-on costs is a reasonable expectation from a formal VM programme, when first applied to any construction project. (Dell'Isola, 1982)

VM is generally recognised and actively used in the member states of the European Community. The European Community's Strategic Programme for Innovation and Technology Transfer (SPRINT) has seen VM as a powerful tool to achieve one of its three objectives, i.e., improving awareness of the innovation mechanism and promoting the convergence of national and community innovation policies (Strub, 1991). Under the SPRINT programme, three European VM conferences have been organised, two VM documents have been produced, and a number of research projects into VM have been funded (Watts, 1992).

According to a recent market survey conducted by the Commission of the European Community DG XIII (1991), although VM is currently under-utilized in Europe, the potential demand for VM should almost double in five years to reach 38,000 VM actions in Europe (8675 actions in the UK alone) in 1996, which represents a yearly growth of 13%. The survey also shows that 83% of the VM cases experienced by the interviewed users are considered as a total success, 14% are considered as a half success, and only 3% of the cases are considered as a complete failure. Among those users, 97% of them are planning to use it again in the future.

In the UK, although VM is not as widely used as it is in the USA, the tremendous potential for the applications of VM to the construction processes has already been noticed. The awareness that VM is a systematic method for reducing overall cost without sacrificing the required function makes some clients eager to apply this technique to their projects. There are, however, a number of problems which inhibit VM implementation in the UK construction industry. They include:

1) Qualified VM consultants and VM companies who can provide VM services are so scarce that it is difficult to find suitable VM specialists to undertake VM work when it is required. This view is also reflected in a recent survey conducted by the Commission of the European Community (1991). It revealed that the lack of skilled VM personnel is considered as a main problem inhibiting VM applications both by the VM suppliers and the users; in many cases companies willing to use VM have stated that they will recruit a VM specialist to start a VM programme.

2) As also indicated by the survey stated above, the time required for a VM study is an important reason which restrict the use of VM. This appears especially true in small and medium sized companies where the solving of day-to-day problems has a higher priority than detailing a long or medium term strategy for value enhancement. The formal 40-hour VM job plan is often blamed by the designers, whose criticism says that time delay and work interruption to the design programme and construction can be more costly than potential savings (Kelly and Male, 1988).

3) The fees for providing VM services are around £600 per day for an external consultant and £400 per day for an internal consultant, according to the survey conducted by the Commission of the European Community DG XIII (1991). Some clients are reluctant to spend the amounts of extra money, unless they have good

experience of VM in advance. This is especially true in small companies which lack the financial capacity to support VM studies and the application of the results (Commission of the European Community, 1991).

4) Although some consultants purport to provide VM services for the construction industry, frequently, VM methodologies were not used properly. Some consultants see VM as purely a cost reduction technique, and they do not analyze the functions of the building and/or elements at all. Kelly and Male (1991) have warned of the danger of organisations leaping on the band-waggon and advertising VM services without possessing the minimum expertise in VM.

5) The time allocated in a 40-hour construction-based workshop is misplaced when compared to Value Management theory, with information assimilation, evaluation, development and presentation taking too high a proportion. The time allocated to functional analysis was too short (Kelly and Male, 1991).

6) Unlike other professions such as architects, structural engineers, and quantity surveyors, VM standards and certifications in the UK have not yet been established. Some designers are therefore critical of the professionalism of the VM team members by saying that: "VM specialists are not professionals", "We do not object to review components by qualified professionals" (Kelly et al, 1988). Government organisations also find it difficult to promote VM to companies, because without an established VM standard it is hard to support VM as a serious and proven method (Commission of the European Community DG XIII, 1991).

Having analysed the above problems, it appeared that the use of computers might be a solution to overcome most of the obstacles, especially for the first five problems. Unfortunately, although the use of creative thinking is an essential element of the VM methodology and the VM profession encourages the use of the latest development of technology, the creative use of computers by the profession was quite limited. Until recently, VM studies have been mainly a manual process. As revealed by the recent survey of the European VM market (Commission of the EC, 1991), the majority of VM suppliers do not use any computer software, except some simple "home made software" based on spreadsheet packages, e.g., Lotus and Excel to process data obtained in the VM studies, rather than to monitor the whole programme.

As a result of the increasing enhancement of performance and the continuing decline in price, computers have become useful and affordable tools which are playing a very important role in every sector of our society. On the other hand, the maturity of information technology, particularly Knowledge-Based Systems (KBS), has made some complex computer applications possible. It was these two recent developments which have led to the original idea of building a KBS to improve VM implementation in the building design process.

KBSs, as will be systematically discussed later in Chapter 3, are reference systems that contain declarative and procedural relationships referenced through user interfaces (Tuthill, 1990). They emerged in the fifties and matured in the late eighties, representing the most exciting fruit of Artificial Intelligence (AI), a branch of computer science dedicated to the study of the manner in which computers can be used to simulate or duplicate functions of human beings (Cleal and Heaton, 1988). Various KBS applications can be found in the construction industry throughout the life cycle of a project, from project inception, through design and construction, to occupation, maintenance and rehabilitation.

With the assistance and support of a KBS containing domain knowledge and expertise of VM, the time spent on tedious time-consuming calculations can be significantly reduced; the productivity of VM studies might therefore be considerably improved. The participants of the studies could concentrate on more creative issues, and better results could therefore be produced. Hence several roadblocks and drawbacks of VM studies (such as accessibility of the valuable expertise, large amounts of time and money spent on the studies, inadequate use of VM techniques, and misplaced time allocation on each phase during a VM study) could therefore be overcome.

1.2 RESEARCH OBJECTIVES, HYPOTHESES AND SCOPE

Having understood the problems concerning the implementation of VM in the UK construction industry, and the potential of using Knowledge-Based Systems to make scarce VM expertise more widely available, a research project was therefore proposed to explore the feasibility of building a KBS to facilitate VM implementation in the building industry to make scarce VM expertise more widely available.

1.2.1 Research Objectives

The overall objectives of this research were initially set up as: *to explore whether a knowledge-based system could be successfully used in facilitating the implementation of Value Management in the building industry to make scarce expertise more widely available, so as to increase its beneficial use in the UK; If feasible, a demonstration* *system with VM domain knowledge and expertise would be developed to illustrate the types of facilities that will be available in a fully developed system.*

The research also attempted to test the adequacy of using KBS to stimulate creative thinking in the design context, and to explore the possibility of letting users extend and customise the knowledge base (new options may be added during each run of the system), so that the system can be gradually refined through its use.

The best way of achieving these objectives seemed to be a comprehensive theoretical analysis of the VM domain against criteria for successful KBS applications, and an actual implementation of such a system followed by a test of its usefulness and applicability in the real world. As will be discussed in Section 1.3 of this Chapter, a combination of case studies and action research methodologies appeared to be most suitable for this purpose and was therefore adopted in this research.

One of the most important characteristics of the combined methodologies is the involvement of an organisation (Galliers, 1992, Antill, 1985, Wood-Harper, 1985). In order to find an organisation to participate in the research project actively, initial effort of the research was devoted to developing a prototype system. The purposes of developing such a pilot system were twofold: firstly, as a means to demonstrate to various relevant organisations the potential and benefits of using KBSs to make scarce VM expertise more widely available; and secondly, as an initial feasibility study of using KBS to facilitate the implementation of VM in the design of buildings.

The knowledge and expertise inside the prototype system were mainly obtained from various publications including text books, conference papers, and articles from various VM-related journals. Since most of the publications highlight the importance and benefits of applying VM at early sketch design stages and relatively large amounts of information on office buildings were available, the pilot system was focused on VM applications in the design of office buildings at the sketch design stage (about 35%

completion of an entire design, as specified by the US counterparts).

The prototype system was proved to be very successful in achieving the two purposes stated above. It not only initially demonstrated the feasibility of using KBSs to facilitate the implementation of VM in the construction industry which therefore to a large extent increased the researcher's confidence in the research, but also attracted and maintained the enthusiasm and interest of one of the largest organisations in this country, Imperial Chemical Industries Plc, to participate in the research.

Following the participation of ICI Plc, a subsequent study was undertaken jointly by Mr G C Dalton at Corporate Management Services of ICI Plc and the author from June to September 1989. Several sessions of interviews with various relevant persons (e.g., project engineer, building manager, value specialist, system support manager) were undertaken. The study indicated that there is a potential for capturing and spreading VM experience, and there is a need to undertake further research into the structure underlying VM and its relation to the information requirements of the rest of the project definition and the design process. It proposed that further research could be done by continuing to work with Qiping Shen at Salford University.

The participation of the organisation enhanced the initial prototype system, and broadened the scope of the research to include a new area of VM applications, i.e., the conceptual analysis. As will be discussed late in Chapter 4, the principles followed by a conceptual analysis are virtually the same as value management. Because of its unique characteristics of applying those principles in the conceptual design stage, it has been distinguished from conventional value analysis by the practitioners in the organisation. The author has therefore also adopted the term of CA and distinguished it from traditional VA throughout the research and in this thesis itself.

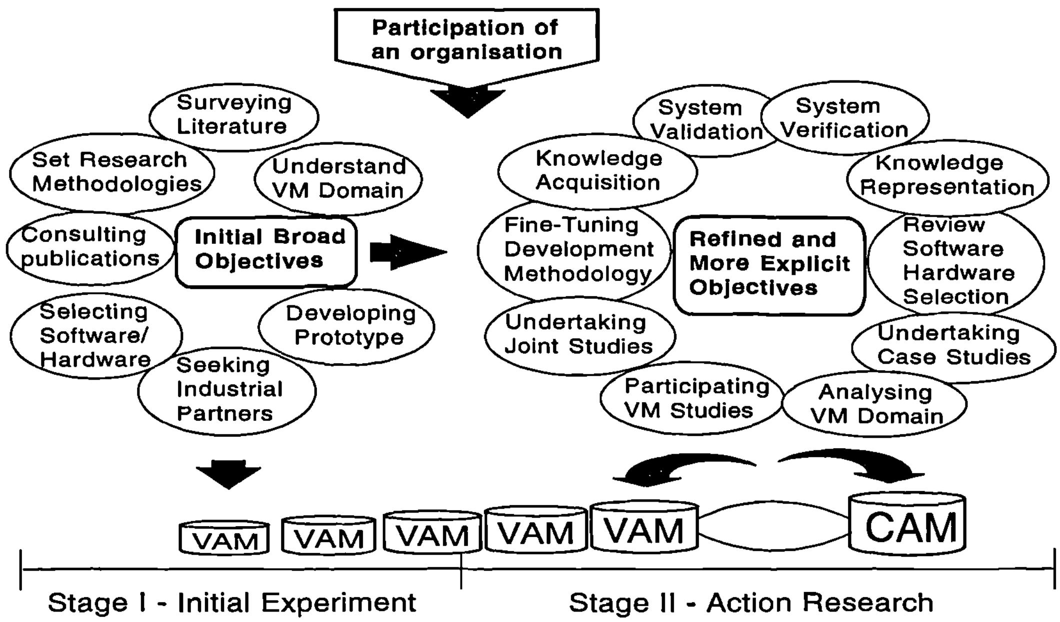
Following discussions with various practitioners in the organisation, it appeared that research effort should be concentrated on office buildings for the following reasons:

firstly, office buildings are conventional type of buildings, relatively large amounts of expertise existed in this area; secondly, cost information plays a very important role in both CA and VA, and the budget module of ELSIE (a suite of successful expert systems developed at Salford University) has been widely used in ICI for this purpose, which at that time can only produce cost estimate for office buildings; and finally, because of the limited time of the research, the author can only concentrate on a specific type of buildings. The principles, if proved successful, can be extended in future development to include other types of buildings.

The knowledge and expertise in CA in the proposed system were acquired from a number of experts in ICI Plc (e.g., Mr. Wilfred Burgess, Mr. John Roberts and Mr. Stuart Lord) through an iterative process of knowledge acquisition, implementation, validation and verification, throughout the research project. In addition to the above process of acquiring knowledge (i.e. through interviews), five historical CA studies undertaken in the organisation were examined to understand/familiarise the processes of CA studies and to obtain additional CA-related knowledge and expertise. Although the research was targeted on office buildings and sources of data were mainly collected around this scope, historical information on other types of buildings was also used in the project for the purpose of cross-fertilisation. These were a computing centre, a research laboratory, two chemical plants, and a spillage control project. The inclusion of such information seems to be a useful step towards future expansion of the system to cope with other types of buildings, though it is still too early to say that the system is capable of conducting CA studies on them as well.

Based on the above discussions, the types of facilities required for the proposed system were therefore gradually clarified through subsequent studies. They include: (1) to support project designers in their decision-making process in the early concept design stages of office buildings, by assisting them in clarifying client's requirements and producing a clear project definition; (2) to assist VM teams in evaluating the concept or sketch design of office buildings through comparisons of costs and performance between initial design and standards, and facilitating the use of VM techniques, methodologies, and the expertise of value specialists to reduce the overall costs without sacrificing its required functions.

As summarised in the diagram below, the entire research is characterised by two distinct stages separated by the participation of ICI Plc: stage 1 - initial experiment, within which a prototype system (focusing on the sketch design stage of an office building project) was developed based on secondary information, i.e., various publications; and stage 2 - action research, within which primary information was used throughout the design and development of the proposed system. The existing prototype (VA module) was improved through subsequent modifications based on the comments made by the practitioners and the utilisation of historical case studies. A brand new module, conceptual analysis, was successfully developed which focuses on the conceptual design stage of an office building project. The broad objectives initially established for the research have also been refined and made more explicit during the second stage of the research project, which exhibited the cyclical feature of action research indicated by researchers (e.g., Susman & Evered, 1978; Wood-Harper, 1985) in the methodological field of action research.



1.2.2 Research Hypotheses

Following the objectives outlined above, the hypotheses of the research are therefore outlined as follows:

1) the total cost of an office building project can be allocated against building functions required and specified by the clients of the project; a detailed information of costs per function would therefore be available.

2) the knowledge and expertise of value specialists in facilitating a VM study of office projects can be successfully elicited, modelled and represented in a knowledge-based system.

3) knowledge-based systems with properly elicited and represented VM domain knowledge can facilitate VM implementation in the design of office buildings at early design stages.

The hypotheses were made based on the assumption that VM is a useful tool in supporting building design decision-making by clarifying client's objectives, identifying and removing unnecessary costs whilst maintaining required performance. These hypotheses were tested throughout the development of the proposed system within the research.

1.2.3 Research Scope

In order to complete the research work within the limited time of three years, the scope of the research has been clearly defined in a specific domain area, i.e., the research explored the feasibility of using a KBS to facilitate the implementation of VM in the design of office buildings at early design stages. The reason for choosing office buildings is that they are a conventional type of building, and expertise in undertaking VM studies on office buildings exists in the UK construction industry. The budget module of the ELSIE system, a successful KBS application developed at Salford University (Brandon et al, 1988), has captured the cost-estimating expertise for office buildings, a feature which is essential to the success of VM studies.

Since major design decisions are usually made in the early design stages, research efforts have been mainly devoted to the development of two parallel modules, i.e., the Conceptual Analysis Module (CAM) and the Value Analysis Module (VAM), which comprise the CAVA (CA and VA) system. CAM assists the project designers in clarifying client's requirements in functional terms, and formulating a project definition of an office building project at early concept design stage. Whereas VAM was designed to assist a VM study team in undertaking complete VM study at the sketch design stage of an office project. (Details about the the proposed system will be introduced in Chapter 6)

1.3 METHODOLOGY TOWARDS RESEARCH OBJECTIVES

The hybrid nature of information processing requires that the researcher should be particularly careful in the selection of an appropriate research method for a particular situation, and in the interpretation of the results in the light of the method chosen (Antill, 1985). There are a variety of widely-used research approaches, such as, laboratory and field experiment, surveys and interviews, case studies, descriptive and interpretive research, and action research. They are introduced and reviewed by many authors, e.g., Galliers, 1985, 1992; Antill, 1985; Wood-Harper, 1985; and Jönsson, 1991. Because of the complexity and the wide coverage of the research, it appeared inappropriate that only one of the approaches should be employed. In order to take the advantages and overcome the shortcomings exhibited by a single approach, the research has adopted two approaches: case studies, and action research.

Case studies are attempts at describing the relationships which exist in reality, usually within a single organisation or organisational grouping (Galliers, 1992). This approach enables the capture of reality in considerably greater detail and the analysis of a considerably greater number of variables, than is possible with most of the other approaches listed above (Galliers, 1992). It has the advantage of obtaining a complete view of the personalised VM domain expertise, which is essential in achieving the research objectives. Since its application is usually restricted to a single event or organisation, the weaknesses of this approach are often cited as the difficulty in acquiring similar data from a statistically meaningful number of similar organisations, and the problems associated with making generalizations from individual case studies. It is however argued by Lawler et al (1985) that single case studies are helpful in developing and refining generalizable concepts and frames of reference.

The reason for selecting the approach of action research is that it enable researchers to investigate a particular route to the realities of a particular situation and build up useful insights, expertise and case law *(Antill, 1985). According to Argyris et al* (1985), action research is an approach where researchers engage with participants in a collaborative process of critical inquiry into problems of social practice in a learning context. It is a strategy of influencing the stock of knowledge of the sponsoring enterprise and also of the researchers.

The main feature of action research is that it is expressly designed to foster learning about one's practice (learning takes place during the course of the project) and about alternative ways of constructing it (Jönsson, 1985). As Wood-Harper (1985) argued, this approach can produce significant insight from investigating real life situations. It has the advantage of linking theory with practice, for without this link the research may end up with theoretical discussions and no practical validation and testing of the research findings. It is therefore one of the few approaches that can be used in the proposed research to prove hypotheses and to validate the research findings.

To achieve the objectives established for this research effectively, and to test the hypotheses initiated thoroughly, the above two approaches have been developed into a detailed research plan, through the use of the systematic function analysis technique employed in VM studies. Within the plan, the higher level task functions appear on the left of the diagrams. By asking the question "how" those task functions can be achieved, task functions at their immediate lower level can be defined. For example, as shown in Figure 1-1, to achieve the overall objective of "Explore the feasibility of using KBSs to facilitate VM studies", functions such as "Survey literature" and "Develop a prototype system" have to be completed.

Explore Feasibility of Using KBSs to Facilitate VM Studies

- **1. Survey Relevant Literature**
- **2. Understand the VM Domain**
- **3. Analyze the VM Domain**
- **4. Develop a Prototype System**
- **5. Demonstrate the Prototype**
- **6. Consolidate the Prototype**
- **7. Verify/Validate the Prototype**

Figure 1-1 Actions undertaken in order to achieve research objectives

Each of the lower task functions has been explored further. For instance, as shown in Figure 1-2, in order to achieve task "Understand the VM domain", a number of sub-functions need to be accomplished. They include: understanding approaches of building design and how VM fit into the design process; exploring techniques used in obtaining a clear brief from the clients; analysing decisions to be made in the early design stages; understanding the kinds of guidance a VM consultant can give to a VM study team; analysing historical VM studies, and finally interviewing experienced VM consultants in order to acquire human knowledge and expertise. Figure 1-3 and Figure 1-4 are illustrations of actions to be undertaken in order to achieve the task functions of analysing the VM domain and developing a prototype system.

2. Understand the VM Domain

- **2.1 Understand the Design Process**
- **2.2 Study VM Books/Reports**
- **2.3 Study VM Case Studies**
- **2.4 Attend VM Training/Workshops**
- **2.5 Analyze VM Studies**
- **2.6 Attend VM Conferences**
- **2.7 Interview VM Consultants**

Figure 1-2 Actions undertaken in order to understand the VM domain

3. Analyze the VM Domain

- **3.1 Analyze VM Concepts/Principles**
- **3.2 Establish Criteria for KBS Appls**
- **3.3 Evaluate the VM Domain Criteria**
- **3.4 Review VM and KBS Literature**

Figure 1-3 Actions undertaken in order to analyse the VM domain

1.4 ORGANISATION OF THE THESIS

Chapter 1 introduces the background of the research, including research objectives, hypotheses, scope of the research, and research methodologies. Chapter 2 is devoted

4. Develop a Prototype System
- 4.1 Understand KBS Methodology
- 4.2 Modelling VM Expertise
- 4.3 Analyze KBS Approaches in Design
- 4.4 Select Development Hardware
- 4.5 Choose Development Software
- 4.6 Acquire VM Expertise
- 4.7 Use Development Methodology
- 4.8 Represent Knowledge/Expertise

Figure 1-4 Actions undertaken in order to develop a prototype

to explaining the current process of design decision making and how VM fits into the building design process. The basic concepts and principles of Value Management, the historical and the latest development of this profession in the European Community are also introduced. Chapter 3 illustrates the current state of the art of Artificial Intelligence and its applications in the construction industry. Current AI approaches in building design have been critically analyzed in this chapter. Chapter 4 outlines the modelling of the expertise in applying VM to the design process in ICI Plc. The current practice of functional cost allocations is critically analysed and a new approach, developed during the research, is introduced. Chapter 5 discusses the domain suitability of applying KBS to VM in building design, and explains how VM domain expertise is represented in a knowledge base. The methodology followed to design and develop the proposed knowledge-based system is also introduced. Chapter 6 describes the generic structure of the system and details of system implementation. Chapter 7 is dedicated to introducing system performance, verification and validation. Chapter 8 discusses and concludes the research findings. Directions for future developments of the system are also proposed.

CHAPTER 2. VALUE MANAGEMENT IN THE CONTEXT OF DESIGN

This chapter examines the relevance of VM to the design process to see whether and how VM can be used to improve the process. It discusses various models of the design process, with particular interests in the functional approaches. The concepts and principles of the VM methodology are addressed and discussed in details in the context of the building design. A conceptual framework, within which VM and other design decision-making techniques can be utilized to produce a better design solution, is presented. Although a knowledge of design theory and the modelling of the design process do not necessarily help a designer in his or her design work, it is essential for the production of design aids.

2.1 THE DESIGN PROCESS AND DESIGN PROBLEMS

Design is a fundamental, purposeful human activity involving functionality, meaning, expression, and aesthetics (Coyne et al, 1990). Our understanding of design as a process and our ability to model it are, however, still very limited (Gero, 1991). The objectives of the research into design are to obtain better understanding of design, and to examine how useful tools such as VM can be used to aid human designers and to develop a computational symbolic model to facilitate the implementation of VM into various stages of the design process.

The terms such as design process, design problem and design method used in the literature of building design are very ambiguous and interrelated. It is therefore necessary to make the meanings of these phrases clear, before any further discussions on design related issues. The following terms were distinguished by Newton (1983), and it is based on these definitions, the design-related issues are discussed:

- **Design Process** - a framework within which design decision-making is sequenced;
- **Design Method** - a technique selected at particular instances in the design process to improve the recognition of design problems;
- **Design Problem** - the context of design, its objectives, constraints, etc..

2.1.1 The Design Process

In the Royal Institute of British Architects' (RIBA) publication "Architectural Practice and Management Handbook" (1965), the design process is described as follows:

Phase-1 Assimilation - The accumulation and ordering of general information and information specifically related to the problem in hand;

Phase-2 General Study - The investigation of the nature of the problem and possible solutions or means of solution;

Phase-3 Development - The development or refinement of one or more of the tentative solutions isolated in phase-2;

Phase-4 Communication - The communication of one or more solutions to people inside or outside the design team.

The problem with this description is, as argued by Lawson (1980), it is hardly a map of the design process, and it is too simple to represent the complicated real design process which by all means should have some loops among the different stages.

The detailed map of the design process suggested by the RIBA handbook (as shown below) is also criticised by Lawson (1980). Having made an explicit review of this map, he pointed out that the issues listed in the map are not the design process at all, but the products of the process. In his opinion, the map can be seen as a business transaction, which is useful to both client and designers in informing each other the development of the design, i.e., the progress of the design.

A:	Inception	A-B	Briefing
B:	Feasibility		
C:	Outline Proposal	C-D	Sketch Design
D:	Scheme Design		
E:	Detail Design	E-H	Working Drawings
F:	Production Information		
G:	Bills of Quantities		
H:	Tender Action		
J:	Project Planning	J-M	Site Operations
K:	Operations on site		
L:	Completion		
M:	Feed-back		

Jones (1970) has expressed his thinking on the design process in a different way. Within his model, the stages of the design process were divided as follows: 1) Divergence - The act of extending the boundary of design situations so as to have a large and fruitful enough, search space in which to seek solutions; 2) Transformation - The stage of putting pieces together in a new way, e.g., pattern-making, high level creativity, flashes of insight, changes of set, inspired guesswork -anything that makes designing a delight; 3) Convergence - The stage after the problem has been defined, the variables have been identified and the objectives have been agreed. The designer's aim became that of reducing the secondary uncertainties progressively until only one of the alternatives is left as the final solution to be launched.

This model is similar to a number of researchers's attempts in describing the stages of the design process in the phases of a decision sequence, i.e., analysis, synthesis, and evaluation, as shown in Figure 2-1. According to Asimow (1962), the first task within the process is to diagnose, define, and understand the problem and produce an explicit statement of goals to achieve. The second task involves finding possible solutions. The third task concerns judging the validity of solutions against the goals defined in the first task.

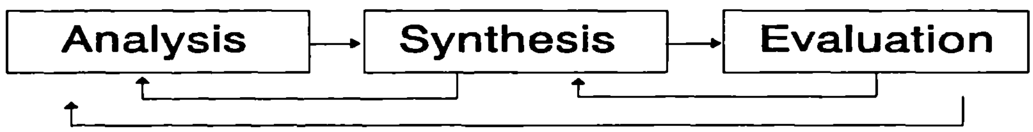


Figure 2-1 Illustration of Decision Sequence

As Page (1963) pointed out, the essential difference between the design process and the decision sequence is that: "the former is a way of structuring the order in which a vast number of decisions may be made". In practice designers go round several times from "analysis" through "synthesis" to "evaluation".

Markus (1969) and subsequently Maver (1970) developed a two-dimension model of the design process, as shown in Figure 2-2. The horizontal dimension is used to express the essential decision-making sequence from analysis through synthesis and appraisal to decision, and the vertical dimension is used to display all design stages from client brief, through feasibility study, outline proposals, scheme design and detail design, to production information. The shortcomings of this model are that there is only one loop between synthesis and appraisal, and this is not always true. As Page (1963) warned, in the majority of practical design situations, by the time a synthesis has been made, the designer may realise that he/she has forgotten to analyse something else, and go round the cycle and produce a modified synthesis.

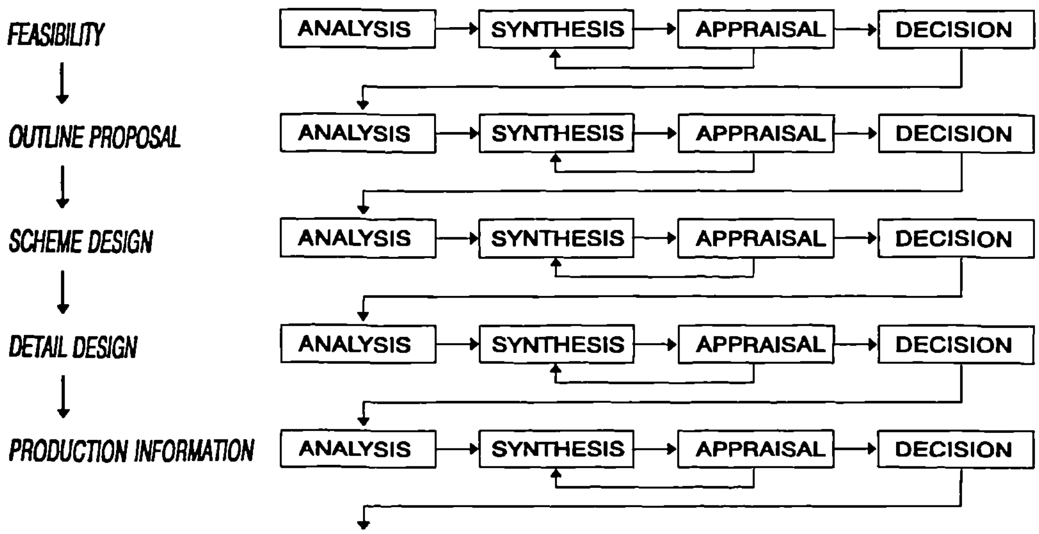


Figure 2-2 Markus/Maver's Model of The Design Process

Kirk et al (1988) extended the process to cover the whole life cycle of a project, which includes: 1) project feasibility phase; 2) project design phase; 3) project construction phase; and 4) project occupancy phase. Kirk also gave some evidence on how the construction and occupancy phases are involved in the design process under up-to-date construction management. Assumptions made by Kirk are 1) a design problem can be analysed and defined at various levels of abstraction, then synthesised in a way that adds to the designers' knowledge of successive -- and hence more concrete -- levels of understanding; 2) the model can be applied in all phases of the project life cycle.

Based on these assumptions, Kirk defined his two-dimensional approach to design problem-solving. The methodology dimension illustrates the methodology of decision-making within design, and the application dimension represents its applications to the design process, which covers the development life cycle of a project as mentioned above. According to Kirk, the methodology dimension includes three separate activities in decision-making, i.e., the **context** - a problem exists within a specific context of abstract ideas, human values, information, economic, social and cultural norms; the **process** - the process of rational decision-making i.e., information and analysis - speculation - evaluation - synthesis - recommendation applied within the context to arrive at an understanding of the nature of the problem. This process is comparable to the decision sequence mentioned earlier, and the **product** - a product or set of instructions to solve the problem emerges from the process in the form of strategies, plans, specifications or buildings.

It is not difficult to see that Kirk's two-dimensional model is quite similar to the model introduced by Markus and Maver, but covers more phases of a project life cycle. The beauty of this model is that it provides a framework within which a number of techniques such as function analysis, group creativity, life cycle costing analysis, decision analysis, post-occupancy evaluation and communication, can be applied to support design decision-making by enriching the process of establishing the measurement scales, generating alternatives, and evaluating design solutions.

Many other researchers have expressed their models of the design process, with emphases on different aspects of the design process. It would be impossible and unnecessary to define the design process perfectly right. The most important issue is how the design process could be improved and become more effective and efficient, rather than to describe the current design process as accurately as possible in every detail. As Coyne et al (1990) argued, "in modelling the design we do not attempt to say what design is or how human designers do what they do, but rather provide models by which we can explain and perhaps even replicate the certain aspects of design behaviour". The following characteristics of the design process summarized by Lawson (1980) are listed to conclude the discussion:

1) The process is endless.

2) There is no infallibly correct process.

3) The process involves finding and solving problems.

4) Design inevitably involves subjective value judgement.

5) Design is a prescriptive activity, as science is descriptive.

6) Designers work in the context of a need for action.

2.1.2 Design Problems

Design problems are built up of constraints which may come from the constraints' generators (e.g., client's and user's requirements and regulations) internally or externally. Lawson (1980) analysed the constraints and divided them into four groups: 1) Formal, 2) Symbolic, 3) Radical (fundamental), and 4) Practical - those aspects of the total design problems which deal with the reality of producing, making or building the design, the technological problem.

In a three-dimensional diagram, as shown in Figure 2-3, Lawson has illustrated how the constraints generators (clients, users, legislators, designers), functions of the design constraints (formal, symbolic, cardinal, practical) and the domains (internal, external) where the design constraints take place, are related to each other.

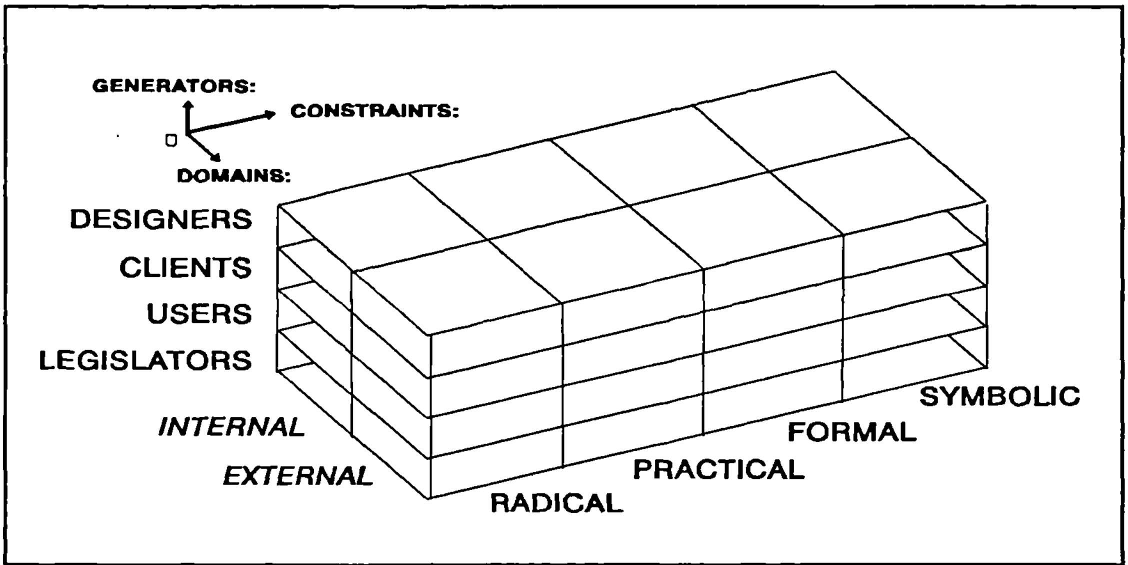


Figure 2-3 Lawson's Model of Design Constraints

According to Lawson (1980), design problems have the following characteristics:

1) Design problems cannot be comprehensively stated.

Both objectives and priorities are quite likely to change during the design process as the solution implications begin to emerge. Thus one should not expect a comprehensive and static formulation of design problems. Rather they should be seen as in dynamic tension with design solutions.

2) Design problems require subjective interpretation.

There are many difficulties with measurement and evaluation of a design, which is a design problem itself. Therefore we should not expect entirely objective formulations of design problems.

3) Design problems tend to be organised hierarchically.

There is no objective or logical way to determine the right level on which to tackle design problems. The decision remains largely pragmatic, it depends on the power, time and resources available to the designers, but it does seem sensible to begin at as high a level as is reasonable and practicable.

Here Lawson concluded the design problems in a very generic way which provides a guidance to research work on design problems. In the practical design world, many design problems could occur. How to deal with these concrete design problems is one of the most important jobs facing the designers. The function of the design constraints is to ensure the designed system or object performs the functions demanded of it as adequately as possible. VM provides the methods and techniques to ensure the achievement of functions demanded by the user/owner.

2.2 FUNCTIONAL APPROACHES TO BUILDING DESIGN

In the early 1970's, a number of researchers attempted to define buildings in functional terms. They included Markus, Hillier and Leaman.

2.2.1 Markus's Model

Markus (1967) classified the functions of a building into five categories: (1) Building System, (2) Environmental System, (3) Activity/Behaviour System, (4) Organisational System, and (5) Resources System. A few years later, as shown in Figure 2-4, in his conceptual model of building and people system (Markus, 1972), he changed term

"Organisational System" into "Objective System". A detailed explanation of the five systems are as follows:

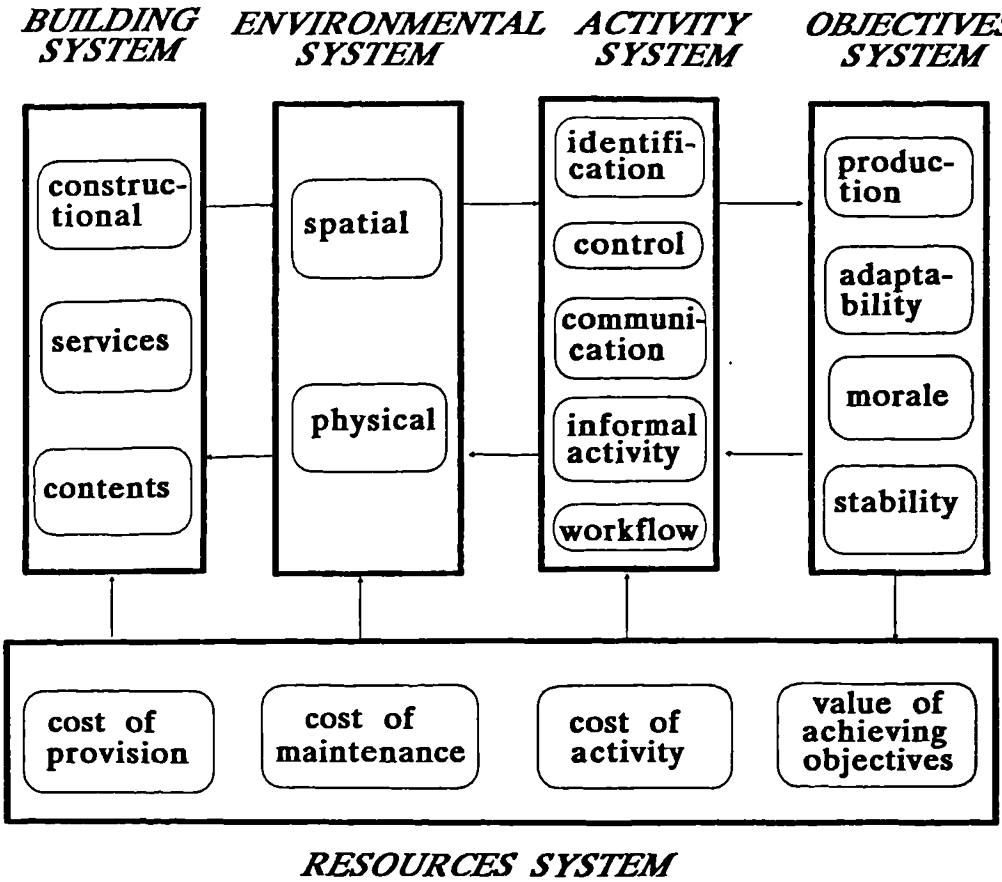


Figure 2-4 Markus's Model of Building & People System

Objective System: As explained by Markus, the main purpose for including the objective system is to provide an important context for the other four systems. Unless it is accepted right at the start of research into design that the bricks and mortar of a building exist to facilitate some specifiable objectives, then it is impossible to proceed further. Four sub-objectives have been defined as "Production" - to create products and/or improve productivity; "Adaptability" - to be able to adapt; "Morale" - to keep members in the organisation happy; and "Stability" - to maintain the organisation in a stable state.

Activity System: Within the activity system, Markus divided organisational activities into five groups, they are: a) Work-flow - modifying resources to give rise to a community of greater value; b) Control - coordinating or controlling activity sub-system); c) Communication - the transmission aspect of the activities, including movement of people, things, energy and information; d) Identification - identifying the difference among different objects; and e) Informal activity - miscellaneous activity.

Environmental System: To function properly, the activity system must have an appropriate environment. The environmental system is therefore established to facilitate the activity system. It consists of a "Spatial" sub-system, including those aspects of the environment related to the dimensional and geometrical properties of spaces and to the spatial relationship between them, and a "Physical" sub-system, including those aspects directly perceived as heat, light, sound, texture and smell.

Building System: The building system includes all those items normally described in the construction drawings, specifications and bills of quantities and all tangible contents other than the occupants. It has been divided into "Constructional" - all the inert, not directly energy consuming, constructional parts of the building fabric; "Services" - installations concerned with the supply and disposal of water, gas, electricity and fluids and solids for use in the activity system or in the modifications of environmental conditions; and "Contents" - plants, furnishings and finishes.

Resources System: All the sub-systems mentioned above consume resources, so that they can function within the system. The resources system is therefore divided into four categories: the cost for providing the building system, the cost of maintaining the environmental system, the cost of governing the activity system and the cost for achieving the objectives.

Broadbent (1973) viewed this model and pointed out its usefulness: "This classification is extremely useful within its defined limits, because it leaves out any references to site, adjacent buildings, climate and so on, into which the building may be placed, on the grounds that by definition any system operates within an environment and that the latter therefore needs no further description".

Although Markus's model is not complete, it is the first time in the history of building design that the objectives and functions of buildings have been systematically considered. The model provides a systematic view of the objectives a building should achieve and the functions to be performed by building elements. It would have been better if Markus had divided the environment system into the internal environment, to include spatial and physical environment, and the external environment, to include landscaping, access and parking, and adjacency to other buildings nearby.

One thing the model did not mention is the hidden logic within the structure, i.e., the "Why-How" logic. The whole diagram can be developed either from the far left box - "building system" by asking questions like "Why is this sub-system needed?", or from the far right box - "objective system" by asking questions like "How can the objectives or functions be achieved". As will be explained later, this Why-How logic has been used in VM programmes for many years, and forms the basis of the widely-used FAST (Function Analysis System Technique) diagrams.

2.2.2 Hillier and Leaman's Model

Hillier and Leaman (1972) developed a different model to describe the functions of a building. They argued that the key idea in the conceptual model of architectural research is the idea of building functions. Within that model, they defined four functions which a building has to perform, they are: (1) Modifying Climate, (2) Modifying Behaviour, (3) Modifying Resources, and (4) Modifying Culture. Figure 2-5 shows how these functions interact with each other.

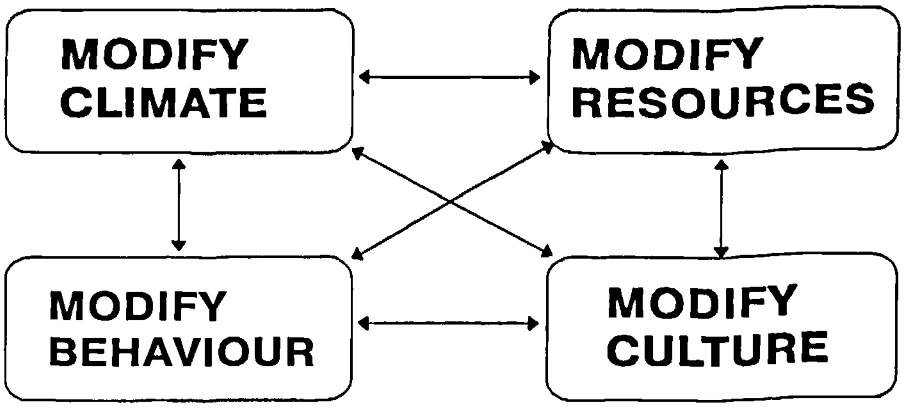


Figure 2-5 Hillier and Leaman's Model of Functions of Buildings

This model illustrated an important issue which was not included in Markus's model, that is, the "modify culture" function of buildings. In addition, the model has been useful in exposing the argument about which functions should be allowed to dominate in the design process, and why. Within their paper, after analysing and summarising various approaches in architectural research in the practical design world, they concluded that "only the emerging conception, which analyses building functions, can succeed". They proposed that "instead of dividing the problem of building into the contributions of different disciplines, the initial distinction should be between the different functions the building performs".

The functions listed above are thought to be universal to all types of buildings. They are, of course, capable of further sub-division. Each function represents one way of thinking about the whole building, not simply about parts of it, or about parts of the human behaviour associated with it. Each represents a comprehensive approach to the building while being concerned with less than the whole building. Examples of research problems have been given against each of the headings. They are:

Modify Climate: How can we minimise energy consumption and maximise comfort by the design of the building envelope? How can we predict and control the micro-climatic effects of different decisions about built form in urban centres?

Modify Behaviour: How can we minimise obsolescence in complex buildings where change of use is rapid because of technological change? How can we develop multi-use buildings in urban centres where land is scarce and public policy is to retain a high level of activity?

Modify Resources: How can we alter capital costs and costs over time in development programmes? What is the relation of different technologies to an overall picture of resource use over time in building?

Modify Culture: What are the general expectations of building form in city centres, why should it be so, and how can we achieve it? How important is the symbolic aspect of housing compared with other aspects?

These two models are useful in providing theoretical bases for analysing functions of building elements and for constructing FAST diagrams. Although in the practical design world, none of them can possibly provide actual assistance to the designers, as they are too broad to guide the designers in solving their actual design problems, they have pointed out a new direction to the researchers and practitioners in the design fields - a direction where the VM programmes can be incorporated into the design process, hence a potential of achieving better value for money is created.

2.3 VALUE MANAGEMENT AND THE DESIGN PROCESS

2.3.1 History and *Development*

VM was first introduced by Lawrence D. Miles of General Electric in the 1940s. In 1963 this technique was introduced into construction industry by Dell'Isola. Since then it has been widely used in the USA, and has made great contributions to cost savings and the enhancement of project value. Although not as widely used as in the USA, its value has already been noticed in the UK. Some consultants and construction firms purport to use this technique to serve their clients. The major developments in the history of VM are listed in Table 2-1.

VM was introduced in Europe around 1955-1960, and from 1965, its development became more noticeable. VM has now become a common management tool, though it is not used as systematically as in some other countries such as Japan. (Commission of the European Communities, 1990). Table 2-2 shows the current situation of VM in several major European countries.

2.3.2 Value Management Definitions and Concepts

Table 2-1 Major Developments In The History of Value Management

Year	Major Historical Developments
1947	Function Analysis and a VM job plan were first developed by Lawrence D. Miles at General Electric Company of the USA.
1947	Function Analysis was developed and used in the practice of work study by the Imperial Chemical Industries Plc in the UK (Gregory, 1984).
1954	US Department of Defense adopted VM when the Navy's Bureau of Ships set up a formal VM programme.
1959	Society of American Value Engineers established
1962	USA Ministry of Defence set up VM programmes in large scale bidding procedures.
1963	VM was first applied to buildings by Dell'Isola, when he introduced Value Engineering to the Navy's Facilities Engineering Command. The US General Service Administration (GSA) began to use VM shortly thereafter.
1965	FAST was introduced by Charles W. Bytheway of UNIVAC Division of Sperry Rand Corporation, at the fifth SAVE National Conference.
1966	The Institute of Value Management was established in the UK.
1969	The National Aeronautics and Space Administration (NASA) began formal VM studies and training.
1972	SAVE twelfth annual conference emphasized the application of VM in the construction industry.
1975	The Environmental Protection Agency (EPA) mandated that VM be used during the design of all waste water treatment facilities over $10 million.
1988	RICS published "A Study of Value Management and Quantity Surveying Practice", by Kelly & Male, which illustrated the practice in North America, and potential of using VM in the UK by the QS profession.
1991	RICS published the second report "The practice of Value Management: Enhancing Value or Cutting Cost", written by Kelly and Male.

According to Miles (1972), the creator of value analysis, "value analysis is a problem-solving system implemented by the use of a specific set of techniques, a body of knowledge, and a group of learned skills. It is an organised creative approach that has for its purpose the efficient identification of unnecessary cost, i.e., cost that provides neither quality nor use nor life nor appearance nor customer features". This definition has pointed out one important feature of Value Management, i.e., identification of unnecessary costs. However, it failed to identify other

Table 2-2 Value Management in Major European Countries

	UK	GERMANY	FRANCE	ITALY
Society Name and Acronym	Institute of Value Management (IVM)	Verein Deutscher Ingenieure (VDI) -Zentrum Wert Analyse (ZWA)	Association Francaise pour L'analyse de la Valeur (AFAV)	Associazione Italiana per L'analisi Del Valore (AIAV)
Year of Creation	1966	1974	1978	1985
Legal Status	Non-profit-making organisation	Technical division of the German Association of Engineers	Non-profit-sharing association	Non-profit-sharing association
Number of Members	>60	>600	>800	>230
Regular Publications	Value (Quarterly)	WA-Kurier (Quarterly)	Valeur (Quarterly) Le bulletin de l'AFAV (Monthly)	Valore
Main Activities	Executive meetings, VM awareness seminars	VM Training, Seminars, Conferences	Regional Meetings, Seminars	Developing and spreading the methodology nationally and abroad.
National Meetings	No National Conference	Two VM conferences each year	International VM Conference every two years	International VM conference every two years
Present VM fees/year	9.5 million ECU	18 million ECU	15 million ECU	3.2 million ECU
Certification	None	Yes (4 levels)	Yes (4 levels)	None
Standards	None. IVM is moving towards standardization	DIN 69 910: The Value Analysis System - description and work plan.	AFNOR x50-150, 151, 152, 153: Definitions of VA terms; Functional expression; Basic features; VA Recommendations.	None. AIAV is moving towards standardization.

features of VM, such as the concepts of value and functions.

Dell'Isola (1982) stated that "Value Engineering is a creative, organised approach whose objective is to optimize cost and/or performance of a facility or system".

Compared to Miles's definition, this definition added the feature of creativity in VM, but again failed to raise the concept of value enhancement.

The definition given by the Society of American Value Engineers (SAVE) is: "Value Engineering (synonymous with terms value management and value analysis) is a function-oriented, systematic team approach to provide value in a product, system, or service. Often, this improvement is focused on cost reduction, however, other improvement such as customer perceived quality and performance are also paramount in the value equation".

Value Analysis is distinguished from Value Management in several documents published by the European Community (e.g., "Value Analysis Glossary" and "Value Analysis in the European Community - A Tool for Value Management"), where VA is defined as a management technique which analyses, by means of a systematic approach, how to reduce cost whilst taking into account customer requirements; it not only assesses the degree of innovation desired or allowed for in the product or service, but also covers the implementation and follow-up of solutions proposed and therefore strengthens companies' innovative capacity and competitiveness.

As indicated by the definition given by the SAVE, the terms Value Analysis, Value Management, and Value Engineering are treated as synonymous in this thesis, and wherever possible VM will be used as representative of them. For the purpose of this research, my preferred definition of VM is as follows:

Value Management is an organised function-oriented systematic team approach directed at analyzing the functions and costs of systems, supplies, equipments or *facilities, for the purpose of enhancing the value of the objects, usually through achieving the required functions specified by the clients at the lowest possible overall cost, consistent with requirements for performance, including reliability, delivery, maintainability and human factors.*

2.3.3 Value Management Principles and Methodology

Five principles of VM methodology have been identified, which are essential to the success and advancement of VM studies. As shown in Figure 2-6, they are: *VM job* plan, functional approach, function-cost analysis, team approach, and environment for creative thinking. There are six simple but fundamental questions to be asked during any VM studies. They are: *What is it? What does it do? What must it do? What does it cost? What else would do the job? What would the alternatives cost?*

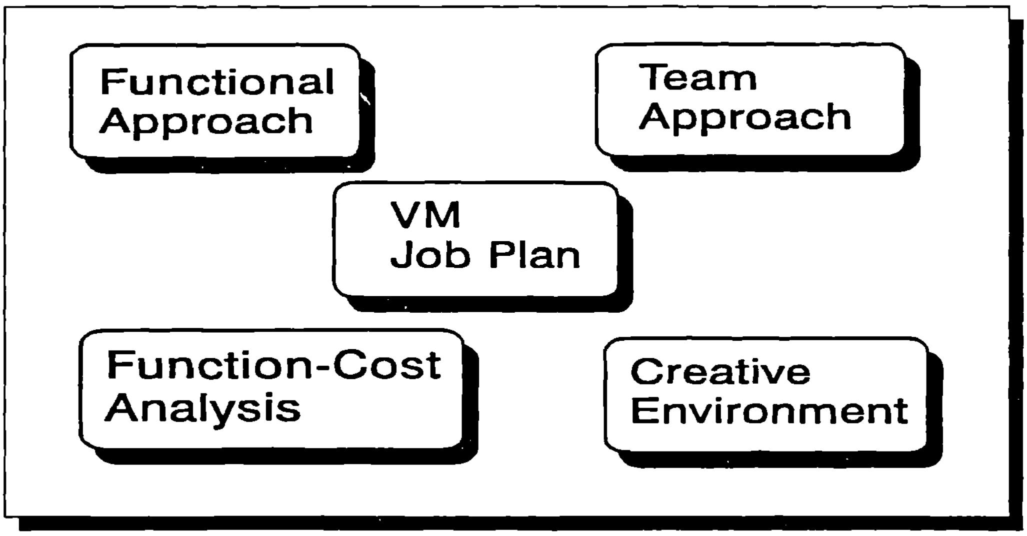


Figure 2-6 Principles of Value Management Methodology

2.3.3.1 The Functional Approach

Functional approach as an essential element of the VM methodology has a relatively long history evolutionary development (Gregory, 1984). It consists of a group of techniques which sets it apart and makes it different from traditional cost reduction and cost planning efforts. The objective of the functional approach is to forget the product as it exists and concentrate only on its necessary functions required by the clients. This approach leads to a systematic identification and clear definition of client's requirements, an improved functional understanding of the design problem, and an effective accomplishment of those functions.

A function is the specific purpose or intended use for a product, it is the characteristic which makes it work, sell, produce revenue, or meet requirements (Dell'Isola, 1982). Functions are usually expressed in two words: an action verb and a noun. This is to achieve a high degree of conciseness and to avoid combining more than one function. Kirk et al (1988) identified two kinds of functions: use functions and aesthetic functions. According to him, use functions involve an action that clients want performed, whereas aesthetic functions please the clients of the facility. For example, a client may want space provided, environment improved, security ensured (use functions), as well as specific colour, shape and appearance to appeal to his/her staff and customers (aesthetic functions). As shown in Table 2-3, the following verbs and nouns are usually used in describing use functions and aesthetic functions:

Dell'Isola (1982) distinguished basic functions (or primary functions) from secondary functions (or supporting functions) by giving the following definitions: a basic function is the purpose of performance features which must be attained if a product is to work or meet the client's needed requirements, whereas a secondary function is any characteristic of a product which is not essential to the user for the desired

Table 2-3 Verbs and Nouns for Use and Aesthetic Functions

	Use Functions	Aesthetic Functions
VERB	absorb, change, circulate, collect, condition, conduct, connect, contain, control, convey, create, detect, distribute, enclose, exclude, improve, insulate, protect, reduce, resist, support, ventilate	create, ensure, establish, experience, feel, finish, improve, increase, reflect, satisfy, smell, taste, think
NOUN	air, compression, current, elements, energy, fire, flow, fluids, force, heat, landscape, load, materials, objects, oxidation, parking, people, power, radiation, sheer, sound, space, temperature, tension, voltage, weight	appearance, balance, beauty, colour, convenience, features, feeling, image, prestige, preparation, shape, space, style

application of the item and does not contribute directly to the accomplishment of a basic function. Secondary functions are also increments of performance in excess of minimum performance levels (GSA, 1978). Usually, secondary functions do not have any value, but, when a secondary function is essential to the performance of one or more basic functions or required by codes, it becomes a required secondary function and a value will be assigned to it.

All facilities involve functions. An intensive search for and expression of functions form the basis of the functional approach which is to enhance the value of the facility being designed. Functional Analysis Systems Technique (FAST) is one of the tools which facilitate the searching for and expression of functions. It was invented by Charles W. Bytheway of UNIVAC Division of Sperry Rand Corporation in the USA, and first introduced in the 1966 SAVE national conference. The result of the FAST is a diagram which systematically demonstrates the logical relationships among the functions of a product or system. Within the diagram, higher level functions appear on the left hand side, lower level functions on the right hand side.

A FAST diagram could be generated either by listing the highest level function on the far left side, and by repeatedly asking how the functions could be achieved, lower level functions could therefore be derived; or by listing the lowest level function on the far right side, and by repeatedly asking why the functions need be achieved, higher level functions could therefore be derived. Two categories of FAST diagrams were identified by Snodgrass and Kasi (1986), they are: technically-oriented diagrams and task-oriented diagrams.

The functional approach might end with a functional performance specification (Commission of the European Communities, 1991) which comprises (1) a list of functions to be met, (2) an indication of the relevant criteria for each function and their levels together with tolerances, (3) a statement on the level of flexibility of the criteria by the client, indicating satisfaction levels for functions deviating from the assigned configuration, together with the benefits or extra costs involved, and (4) recourse to alternatives where the client encourages the designers to propose solutions that might combine several responses as regards functional performance.

2.3.3.2 The VM Job Plan

The term "organised and systematic approach" is commonly referred to as a job plan or workshop, which is highly emphasized in the VM methodology, and contains systematic procedures for accomplishing all the necessary tasks associated with a VM study. It is naturally at the centre of all existing European VM Standards, in particular, both the French and German VM standards. There are a variety of VM job plans introduced by a number of researchers and practitioners in the VM field, with phases ranging from five to eight. The most commonly-used job plans include:

Charette, SAVE 40-hour plan, VM audit, Contractor's change proposal, Truncated workshop, and Concurrent study. Based on these job plans, various VM studies can also be categorised into different groups (Kelly & Male 1991). The first two job plans will be introduced in details, because the Charette plan has some similarities with the conceptual analysis, *whereas the 40-hour job plan is widely used in VM* studies. Other job plans will not be discussed here, because they are less popular approaches, and are out of the scope of discussion in this thesis.

The Charette job plan attempts to rationalise the client's brief primarily through functional analysis of space requirements. If time is available for the study, this plan could be broadened to include other issues concerning the client's requirements. The main focus is to ensure that the designers understand fully the client's requirements. This method is very similar to the Conceptual Analysis practised in ICI Plc, which will be introduced systematically in Chapter 4. The main advantages of the Charette plan, as Kelly and Male (1991) outlined, are that it is considered by many clients to be an inexpensive and effective method of briefing the design team and clarifying their own requirements, taking less than 2 days compared with 5 days required by the 40-hour job plan. By so doing, abortive design work could be avoided. As the study is usually carried out in the very early design stage, it therefore has a major role to play in controlling the cost and enhancing the value of a project.

The 40-hour job plan is the most commonly accepted formal approach. As shown in Figure 2-7, a 40-hour VM job plan usually consists of the following phases which, in essence, consist of the core of all other types of VM job plans (The objectives and techniques used in each phase are summarised in Table 2-4):

1) Information Phase (4 hours) - The main tasks in this phase include: to collect historical cost data, client's requirements, design standards as well as specifications;

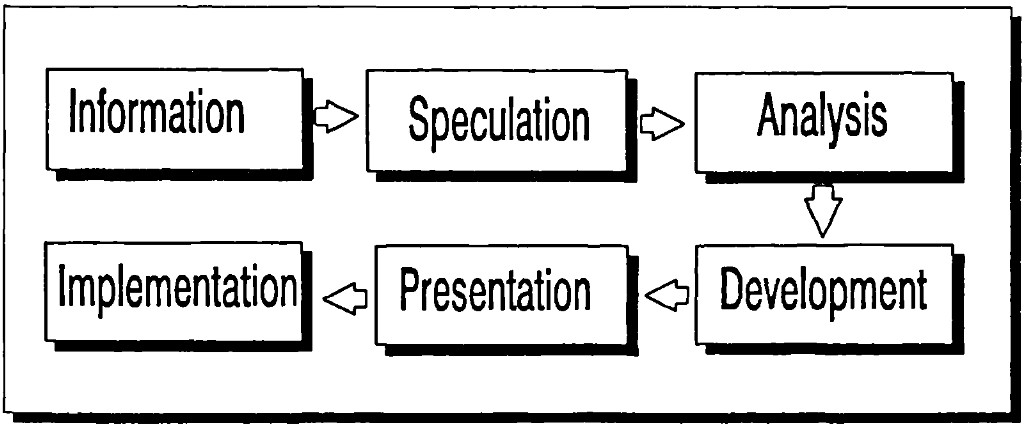


Figure 2-7 Illustration of The 40-Hour Job Plan

to obtain a thorough understanding of the project; to undertake functional analysis and select components for detailed studies. It answers the following questions: "what is it?", "what does it do?", "what must it do?", "what does it cost?".

2) Speculation Phase (or Creativity Phase, 8 hours) - The main tasks in this phase are: to generate numerous alternatives for accomplishing basic functions required by the clients, by means of creativity stimulating techniques, such as Brainstorming, Synectics, Morphological Chart, and Lateral Thinking. This phase answers the question: "what else would work (preform the basic functions)?".

3) Analysis Phase (or Evaluation Phase, 4 hours) - This phase attempts to set up a number of criteria, evaluate and select alternatives generated during the creativity phase, by using various models, such as, cost models and energy models. In this phase, the question "what would the alternative cost?" will be answered.

4) Development Phase (or Proposal Phase, 16 hours) - It attempts to investigate selected alternatives in sufficient depth, develop them into written recommendations for implementation. This involves not only detailed technical and economic evaluation

but also consideration of the probability of successful implementation.

5) Presentation Phase (8 hours) - to define and quantify results; to prepare and present a Value Management Change Proposal (VMCP) to the final decision makers. The proposal usually includes an analysis of the potential benefits and a statement of the follow-up procedures which are necessary to ensure the implementation.

6) Implementation Phase (time varies) - to ensure the recommendations in the VMCPs are fully operational; to provide assistance and clear up misconceptions; to audit and resolve problems that may develop in the implementing process; and to compare the actual results with what were originally expected by the VM study team.

This common form of delivering VM to a construction project, if well managed, can produce excellent results for minimum effort. This statement has been proved over the past four decades by many VM practitioners, and the job plan is regarded as one of the VM milestones by SAVE and many other VM organisations. It has, however, a number of drawbacks (Bowen, 1984):

Firstly, it is difficult to assemble the key project participants for such a concentrated period and retain their undivided attention. Secondly, since much of the session must be devoted to educating participants who are rarely familiar with the VM processes, it is rather difficult to bring these processes to bear on the problem at hand. Thirdly, the evaluation and development are particularly difficult to complete effectively in such a short time, because many ideas proposed in the speculative phase often require intensive design and engineering analysis, particularly where these involve long-term life cycle cost trade-offs. Finally, the VM effort is often isolated from project cost

Table 2-4 Objectives and Techniques Used in the 40-hour VM Job Plan

Objective	Phase	Key Techniques	Supporting Techniques
Collect Information	Information	Get all facts Determine costs and quantities	Obtain all information Work on specifications
Define Functions		Define functions Put value on specifications and requirements Determine cost, worth & energy models	Divide problem into functional areas
Create Ideas	Speculation	Blast and create	Create, innovate and defer judgement
Evaluate Basic Functions	Analysis	Evaluate Basic Functions by comparisons	Evaluate functional areas
Evaluate New Ideas		Quantify and put value on ideas Refined ideas	Analyze costs using subjective judgement
Consult		Investigate suppliers, companies and consultants	Investigate advanced techniques
Compare Alternatives		Use standard Compare methods Compare products and materials	Develop new ideas
Develop Alternatives		Determine costs	Use teamwork
List best ideas	Proposal	Extract data	Use good human relations
Summarize		Motivate positive action	Finalize solutions
Prepare Documents			Documentation Present solution for action
Implement ideas Validate results	Presentation	Check tender prices Post-occupancy evaluation	Life cycle costing On-site inspection

management and it is not unusual for a successful VM workshop to be followed by a situation where overall cost exceeds budget because of lack of this integration.

One way to solve this problem, as Bowen (1984) suggested, is to disperse the VM process continuously from project inception to completion including: feasibility study, project definition, concept design, design development, contract documentation, procurement and construction, hand-over and operation, and feedback and evaluation. Although this procedure has some advantages such as a flexible timetable for each person participated in the process, some merits of the original 40-hour job plan are ruled out, for instance, the team effects. The real challenge is that it would be impossible to implement this proposal without the support of the latest computer technology, because each VM team member should be provided with updated project information in order to make any comment and evaluation.

Kelly and Male (1991) pointed out another defect of the 40-hour workshop by stating that the time allocated in this 40-hour job plan is unbalanced when compared to VM theories. The phases of information assimilation, development and presentation take too high a proportion, and the time allocated to functional analysis is too short. As will be discussed in the following chapters, this shortcoming can be partly overcome by developing a knowledge-based system that (if properly equipped with VM domain knowledge) could reduce the time proportions allocated to tasks such as information retrieval, alternative evaluations, and presentations, therefore, more time can be allocated to more important tasks such as function analysis.

2.3.3.3 The Function-Cost Analysis

The function-cost analysis makes it possible for costs per function to be established, giving a true picture of the product at the time of the project. In the majority of cases, a monetary parameter is used to estimate the cost of functions. Other parameters such as reliability and life cycle may also be used.

Theoretically, the sum of the costs for achieving functions specified by the clients are the same as the sum of elemental costs which are obtained based on the costs of materials, labour, equipment, and overheads. In practice, because a building element or component serves more than one function, it is usually difficult to allocate the cost of the item against the functions it serves. Although function-cost analysis is thought to be one of the most important aspect of the VM methodology by many researcher and practitioners, the author was surprised by the lack of research and formal methods in splitting cost against functions. A method has therefore been developed during the research which will be illustrated later in Chapter 4.

2.3.3.4 The VM Team Approach

The design and construction of a building is an extremely complex undertaking, involving people from many different professional backgrounds having different commercial interests. Each party is likely to give primacy to certain aspects of the whole. The developers seek to minimise non-lettable space, architects emphasise aesthetics, engineers stress the structures and services, space planners focus on work-flow, adjacency and furniture layout, and the ultimate occupant will probably want a building that is attractive to staff and visitors, convenient to use, and economical to occupy. As Duffy (1991) stated, "many of the problems of today's buildings are due to ineffective communication between different disciplines".

The complexity of construction projects has led to greater interdependency between the specialisations which produces a consequent need for strong integration of the independent professions and skills (Walker, 1989). Although the interdependency of the contributors to the construction process has long been recognised, it is often regarded as sequential interdependency, i.e., one discipline can only participate after the previous disciplines has done their work. It, however, as Walker stated, should be interactive, and the process should move forwards following decisions to which all appropriate parts of the system have made a contribution.

Although economic studies might be conducted during the decision-making process of a complete building design, they are usually undertaken by an individual engineer or architect working on a particular aspect of the design. For example, structural engineers select the most appropriate structural system, electrical engineers choose the most preferred generators, panel boxes, conductors, etc. In some cases, a team is called together, but, as Macedo (1978) pointed out, "normally no formal job plan is followed, nor are any employees assigned full time to organise and co-ordinate the activities or follow through on any new ideas generated".

The results of the studies carried out by individuals are that, each discipline, from its own points of view, generates and reviews requirements, establishes and modifies its particular criteria, and even modifies client's standards and criteria. This is known as a sub-optimisation approach, which tends to sacrifice the overall system performance in maximising subsystem performance. The sum of sub-optimisation is however not necessarily equal to the overall optimisation. The narrow viewpoint of a subsystem level can lead to apparently sound local solutions which create problems for the system as a whole (Little, 1990). It is therefore clear that the success of the design process, to a large extent, depends upon the way in which the architects, engineers, quantity surveyors and others work together. As Walker (1989) argued, "it depends upon them perceiving the same objectives for the project and recognising that what each of them achieves depends upon what the others do".

The up-to-date project management has to some extent improved the coordination between different disciplines, so that better design solutions could be produced. As Bennett (1985) pointed out, two approaches are currently used in coordinating different design disciplines. Firstly, interactions between their tasks could all be referenced to a design manager to determine the detail design. Secondly, regular design team meetings would be held where problems arising from interactions among separate teams are discussed and answers or methods for finding answers are arrived at. Bennett did not mention the detailed job plans and methodologies used in these approaches. Experience has proved that VM is one of the best methods in organising people from different disciplines to solve their disputes over some design issues. Since VM encourages people to consider a project in functional terms (all decisions within the design should satisfy the functional requirements), better understanding of the project can be achieved, agreement among disciplines can be reached more easily. As Kelly et al (1991) argued, VM provides a method of integration in the building process that no other management structure in construction can provide.

It is the VM programme which organises all relevant disciplines e.g., architect, structural engineer, electrical engineer, and client, together as a team. Instead of seeking sub-optimisation within each individual domain, the team explores the overall optimisation of the system. The advantage of this group thinking process is, as Jones (1983) argued, it enables a number of people (specialists and non-specialists), to work and think together on the project as a whole, or in larger chunks than is possible with the more solo methods they replace. Clients and users of a project are often called in to attend a few sessions of the VM study. This participation makes the process of designing sufficiently visible and discussable, for customers and clients to contribute to it the experience and insight which can only be obtained at the receiving end, but not in the design office (Jones, 1983).

2.3.3.5 The Environment for Creativity

During a VM study, each member's ideas can be stimulated by others within the team under a specially-designed circumstance for creating large amounts of ideas. According to Dell'isola (1982), a multi-disciplinary design group can work out 65 to 93% more ideas than that from an individual working alone. Better ideas can therefore be derived from the large number of ideas generated. This is one of the reasons that the Commission of the European Communities has seen VM as a potentially-useful tool for innovation and technology transfer.

2.3.4 Value Management in the Design Process

The significant difference between VM and cost reduction is that: VM is a function-oriented technique which analyses the functions of a project, and seeks alternative means with lower overall costs to achieve the functions - the alternatives found might be totally different from the original design; whilst the latter is a part-oriented technique which does not analyse the functions of the building, the number of alternatives created can be quite limited, and the performance or quality requirements may sometimes be overlooked. Function analysis, as the core of VM methodologies, is a unique approach in identifying and expressing client's requirements in functional terms, and seeking alternative means to achieve the required functions with lowest life cycle cost. According to Macedo (1978), the emphasis on initial cost and the failure to consider the overall effect of related life cycle costs are probably the greatest shortcomings in the current design process.

It is difficult to separate design techniques from VM techniques. Designers may use some of the VM techniques in the design process without knowing that they belong to the VM domain. Jones (1970) gives a comprehensive list of thirty five design methods and techniques which can be categorised into six groups as shown below:

1. Methods of prefabricated strategies
2. Methods of strategy control
3. Methods of exploring design situations (divergence)
4. Methods of searching for ideas (divergence and transformation)
5. Methods of exploring problem structure (transformation)
6. Methods of evaluation (convergence)

As shown in Table 2-5, 6 out of 35 of these techniques are relating to identifying and clarifying organisational objectives, defining and analyzing elemental functions. Although the techniques were developed and used in manufacturing industry initially, some of them, especially the concept and methodology, have already been widely adopted and used in the construction industry.

Traditionally, VM technique is used at the detail design stage when most of the essential design decisions have been made. Because of its successful performance when applied to building design, this technique was developed and recommended for use throughout the design of a building project (e.g., Bowen, 1984). In theory, VM can be applied at any stage of the building design process. In practice, in order to get maximum return of VM input, VM is usually applied to a project at the conceptual design and sketch design stages, and is rarely used in the detail design stage.

Table 2-5 Design Techniques Related to Value Management

Methods	Objectives
1. Value Analysis	Reduce Life Cycle Cost without sacrificing required functional performance.
2. Stating Objectives	To identify external conditions with which the design must be compatible.
3. Morphological Charts	To widen the area of search for solutions to a design problem.
4. Function Innovation	Find new designs capable of creating new patterns of behaviour and demand.
5. Specification Writing	To describe an acceptable outcome for designing has yet to be done.

As Bowen (1984) pointed out, to get overall optimisation of a building system, VM should be invoked at all stages of the design process mentioned above. As shown in Figure 2-8, the overall framework of the design process, should therefore be changed to include VM and similar programmes. In this modified model, at each stage of the process, VM or Business Analysis or Conceptual Analysis can be called in to assist the designers either in clarifying client's objectives, accomplishing project definition, or analysing functions of each building element, using VM techniques such as group creativity to generate, evaluate and select alternatives performing the same functions but with lower LCC. Here the "Business Analysis" is an organised effort aiming to explore the feasibility of releasing a product or building project onto the market, by organising a number of key personnel on the project to analyse the external environment (including external information, market situation, economic policy, laws and regulations) and the internal environment (including internal information, company objectives, company potential, new technology and other information).

VM is a proven management tool which ensures the cost effectiveness of design or construction projects. The programme has exhibited excellent results in all fields of

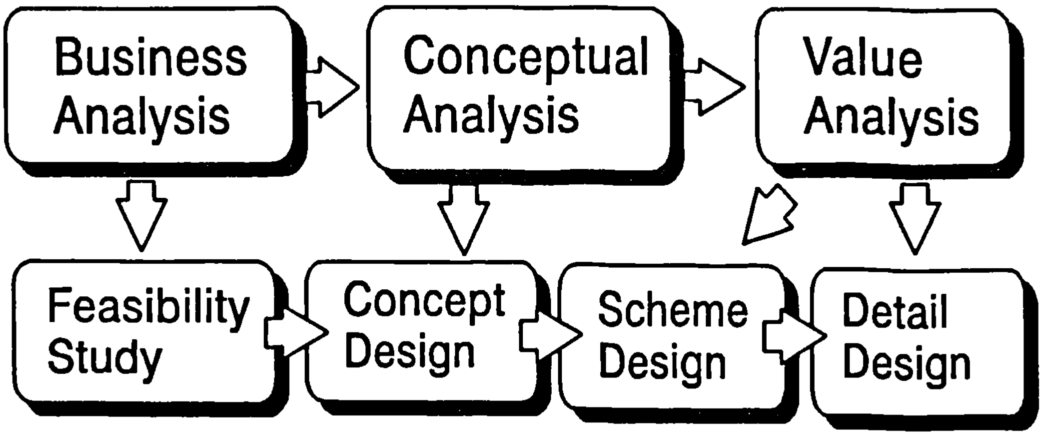


Figure 2-8 A Recommended Framework for The Design Process

construction and manufacturing (Zimmerman, 1982). Although traditionally, VM is often implemented by a team independent from the original design team, there is an increasing tendency of combining the study into the design process. The following features explain why VM works when applied to the design process (Figure 2-9):

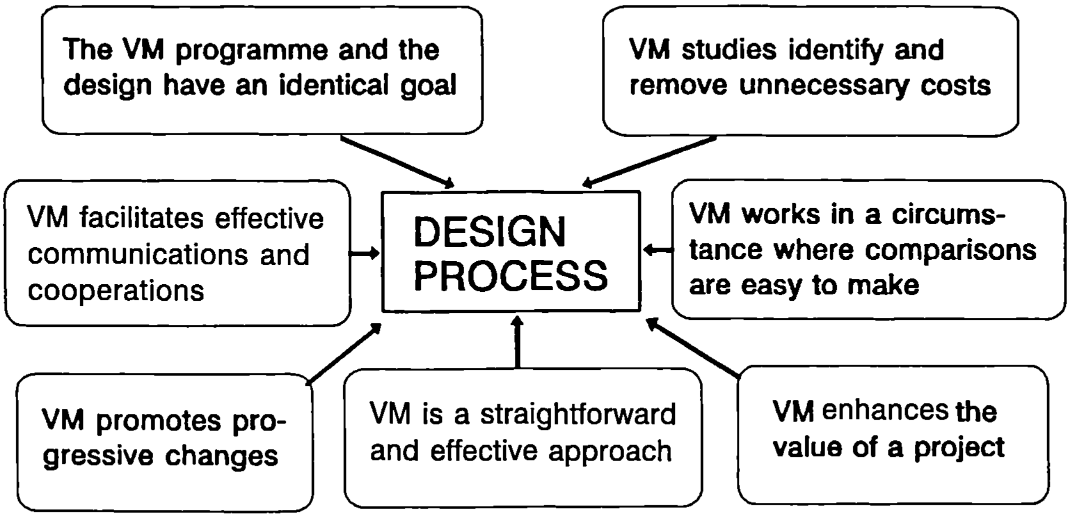


Figure 2-9 Reasons Which Explain Why VM Works

1) VM is a straightforward and effective approach - This organised approach is an incentive process which seeks out information, stimulates the thought process in a

group or single session and evaluates these thoughts and ideas to produce recommendations for implementation. When the technique of group creativity is employed, the pitfalls of premature criticism are avoided by separating the creative aspects of the study from the judging aspects.

2) VM programmes identify and remove unnecessary costs - Each design is itself a creative thinking process. There are an infinite number of combinations of designs, materials and methods that can be used to achieve the ultimate goal of a project. Whether or not they include the best balance between the cost, the performance and the reliability of the project is a real question. Each designer working on a project carefully develops a number of alternatives that can be used to perform a function. Due to the time and budget constraints, however, that number of alternatives is often limited, because a designer might by-pass many comparisons and use his experience in the interest of meeting due dates and design budgets. The analysis of historical projects has shown that the depth and thoroughness of the design partly depend on the time and resources allocated (Zimmerman, 1982). Given the time and resources, under proper project management, proper comparisons might be made to optimise the design. Information about the project and an objective second look by someone not involved in the design may change the outcome of previous comparisons.

3) VM facilitates effective communications and co-operations - VM drives the team members beyond their habit patterns and procedures. A multi-disciplinary team will provide motivation to its members by the fact that they are participating in a group-thinking process, and working towards the same objective. A successful design project involves co-operation between various elements in the design, i.e., electrical, mechanical, architectural, structural etc. Hence a design is dependent upon the co-

operation among these various groups. The basic physical limitations of an office set-up prohibits the free flow of information between various groups, whilst a VM programme provides a way of mobilising and uniting individual talents of each member to achieve objectives designated to the project. As Jones (1983) stated, "the secret to the success of design is to organise the process so that each person is acting as much as possible adaptively and creatively, and so that we minimise the need to work to rule, shutting the mind to the evident effects of what one is doing."

4) VM works in a circumstance where comparisons are easy to make - A design by its nature is a creating process, as Jones (1970) stated, "design is to initiate changes in man-made things". This process of creation is made in a step-by-step fashion. As design develops, those pieces are pulled together into a whole. A deductive reasoning process is used, in which the major mental process is the recall of past knowledge. In contrast, when a VM programme is carried out, those pieces have already been pulled together and the inductive reasoning process is used to analyse the project. In this case, the major process is the comparison of alternatives, and it is easier to evaluate a given idea than to come up with the original concept (Zimmerman, 1982).

5) VM promotes progressive changes - VM tends to establish an atmosphere where changes can be made gracefully without anyone losing face. Many times self-interest allows our thoughts to be dominated by our desires. This is a very thought-provoking concept. It is a regular occurrence in engineering practice.

6) The VM programme and the design have an identical goal - The identical goal is to provide a satisfactory design for the project that can meet owner's requirements at the best balance among cost, performance and reliability (Zimmerman, 1982).

"Keeping this in mind, it is easy for the project engineer to realise that the VM team is a supplement to his design effort. A second look is taken at the design in an attempt to improve the cost impact of the project, rather than to criticise designer's work". This statement is probably true when VM is applied at the conceptual design stage. Later applications of VM into a building design could lead to abortive design work and is unlikely to be accepted by the designers.

7) VM reinforces the value of a project - Although this comes last in the list, it is by no means the least in importance. VM consists of a range of well developed techniques such as function analysis, life cycle costing analysis, decision analysis, individual and group creative thinking, which reinforce the value of a project by enhancing its performance and/or reducing the overall cost. Although a VM programme itself costs money, a benefit of ten for every one dollar investment can be expected from a formal VM programme (Dell'Isola, 1982). The earlier one can apply VM, the bigger savings can be expected.

2.3.5 The Benefits and Limitations of VM

The benefits from implementing VM technique to the design and construction of a building project are as follows (Dell'Isola, 1982):

A. Time ---- Early application of VM will save design time by clarifying scope, reducing false starts, and helping to prevent budget overruns and re-design.

B. Standardisation and Simplification ---- VM helps ensure that simplified and standardised alternatives are considered to reduce cost through analysis of redundant and unnecessary functions.

C. Isolating Design Deficiencies ---- a VM team can uncover the potential design deficiencies occurred during the design process.

D. Helping in Solving Problems ---- VM is one of the best methods for solving the problems of performance, reliability, unforeseen conditions etc.

E. Conducting Special Studies ---- techniques such as cost control, life cycle costing, energy conservation can all be enhanced by combining them with VM studies. VM provides a comprehensive umbrella to optimise all inputs.

The major criticism of VM is the time delays to, and the extension of, the design programme. Some designers blame the VM exercise for adding to the time required for design. Although these critiques are not absolutely right, they reflect some of the limitations of the VM Programme. They are as follows:

(1) If the VM workshop is not properly organised, the study can be fruitless. Some designers complained that many suggestions in the VM proposal had previously been considered and discarded. On the other hand, a poorly implemented VM programme (for instance, the VM team did not analyse the required functions properly) could lead the study to nothing more than a cost reduction process. Since the required functions may not be satisfied, a poor design may therefore be produced.

(2) Although the functional approach in the VM methodology provides a fresh look at the design problem, it is sometimes difficult to provide a holistic view of a

complex artifact such as a building in functional terms in one go (This opinion was derived from a discussion with Brandon P S, 1992).

(3) Unlike other professions such as architects, structural engineers, and quantity surveyors, VM standards and certifications have not yet been established in countries such as the UK. Some designers are therefore critical of the professionalism of the VM team members by saying that: "VM specialists are not professionals", "We do not object to review components by qualified professionals".

(4) The implementation of recommendations suggested by a VM team, to a large extent, depends on the co-operations of the original design team. To get the designers actively involved and be co-operative is vital to the success of any VM studies. It is also one of the most difficult aspect of the VM studies.

(5) In theory, a VM programme can be implemented at any stages of a construction project. In practice, however, later applications of VM could cause a huge amount of abortive design work and delay to project completion. The VM change proposals are therefore unlikely to be accepted by the designers and clients.

2.4 SUMMARY AND CONCLUSIONS

In this chapter, the nature of the design process and design problems are discussed, which provides a background for the implementation of VM into the design process. The concepts and principles of the VM methodology are introduced, which form the basis of developing a knowledge-based system to facilitate the implementation process.

The functional approaches to building design started in the 1970's. Since then, a number of researchers have tried to define buildings in functional terms. Markus (1967), Hillier and Leaman (1972) can be seen as the first generation of functional approaches to building design. Although the models introduced are not complete, it is the first time in the history of building design that objectives and functions of buildings have been systematically considered. They have also provided theoretical bases for analyzing building functions and constructing FAST diagrams.

Pahl and Beitz (1988) presented a model of systematic approach on engineering design, which strongly emphases the importance of analyzing objectives and functions of the systems. Although the procedure is mainly used in the manufacturing industry, the concept and methodology could be adopted in the building industry.

Markus's two-dimensional model of the design process is currently accepted by most of the designers, within which the essential decision-making process, i.e., from analysis through synthesis to decision, is expressed in the horizontal dimension, design stages from client brief through feasibility study, outline proposals to production information are displayed in vertical dimension. Kirk has defined a similar but refined two-dimensional model of the design process, with the methodology of decision-making within design as one dimension, its applications to the design stages as another, covering the life cycle of project development. Kirk's model has provided a framework, within which a number of techniques can be applied to support design decision-making by enriching the processes of clarifying client's goals/objectives, establishing measurement scales, generating and evaluating design solutions.

In theory, VM techniques can be applied at any stage of the building design process, in fact, VM has been used throughout the life cycle of a project; in practice, however, in order to get maximum return of VM input, it is usually applied to a project at early design stages e.g., the Conceptual Design and Sketch Design. Currently it is rarely used in the Detail Design stage. In order to obtain overall optimisation of a building system, VM techniques should be included in the design process. The overall framework presented by Kirk on the design process, therefore should be modified.

In addition to the methodology of decision-making described by Kirk, at each design stage, the horizontal methodology dimension should contain one of the three VM branches which are used to support the designers at different design stages. At the feasibility study stage, Business Analysis provides support in the decision-making on whether the development of a new project should be undertaken; at the conceptual design stage, Conceptual Analysis assists the designers in clarifying client's objectives and introducing a project definition; while during the sketch design, Value Analysis may be called in to assist the designers in analyzing functions of building elements, and generate, evaluate and select alternative design solutions. The vertical dimension i.e., project life cycle will remain the same.

CHAPTER 3. KNOWLEDGE-BASED SYSTEMS IN BUILDING DESIGN

The purpose of this chapter is to set up the basis of the knowledge-based approach to facilitate the implementation of VM into building design. Section 3.1 gives a brief introduction about the emergence of Artificial Intelligence (AI). Section 3.2 introduces the definitions and concepts of Expert Systems (ES), a particular branch of AI. Section 3.3 outlines the current state of the art of ESs. The major principles and techniques concerning ES design and development are illustrated. They include the roles and potential benefits, the mechanism of search and inference, knowledge acquisition, knowledge representation, and limitations of ESs. Section 3.4 delves into ES applications in various areas of the construction industry, from pre-design through design to construction. Recent developments and approaches in knowledge-based design systems are summarised. Considerable attention has been given to computer applications in the VM domain. Section 3.5 summarises and concludes this chapter.

3.1 THE EMERGENCE OF ARTIFICIAL INTELLIGENCE

AI is a term that is widely used but lacks of precise definition. It was first introduced by John McCarthy at a conference organised by Dartmouth College in 1956. The participants of this conference are considered the AI pioneers. They included Marvin Minsky (founder of the AI Lab at MIT), Claude Shannon (Bell Labs), Nathaniel Rochester (IBM), Allen Newell (first president of the American Association of Artificial Intelligence), and Herbert Simon (a Nobel Prize winner from Carnegie Mellon University). Although two other expressions "Machine Intelligence" and "Computational Intelligence" are much better than "AI" (as suggested by Partridge, 1991), none of them succeeded in replacing the term AI. This is because: (1) the most important thing is what AI represents, rather than the term itself; (2) the term AI has been established and widely used for a relatively long period of time and there is a general consensus about what it represents.

AI is defined in the Encyclopedia Britannica as "the branch of computer science that deals with ways of representing knowledge using symbols rather than numbers and with rules-of-thumb, or heuristic, methods for processing information". A well-publicized definition of AI given by Barr and Feigenbaum (1981) is: "AI is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding, language, learning, reasoning, solving problems, and so on". Rich (1983) defined AI as "the study of how to make computers do things at which, at the moment, people are better". Schank (1990) listed 10 features which he considers to be characteristics of AI, they are as follows:

(1) Representation - how do we represent what we know in a machine;

(2) Decoding - translation from the real world into the representation selected;

(3) Inference - the process of figuring out the significance and full meaning of a collection of knowledge represented explicitly, or sensed directly;

(4) Control of Combinational Exploration - finding ways to limit the potentially limitless inference process;

(5) Indexing - organisation and labelling of memory such that relevant items can be located quickly;

(6) Prediction and Recovery - ability to predict from current knowledge and recover from inevitable mistakes;

(7) Dynamic Modification - knowledge structures must change over time;

(8) Generalization - the process of drawing conclusions from disparate data, the basis of creativity;

(9) Curiosity - a process of probing beyond the known and understood, of constructing both questions and explanations;

(10) Creativity - the process of generating new information, often viewed as generating useful relationships between known items that were previously thought to be unrelated.

AI comprises hardware and software systems and techniques which attempt to emulate human mental and physical processes such as thinking, reasoning, decision making, data storage and retrieval, problem-solving, learning, human senses, and motor skills (Tuthill, 1990). Since various overlapped and interacted disciplines participate in the AI fields, it is difficult to classify AI applications according to the disciplines. Turban (1988) listed a number of AI branches based on their output. They include: Knowledge-Based Systems (KBS) (including ESs), Natural Language Processing, Computer Vision and Other Sensory Systems, Speech Recognition and Voice Synthesis, Robotics, and Intelligent Computer-Aided Instruction.

AI is sometimes confused with Information Technology (IT). The term IT is used to describe technologies that enables us to record, store, process, retrieve, transmit and receive information. It includes modern technologies such as computers, facsimile transmission, micrographics, telecommunications and microelectronics. According to Behan and Holmes (1991), there are 4 types of information systems which represent the evolution in this field. They are: 1) Simple task-oriented transaction processing systems -- systems which use standard procedures and are very well structured, i.e., the outputs, inputs, controls and programming steps are clearly defined and well understood within the organisation; 2) Complex transaction processing and control systems -- systems such as Office Automation Systems and Management Information Systems (MIS), which evolve from the simple processing system and are able to solve more complex processing and control problems; 3) Decision Support Systems (DSS) -- systems which couple the intellectual resources of individuals with the capabilities of computers to support decision makers in improving the quality of decisions; and 4) Knowledge-based systems. It is therefore clear that both AI and IT are broader terms than KBS, and in this sense, AI and IT are overlapped.

Over the past decade AI has attracted increased interest and publicity. Many firms have been involved in the development of AI applications. Research institutions in the UK as well as in other countries such as the USA and Japan, are also heavily committed to AI research. In October 1981, the Japanese Ministry of Trade and Industry announced its Fifth Generation Computer Projects. The aim was to build a new generation of computer systems i.e., symbolic inference machines capable of learning and communicating in natural language, and running PROLOG as its basic language. In response to the Japanese challenge, in 1983, the British Government launched its ALVEY Programme of advanced Information Technology with a budget of £350 million, aiming to stimulate research and development in IT. Directed at developing basic technologies for the European IT industry, promoting European industrial cooperation in pre-competitive R & D, and developing internationally accepted standards, the European Communities' ESPRIT (European Strategic Programme for Research and development in Information Technologies) programme stands for the biggest investment in AI so far, with a budget reaching 1600 million ECUs over a duration of 5 years.

Despite the recent achievement in the AI community, some fundamental roadblocks still need to be cleared. A number of researchers have warned of the possible dangers and the complexity of the nature of AI. Partridge (1991) argued that "the major problems in AI are not solved, or even nearly solved. In fact, the major discovery by AI workers over the last two decades has been the discovery that the phenomenon of intelligence is quite astonishingly complicated". Dreyfus (1979) challenged what he considers the four erroneous assumptions in the AI approach to a thinking machine: that a digital computer resembles the brain in the way that it handles information; that the brain processes information as a computer does, at some level; that human knowledge and behaviour is formalizable; and that knowledge can be meaningful in discrete chunks.

3.2 EXPERT SYSTEMS AS A BRANCH OF ARTIFICIAL INTELLIGENCE

An expert system is a type of artificial intelligence that attempts to replicate or imitate the knowledge and reasoning processes of human experts on some specialised tasks. They are sometimes referred to as Knowledge-Eased Expert Systems (KBES) (e.g., Maher and Fenves, 1985), or used as a synonym of Knowledge-Based Systems (KBS) (e.g., Hickman et al, 1989). Tuthill (1990) suggested that ES is one of the five basic types of KBS (The others are: Database Management Systems, Hypertext and Hypermedia, Case Engineering, and Intelligent Tutoring Systems). The two terms, ES and KBS, will be used synonymously throughout the thesis. Nevertheless, they are of great interest to business and scientific communities, because of their potential to enhance productivity and to augment work forces in many specialised areas where human experts are becoming increasingly difficult to find and retain (Turban, 1988).

Similar to the term AI, it is difficult to give a unique definition of ES. The following definitions are given by a number of researchers within the field of ESs:

> "An expert system is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution."
>
> ---- Feigenbaum (1983)

> "An expert system is a computer program that represents and reasons with knowledge of some specialist subjects with a view to solving problems or giving advice. Such a system may completely fulfil a function that normally requires human expertise, or it may play the role of an assistant to a human decision maker. The decision maker may be an expert in his of her own right, in which case the program may justify its existence by improving the decision maker's productivity. Alternatively, the human collaborator may be someone who is capable of attaining expert levels of performance given some technical assistance from the program."
>
> ---- Jackson (1990)

> "An expert system is the embodiment within a computer of a knowledge-based component from an expert skill in such a form that the system can offer intelligent advice or take an intelligent decision about a processing function. A desirable characteristic, which many would consider fundamental, is the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the enquirer."
>
> ---- British Computer Society - Specialist Group on Expert Systems

There are many other definitions of ESs. The common points raised in the above definitions, however, can be summarised. As shown in Figure 3-1, the following three interacting components should be included in an ES: a) a knowledge base which contains knowledge and expertise of a specific subject domain, represented explicitly in forms of such as rules and facts; b) an inference engine which uses one or more reasoning mechanism, such as forward-chaining and backward-chaining to utilise the knowledge; and c) a dynamic store holding temporary data, which can explain the reasoning process and the rules used, i.e., to answer questions such as how the conclusions are derived, and why certain questions are asked.

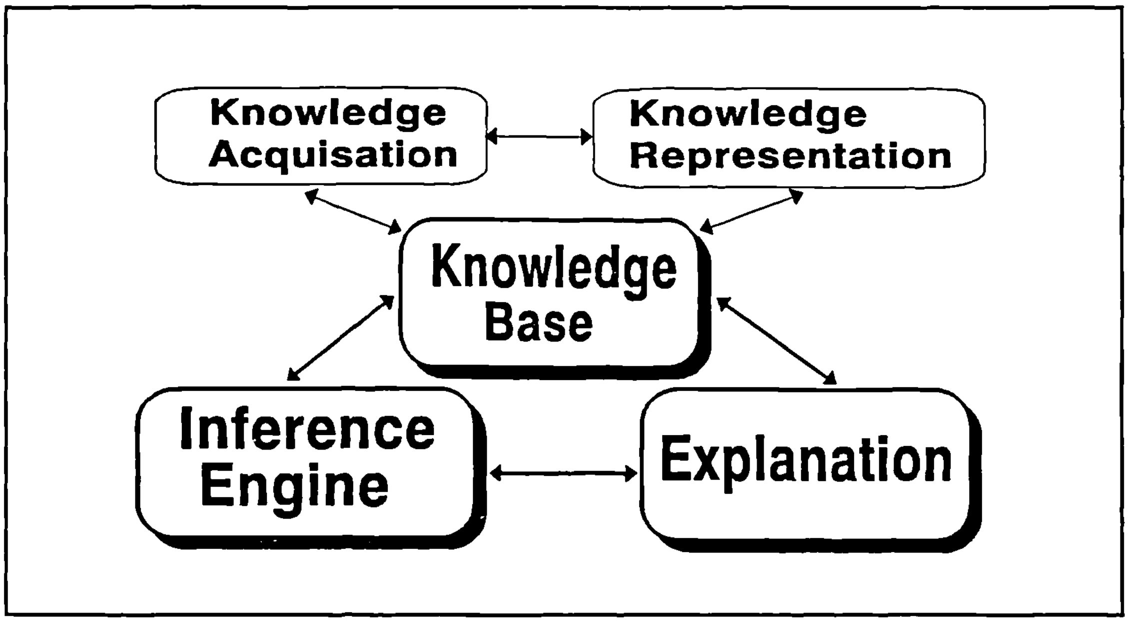


Figure 3-1 Components of A Typical Expert System

The following reflect some widely held beliefs about the characteristics of ESs:

- It is limited to a specific domain or area of expertise.
- It has a great deal of information about this domain.
- It can use uncertain data to reach a probable conclusion.
- The knowledge and the inference mechanism are separated.

- The knowledge contained in the system can be extended.
- The output of the system is advisory rather than factual.
- It can provide an explanation.

The significant differences between ESs and conventional programmes are summarised on Table 3-1.

Table 3-1 Differences Between ESs and Conventional Programmes

Expert Systems	Conventional Programmes
Knowledge base can be separated from the processing mechanism.	Knowledge and processing are combined in one programme.
Modifications on the knowledge base are relatively easy.	Changes in the knowledge are difficult.
Explanation (answering why and how) and what-if facilities are usually included in Expert Systems.	Do not explain why the input data are needed and how the conclusions are derived.
Oriented toward symbolic processing	Oriented toward numerical processing
Highly interactive process	Sequential, batch processing
Inefficient at large amounts of numerical calculations.	Efficient at processing large amounts of numerical information.
Effective manipulation of semi-structured problems.	Effective manipulation of well-structured problems.
Mainly use heuristic approach and complex logic.	Mainly use algorithmic approach, and mathematical calculations.
Most expert systems can deal with uncertainty problems.	Conventional systems have difficulty in dealing with uncertainty problems.
System testing is more difficult.	system testing is relatively easy.

It is worthwhile to spend some time in explaining the differences between ESs and DSSs. A DSS couples the intellectual resources of individuals with the capabilities of computers to support decision makers in improving the quality of decisions on semi-structured problems. An ES involves a typical closed-system assumption, i.e., the problem domain is circumscribed and the system's functions are restricted to its boundaries. Whereas in DSS contexts, the world is open. A DSS must be flexible and adaptive to meet the changing conditions in the environment and the evolving needs of the user.

A DSS is composed of three sub-systems: a knowledge sub-system, a language sub-system, and a problem processing sub-system. The major characteristics of DSS are as follows (Bonczek, Holsapple and Whinson, 1981, 1984):

(1) DSSs incorporate both data and models.

(2) DSSs is designed to assist managers in their semi-structured decision tasks.

(3) DSSs support, rather than replace, managerial judgement

(4) The objective of DSSs is to improve the effectiveness of the decisions, not the efficiency with which decisions are being made.

According to Turban (1988), a DSS would support higher levels of decisions if it is enhanced by AI. The idea of making "intelligent" DSS is supported by all major researchers in the DSS field. Within the framework developed by Bonlzek et al (1981), DSSs exhibit three major characteristics, all of which are present in ESs: (1) DSS aids a decision maker in solving semi-structured problems; (2) DSS possesses an interactive query facility; (3) DSS uses an English-like dialogue language. Based on this discussion, DSSs with an open system view would seem also appropriate for facilitating VM studies in early design stages. The major differences and similarity between ESs and DSSs are summarised in Table 3-2 (after Turban, 1988).

Table 3-2 Differences Between DSSs and ESs (After Turban, 1988)

Attributes to Compare	DSS	ES
Objective	Assist human decision maker	Replicate human advisers & replace them
Who makes the decisions	The human and/or the system	The human and/or the system
Major orientation	Decision making	Transfer of expertise
Major query direction	Human queries the machine	Machine queries the human
Nature of support	Personal, groups and institutions	Personal (mainly) and groups
Manipulation method	Numerical	Symbolic
Characteristics of problem area	Complex, integrated, wide	Narrow domain
Type of problems	Ad hoc, unique	Repetitive
Content of database	Factual knowledge	Procedural and factual knowledge
Reasoning capability	No	Yes, limited
Explanation Capability	Limited	Yes, limited

3.3 THE CURRENT STATE OF THE ART OF EXPERT SYSTEMS

Over the past two decades many ESs have been built successively in various areas, from DENDRAL (a system which determines the molecular structure of an unknown organic compound, Buchanan & Feigenbaum, 1978) to MYCIN (a bacterial infection diagnosing system, Shortliffe, 1976), from MOLGEN (a system for scheduling experiments in molecular genetics, Stefik, 1981) to XCON (an ES for configuring computers, McDermott, 1982). A fairly comprehensive list of applications of ESs was given by Hayes-Roth (1983) as follows:

- Interpretation: Inferring situations descriptions from sensory data

- Prediction: Inferring likely consequences of given situations
- Diagnosis: Inferring system malfunctions from observable events
- Design: Configuring objects under constraints
- Planning: Designing actions to achieve goals
- Monitoring: Comparing observations to expected outcomes
- Debugging: Prescribing remedies for malfunctions
- Repair: Executing diagnosis and prescribing instruction
- Instruction: Diagnosing and treating students' misconceptions
- Control: Governing overall system behaviour

This classification, however, has a number of shortcomings: some of the categories are overlapped with others (e.g., debugging, repair, monitoring and instruction) and some of the categories are subordinate to others (e.g., planning can be seen as a special case of design).

Instead of categorising ESs in terms of the kinds of tasks they can address, Clancey (1985) proposed an alternative analysis in terms of the generic operations a system can perform. As shown in Figure 3-2, he distinguishes between synthetic operations that construct a system and analytic operations that interpret a system. The analytic operations are divided to include identify, predict and control. "Identify" observes system operations, detects discrepant behaviour and explains it. "Predict" infers likely consequences. "Control" determines required inputs and achieve desired outputs. The synthetic operations, on the other hand, include "specify" which states constraints that a system design should satisfy, "design" which consists of configuring and planning, and "assemble" which integrates necessary parts or subsystems together.

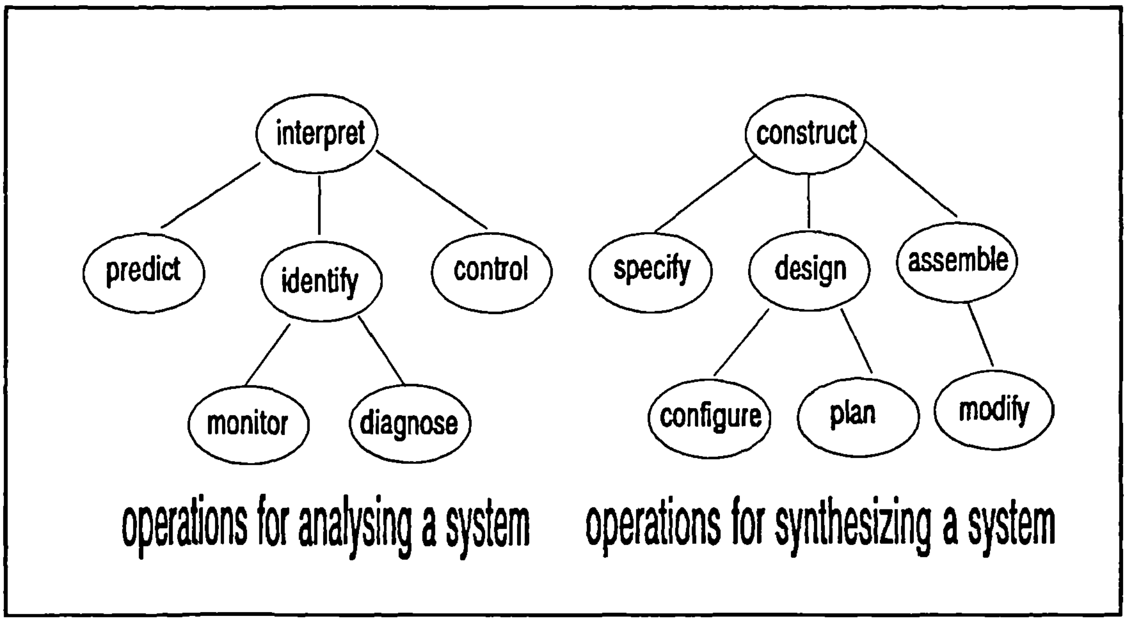


Figure 3-2 Generic Operations of Analytic and Synthetic Systems

The following paragraphs will discuss some of the fundamental issues concerning ES design and development. They include: the roles and potential benefits, domain selections, techniques for knowledge acquisition and representation, development methodologies, and limitations.

3.3.1 The Roles and Potential Benefits of Expert Systems

The roles an ES can perform, as outlined by Brandon et al (1988), include:

1) Consultancy - This role offers greater speed in coming to a decision, easier access to expertise and greater reliability and consistency as well as fairly meaningful explanations of its reasoning if necessary.

2) Checklist - This is a cut-down version of the consultancy role. The important thing here is that all the right questions are asked by the system, so that the user will not overlook some of the vital facts. The system may give some advice and explanations,

but these are of less importance. The benefits from this check-list role are that the system can add consistency, reliability and record-keeping.

3) Monitoring - Here the ES is used for monitoring some processes continually, such as the reaction process within a chemical plant. An ES could contain knowledge like what constitutes error conditions and what to do when they happen.

4) Training - ESs can also be used to train a semi-skilled person or a novice in a specific domain. The trainees may learn much of the expertise which has been embodied in the system.

5) Knowledge Refinement - The processes of knowledge acquisition and knowledge representation are usually involved in the development of an ES. Gaps within the knowledge may be identified during the processes. The knowledge is therefore refined and sharpened.

6) Communication - In this role the ES acts as a communication medium, enabling or encouraging the setting down of complex and judgmental, even intuitive expertise in a reasonable standard and neutral format.

7) Demonstration - Historically, many ESs have this role of demonstrating the capabilities of the technology. The most important aspect is that it can demonstrate how real business benefits can be obtained by using an ES.

If an ES is properly designed, verified and validated, the following potential benefits can be expected:

1) Improved Efficiency - efficiency can be dramatically improved, for example, the ELSIE budget module is felt to improve estimating speed and presentation by at least a factor of ten (Brandon, 1990).

2) Improved Acceptability - compared with conventional computer programmes, most ESs follow conventional questioning, methodology and output, and offer explanation on their reasoning processes. Users are therefore more likely to accept the system.

3) Improved Reliability - this is because computers consistently pay attention to all details and do not overlook relevant information and potential solutions, provided that the knowledge inside the system is robust and well represented.

4) Improved Accessibility - with the help of ESs, scarce expertise could be more widely available. Since most systems were designed for using affordable machines, such as Personal Computers (PCs), additional systems can be easily obtained. (A recent survey conducted by DTI (DTI, 1992) shows that PCs are most frequently used for development and operation of KBS: 64% of surveyed systems use PCs for operating hardware, and 58% of surveyed cases use PCs for development hardware.)

5) Education and Training - this benefit could be significant, for instance, the complete cost estimating strategy inside the ELSIE budget module could be learned in a single day, which would normally take many months to develop.

3.3.2 The Search and Inference Mechanism

Expert systems, as Jackson (1990) pointed out, attempt to tackle the difficulties of search by explicitly representing both the knowledge possessed by human experts about a domain and the strategies used by them to reason about what they know. Since exhaustive search is not feasible for problems in the real world (except small search spaces), the strategies of searching for a solution is essential. A commonly-used strategy is heuristic search - a search that uses one or more items of domain-specific knowledge to traverse a state space graph. The heuristic is best known as a rule of thumb. Although it does not guarantee the success of a search in the same way as an algorithm, but in the majority cases it is useful and effective.

The inference mechanisms adopted in an expert system are the strategies of searching for a solution in the specific domain. They can be categorised into backward chaining and forward chaining, based on the direction of the search. They can also be categorised into depth-first chaining and breadth-first chaining, based on the priority of the search.

Backward chaining (sometimes called goal-directed chaining) is associated with "top-down" reasoning i.e., reasoning from goals to facts; whilst forward chaining (also called data-driven chaining) is associated with "bottom-up" reasoning, i.e. from facts to goals. In a depth-first search, the inference engine takes every opportunity to produce a sub-goal, i.e., it pursues a single path at a time and picks another path only if the current path fails. A breadth-first search sweeps across all premises in a rule before digging for greater detail, i.e. it searches layer by layer through successive levels of the search space. Breadth-first search finds the shortest solution path, if there is one; whereas the depth-first search reaches the goal faster as long as it is guided in choosing which path to pursue next (Jackson, 1990).

3.3.3 Knowledge Acquisition Techniques

As suggested by Feigenbaum (1983), the technical issues of acquiring knowledge, representing it, and using it appropriately to construct and explain lines-of-reasoning are important problems in the design of knowledge-based systems. It is the very complexity and difficulty in the design and development of an ES which require the support of knowledge engineering - a discipline whereby knowledge is extracted from human experts and represented in computer systems in order to solve complex problems which would normally require a high level of human expertise (Tuthill, 1990). Knowledge engineering is described by Feigenbaum (1983) as "the art of bringing the principles and tools of AI research to bear on difficult applications problems requiring experts' knowledge for their solutions", "the art of building complex computer programs that represent and reason with knowledge of the world".

Knowledge Acquisition (KA), as the phrase suggests itself, is the extraction and formulation of knowledge derived from various existing knowledge sources, such as books and human experts. Several researchers e.g. Hickman et al (1989) and Jackson (1990) distinguished this term from knowledge elicitation by saying that the latter is specially related to the acquiring of knowledge from human experts by a knowledge engineer through interviews. Types of knowledge within a knowledge base can be seen in Figure 3-3 (Turban, 1988). KA was described as a bottle-neck problem in ES development (Feigenbaum, 1977). Recent reports, however, claim that among those few KBSs that are actually operational, acquiring the knowledge was not considered to be a significant problem (Hickman et al, 1989).

The following stages, as shown in Figure 3-4, were suggested by Hayes-Roth (1984)

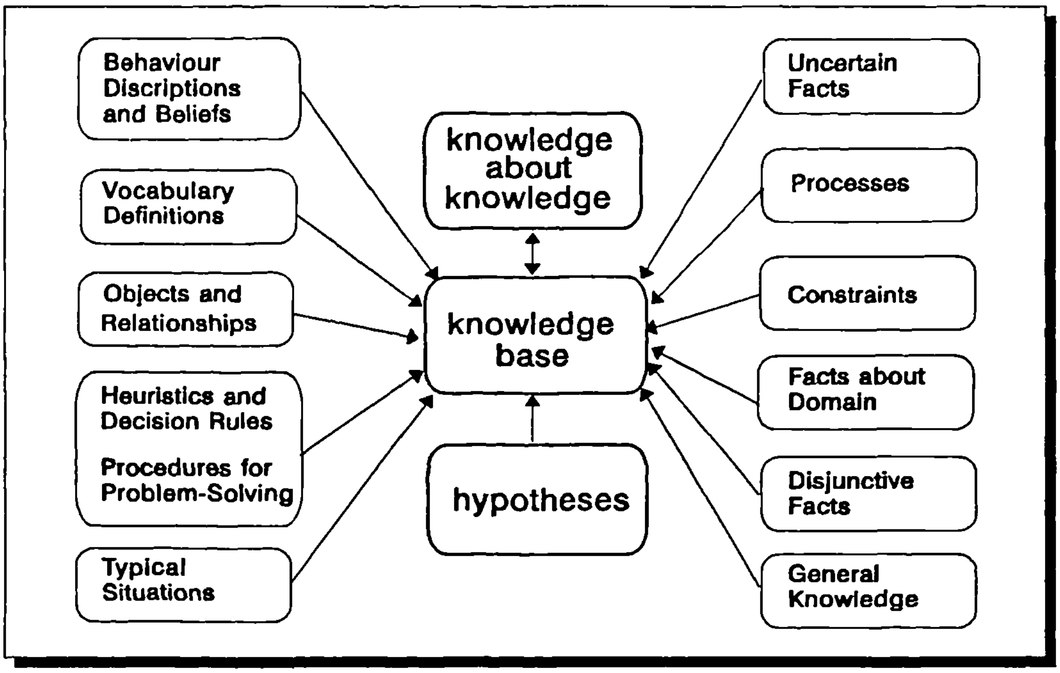


Figure 3-3 Types of Knowledge in a Knowledge Base (Turban, 1988)

to be included in the KA process: 1) Identification - major characteristics and knowledge requirements are identified at this stage. The following questions will be asked: who will be the likely users, what will be the likely users' requirements and expectations of the system, and in what situations will the proposed system be used; 2) Conceptualization - the process of determining the concepts to be used in the system and their relationships by means of, for instance, inference nets; 3) Formalization - the process of acquiring knowledge and designing structures to organise and represent the knowledge; 4) Implementation - the stage of formulating rules, frames etc. to embody knowledge; and 5) Testing - the period of validating the rules that organise the knowledge.

The effectiveness of an ES, to a large extent, depends on the quality of the knowledge inside the system. This statement obeys the GIGO (Garbage In, Garbage

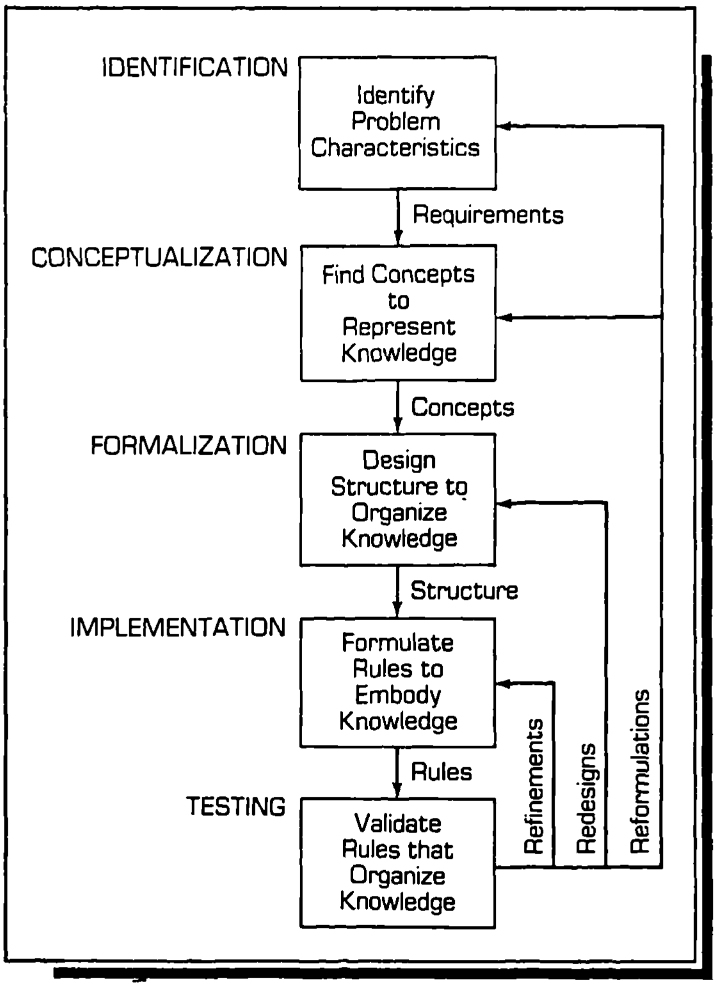


Figure 3-4 Stages of Knowledge Acquisition (Hayes-Roth, 1984)

Out) principle in computing. The selection of appropriate acquisition methods is therefore essential to the success of obtaining quality knowledge. Although no method could guarantee the complete success in knowledge acquisition, the following broad categories of KA methods are commonly used in the ES development (Slatter 1987, and Cleal and Heaton, 1988):

1) Text Analysis - This is the acquisition of knowledge without recourse to an expert but through the use of text books, reports or user manuals. This is probably the least successful method and should be only sparingly used (Cleal, 1988). It can be used as a starting point for a knowledge engineer to gain basic understanding of the domain which the ES is concerned with. The danger of this method is that the

resultant system is less likely to be successful, as it is usually difficult for the knowledge engineer to evaluate and validate the system, and the system may not address many of the domain problems.

2) Verbal Protocols - The expert is asked to "think aloud", i.e. to verbalise the thinking process while performing a task or solving a problem. The expert's narrative is usually recorded which will be interpreted and analysed after the recording. Verbal data obtained in this way provide a rich source of information about human thinking. A less time-consuming variant on the classical method used by Myers et al (1983) involves: a) highlighting the substantive knowledge in the transcript using a text editor, and b) coding it directly into rules to form a prototype ES. It is credited as creating more natural task situations, and permitting inference of knowledge which the experts cannot directly verbalise, especially the expert's procedures. The main limitations of verbal protocols are that they are often incomplete and inaccurate because of the inability of human experts to access to the higher order cognitive processes (Nisbett and Wilson, 1977). This method is also criticised for interfering with experts' performance, and the transcript can be highly ambiguous, requiring much interpretation when analysed.

3) Interview Analysis - This includes Questionnaire Interview - extracting knowledge by means of questionnaires, and Informal Interviews - talking to the expert directly during an interview. By interviewing the expert, the knowledge engineer gradually builds a representation of the knowledge in the expert's terms. To ensure the accuracy of observation, the interviews should be tape-recorded and subsequently transcribed. Although there are some advantages, such as being relatively easy to analyse, interpret and incorporate the information into the system designed, and that

explicit knowledge can be elicited quickly (Slatter, 1987), the following are seen as the drawbacks: firstly, it is difficult for the knowledge engineer to ask detailed questions; secondly, the questions may constrain the answers given by the experts, some crucial expertise may be overlooked; thirdly, it may prove difficult to uncover underlying information used by the expert. To overcome these obstacles, techniques such as "repertory grid technique", "critical incident analysis", "problem discussion" and "personalized task representation" may be used (Cleal, 1988).

4) Behaviour Analysis - This includes On-line Comment Analysis, Observational Studies, Interruption Analysis, and Incremental Simulation. This group of methods requires the knowledge engineers to make observational studies such as recording when the expert is working. The advantages of this group of methods are that: they do not require the expert to repeat the same task many times, so that the amount of expert time used can be kept to a minimum; good quality data are likely to be obtained which cannot be gained in any other way; and the knowledge engineer can examine what the expert said and what s/he has actually done, as experts may have difficulties in expressing their expertise; and if involved, the user's contribution can be identified. This group of methods, however, may be obtrusive and intimidating to the domain expert, and the knowledge engineer has to deal with large amounts of information, of which the majority are of little or no importance.

5) Machine Induction - This is the method which involves inputting large amounts of cases and examples in a domain into a computer system, and using the machine power to induct the general rules which govern all the examples. The most exciting gain of this method is that it can deduct new knowledge and the only input is pre-classified examples, which may save considerable time and effort of the knowledge

engineers. As Cleal (1988) suggested, the technique should certainly be considered where there are plenty of test data and a well-defined classification problem to solve. The major limitations include: it allows only the development of classification rules; the system requires a relevant and complete set of criteria; the selection of a good example set is essential to the success; the system may not solve a problem in the same way as the expert; and furthermore, the unnatural rules generated by the system will not make it easy to supply meaningful explanations to the user.

Two other methods, "conceptual scoring" and "multi-dimensional scaling" were also illustrated by Slatter (1987) which were based on cognitive psychology. It is unlikely that only one of the above methods is used in a knowledge acquisition process. Knowledge may be elicited through a combination of the above methods.

3.3.4 Knowledge Representation Techniques

Knowledge Representation (KR) studies the way in which information might be stored in the human brain, and the (possibly analogous) ways in which large amounts of knowledge can be formally described and presented in a computer for the purposes of symbolic computation (Jackson, 1990). Cognitive research findings have provided an underlying basis for the methods used in knowledge representation. An interesting analogical model of the human cognitive structure and its relations to ES architecture, as suggested by Slatter (1987), is diagrammatically shown in Figure 3-5. As outlined by several researchers such as Harmon and King (1984), and Ringland (1988), the following methods are commonly used to represent knowledge:

1) Logical Expressions - They include propositional logic and predicate calculus.

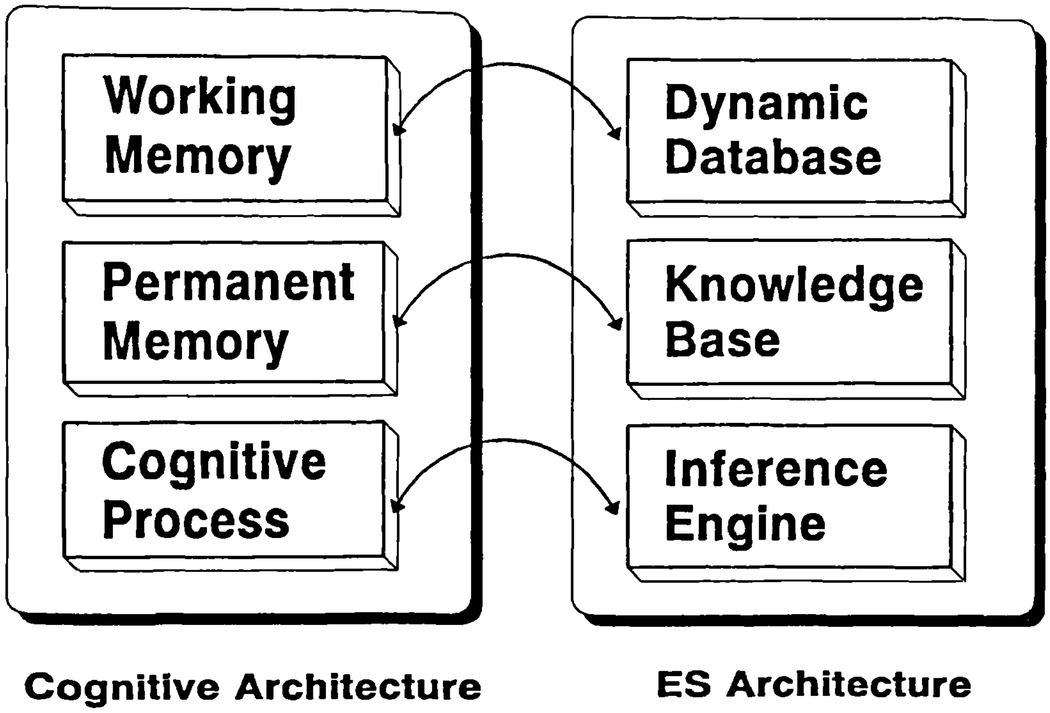


Figure 3-5 Model of Human Cognitive Structure and ES Architecture

Propositional Logic, which is also known as first order logic, is a formal logical system of reasoning in which conclusions are drawn from a series of propositions according to a strict set of rules. For instance, Proposition 1: all buildings house people or goods, Proposition 2: office buildings are buildings, Conclusion: office buildings house people or goods. The limitation of propositional logic is that it deals only with complete statements, which can be either true or false, and it can not make assertions about the individual elements that make up the statement. Predicate Calculus is therefore developed to overcome this problem. It is an extension of propositional logic, whereby a predicate makes statements about objects that can be either true or false. Predicate calculus forms the basis of PROLOG (Programming in Logic), a widely-used AI language (Bratko, 1986).

2) Semantic Networks - A semantic network (also known as an associative network)

consists of a network of nodes, standing for concepts or objects, connected by arcs describing the relations among nodes. The systematic use of this representation scheme begins with Quillian's (1968) work on language understanding. Figure 3-6 shows a semantic network which represents a part of the knowledge about a building. Flexibility is a major advantage of this representation scheme, because nodes and links can be easily added or deleted as needed (Harmon and King, 1984). Another advantage of this scheme is that a property can be inherited through the hierarchy of objects on the networks. For example, based on the facts that "dog has a tail" and "poodle is a dog", the fact "poodle has a tail" can be derived, as poodle inherits the property - a tail - possessed by all dogs.

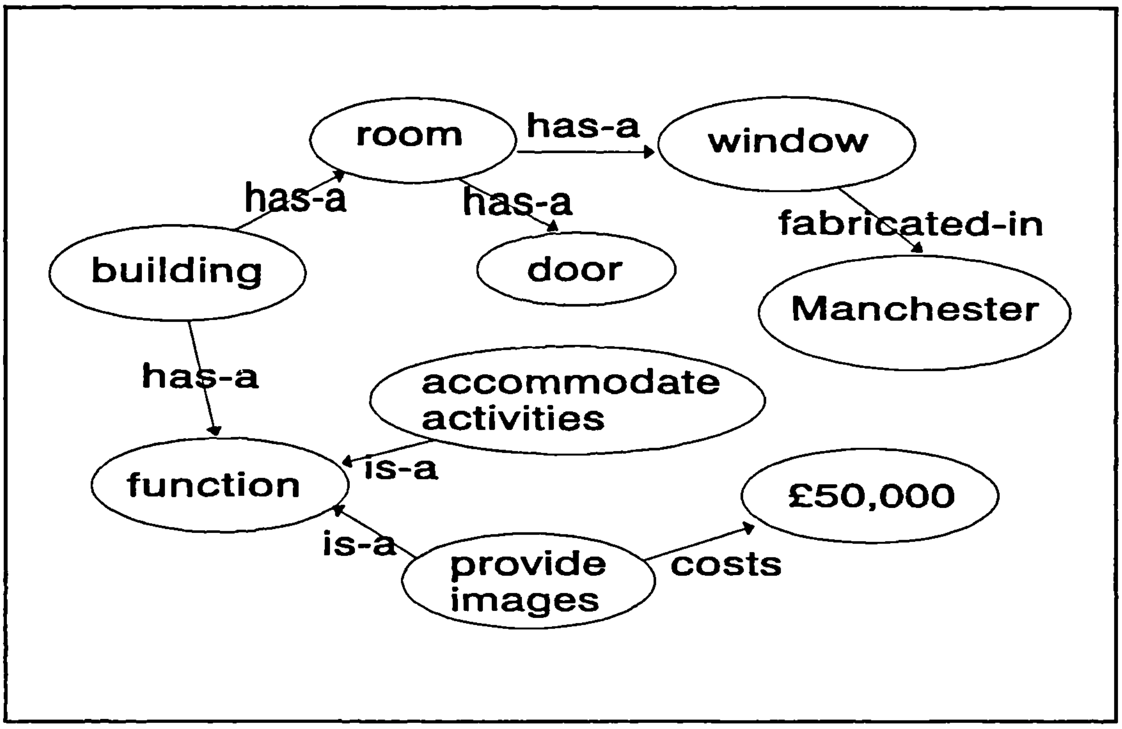


Figure 3-6 The Representation of a Building in a Semantic Network

3) Object-Attribute-Value Triplets - In this representational scheme, objects can be either physical entities (e.g., a room or a building) or conceptual entities (e.g., a function or an image). Attributes are general characteristics or properties associated

with objects. For example, size and shape are the properties of a room, name and cost are the properties of a function. A value specifies the specific nature of an attribute in a particular situation, for instance, the shape of a room is rectangular. When compared with the semantic network representation, it is not difficult to find out that the object-attribute link is a "has-a" link, the attribute-value link is a "is-a" link, and the objects, attributes and values are simply the nodes. The object-attribute-value triplets are therefore a specialised case of the semantic network approach.

According to Harmon and King (1984), the object-attribute-value triplet has three unique features. Firstly, during system consultation, specific values for the attributes of an object stored in a static knowledge base will be assigned either by the user or by the system itself. Secondly, objects within the knowledge base are ordered and related to each other, which allows the inheritance of properties from a higher-level object. Thirdly, uncertainty can be handled by modifying the triplet and using a certainty factor to represents the confidence that one has in a piece of evidence.

4) If-Then (Production) Rules - They are a widely-used knowledge representation method in which knowledge is formalized into "rules" containing a condition (if) part and an action (then) part. The knowledge represented by the production rule is applicable to a line of reasoning if the condition part of the rule is satisfied; consequently, the action part can be concluded or its problem-solving action taken. Production rules are useful as mechanisms for controlling the interaction between statements of declarative knowledge (which asserts a status of true or false to a fact) and procedural knowledge (which includes a set of instructions that, when carried out, arrive at a result consistent with the fact). They have been widely-used in several ESs such as DENDRAL and MYCIN, and a number of ES development tools.

5) Frames (Structured-Objects-Representation) - Minsky (1975) described frames as data structures for representing stereotyped situations. A frame provides a framework to store and organize all the knowledge about a particular object in a number of predefined slots. The knowledge about a room and a dog, for instance, can be represented in frames as shown in Figure 3-7. Like attributes, slots may store values.

A frame for a room

SLOTS	VALUES
Function	Sitting room
Size of room	4m * 5m
Shape	Rectangular
Decoration	Wall papers

A frame for a dog

SLOTS	VALUES
Name	Poodle
Size	Large
Colour	Black
Owner	John

Figure 3-7 Representation of Knowledge and Facts in Frames

They may also contain default values, pointers to other frames, sets of rules, or procedures by which values may be obtained (Harmon and King, 1984). Although this scheme has been criticised as adding nothing really new to the tools of AI (because by their nature, frames are a special case of the semantic networks) (Hayes, 1979), it remains widely popular both in practical applications and in research (Ringland, 1988).

According to Minsky, frames are a very general and powerful representation form, within which it is easy to set up slots for new properties and relations or to create specialized procedures. This method has been used in several ES development tools such as Leonardo, a knowledge representation language developed by Creative Logic in the UK. Within Leonardo, there are five groups of frames: real, text, list, procedure, and class. Each group has a set of default slots, and the user can add some optional slots as required. A detailed introduction to Leonardo can be found in Chapter 5 and the Leonardo User's Manual.

In addition to the methods stated above, neural networks are an area of increasing and wide-spread research interests. Researchers such as Croall (1988) on neural networks claim that traditional AI is based on psychological rationalisation, which is confronted with a whole class of problems, such as speech recognition, vision, sensor interpretation, and robot control. For such problems, a biological rather than psychological metaphor is more fruitful. One fundamental difference between neural networks and other knowledge representation techniques is that the former are taught, rather than programmed, the user therefore needs only specify constraints and provide examples (Forsyth, 1989). It is, however, still not known yet whether and how neural networks can be successfully combined into knowledge-based systems to utilise both of their strengths.

Since the development of ESs requires powerful knowledge representation tools, a number of commercially available development tools such as Savoir, Leonardo, and Kappa have been launched. The proper use of these tools saves time, effort and cost on programme development (Brandon et al, 1988). The selection of tools, however, should be based on systematic analyses of the domain itself and the complexity of the problem to be addressed. All too often developers purchase a tool that can accomplish their first diagnostic or advisory system, only to find that they have reached the product's limitations. The selection of an appropriate tool is therefore a very important issue in the development of ESs (see Chapter 5).

3.3.5 Limitations of Expert Systems

Turban (1988) listed a number of difficulties in developing an ES. They include:

- Knowledge is not always readily available.
- Expertise is hard to extract from humans.
- The approach of each expert to a situation may be different.
- It is hard for experts to abstract good assessments when under time pressure.
- Users of expert systems have natural cognitive limits.
- Most experts have no independent means of checking their conclusions.

Although ESs are used in more and more areas, their limitations should not be overlooked. There are two boundaries to the applicability of ESs, one is in the area of structured information where a conventional programme is more suitable to deal with it (whereas ESs can not handle numerical information very efficiently), and another is in the area of unstructured information where human thinking is more suitable. It is very difficult for an ES to process sensory and pictorial information or to contain the kind of wide-ranging information. The ability to understand "natural languages" inside ESs is severely restricted - often they can only understand single words or short phrases from the human user. The explanations given by an ES are often unnatural, inappropriate and verbose. In some cases, they are purely the list of all the rules used in reaching a conclusion. So ESs can only be used in well-bounded areas such as scientific, engineering and some legal domains.

Contrary to what some authors have suggested, that ESs can perform difficult tasks at expert levels of performance (e.g., Hayes-Roth, 1983), at present they can only emulate human experts in a few very narrow domains. As Brandon (1990) pointed out, "except in very narrow subject domains with clear boundaries, well structured classifications, standard methodologies, and total agreement on process, diagnosis and end goals, this is unlikely to be true".

For user organisations, IT as a whole is a high risk business, with considerable hidden costs. A recent research shows that current IT investment in the UK exceeds £12 billion, but up to 40% of IT projects have no net benefits (however measured), another 40% show only marginal gain. On objective criteria only 11% of companies are successful users of IT (Council for Science and Society, 1989). Because of the risk of IT investments, senior managers in some organisations increasingly question whether the IT route is a wise decision. They need methods to evaluate IT-related projects. At the same time operational managers need means to justify, monitor and manage IT development, implementation and operation.

There are many inter-related ways of improving the payoff from IT, but it is now clear that an essential element is in gaining control over the investment. This needs to be achieved at the stage of formulating strategy in alignment with business needs and organisational capabilities. Thereafter the evaluation needs to continue through the critical feasibility stage, through development, implementation and over the lifetime of systems. The problems are ones of assessing cost, risk, finding out where the benefits will be, whether they are being delivered, and if not, how this can be remedied. These raise questions of methodologies, the degree to which qualified measurement is appropriate, which measures are suitable and what improvements in managerial arrangements can be made. Detailed discussions on the risks and benefits go beyond the scope of the research, the author therefore will not address further.

3.4 EXPERT SYSTEMS IN THE CONSTRUCTION INDUSTRY

A number of researchers have theorised how ESs might be structured and usefully applied in the construction industry (e.g. Bennett and Engelmore, 1979; Mohan, 1987; Adeli, 1988; Allwood, 1989). They also outlined the reasons which made the implementation of ESs in the construction industry feasible and necessary. Many ESs have been developed during the past several years within the construction industry, and more are currently under development. The applications of ESs can be found in every phase of a construction project, i.e., feasibility study, design, construction and maintenance (Allwood, 1989).

3.4.1 Expert Systems in Pre-Design and Design

In pre-design ES applications, the Royal Institution of Chartered Surveyors (RICS) in collaboration with the University of Salford has successfully developed ELSIE (Brandon, 1988), a set of ESs including four modules: financial budget, procurement, time, development, and appraisal. The systems offer advice during the strategic construction planning of office building projects. Its budget module gives a reliable cost estimate of an office building at the early pre-design stage. Murry et al (1990) illustrated the feasibility and difficulties in building an ES to provide guidance to inexperienced clients in producing a clear and precise brief.

As far as ES applications in design is concerned, Bennett and Engelmore (1979) took an early lead in developing ESs for structural analysis and design. Their system SACON - Structural Analysis CONsultant - was designed to help the less experienced engineers to use MARC - a complex structural analysis software package. Maher and

Fevens (1985) at Carnegie-Mellon University developed HI-RISE - a widely-cited knowledge-based system for preliminary structural design of rectangular commercial or residential high-rise buildings which are more than ten storeys high. Adeli and Balasubramanyam (1988) produced BTEXPERT - an ES for interactive analysis of bridge trusses under moving loads. Coyne et al (1990) systematically introduced the bases, approaches, techniques, and implementations of knowledge-based design systems. McCullough (1991) reviewed eleven research projects in KBS applications in building design codes. He examined the principle issues about the representation, use and integration of building design codes in computer-aided architectural design systems, with particular emphasis on knowledge representation issues using AI tools such as knowledge-based systems. Gero (1991) edited a book including 47 papers presented on the first international conference on artificial intelligence in design, covering wide areas of AI applications in design.

Despite the fact that many ESs have been successfully developed and used in various areas such as diagnosis and prediction, most knowledge-based design systems are still at research/laboratory stages, because design is a very complex activity, and current understanding about the design process and the ability to model it are still quite limited (Gero, 1991). Two types of separable design knowledge have been identified so far (Coyne, 1990), they are: interpretation - the mapping between design descriptions (or solutions) and their performance requirements, and generation - the composition of designs. There are two approaches towards knowledge-based design systems, they are: case-based reasoning and prototype-based reasoning.

Case-Based Reasoning is one of the computational approaches to design synthesis (Maher, 1990). It requires specific cases or examples of design situations and generalized knowledge about how to transform a previous design situation to work in a new design context (Maher, 1991). The model, as illustrated in Figure 3-8, employs analogical reasoning to select and transform specific solutions to previous design problems to be appropriate as solutions for a new design problem. This model, as reported by Maher and Zhang (1991), is attractive because the knowledge acquisition for developing generalized representations of design knowledge in a particular domain can be difficult and time-consuming. Whereas the case-based reasoning approach requires specific design situations rather than generalizations about a design domain.

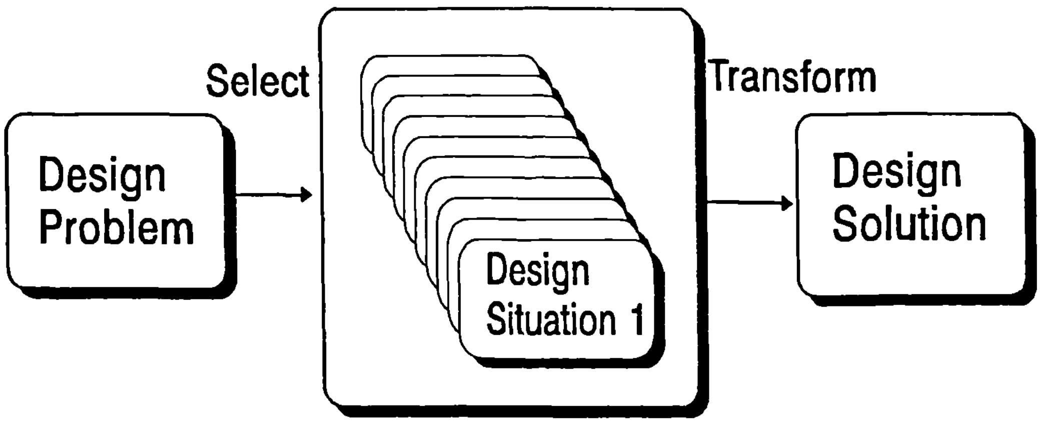


Figure 3-8 Case-Based Reasoning Approach to Design

Prototype-based reasoning, on the other hand, consists of three types of design activities i.e., prototype refinement, prototype adaption, and prototype creation. A prototype, as outlined by Coyne el al (1990), denotes to a representation of a class of designs that embodies a notion of the design description (solution) to be produced. Prototype refinement involves working within the constraints of a particular class of designs, i.e., the constraints of the knowledge that defines the space of designs. Prototype adaption involves extending the boundaries of a particular class of designs, i.e., adjusting the concepts that define the space of designs. The prototype creation, is the creation of a totally new design, which is the highest of design endeavours.

The relationship of these activities, as explained by Coyne (1990), is that a prototype defines a state space within which a design description can be produced. Prototype refinement commences by accepting this (implicitly or explicitly) defined state space and searching for descriptions. Prototype adaptation changes the state space prior to refinement. Prototype generation, which is concerned with producing a new state space, therefore constitutes a kind of abduction, where the artifact of the process is not a design but a prototype - the creation of an entirely new vocabulary and syntax combination.

These two approaches can be combined together and used in the same design system. For example, Maher and Zhang (1991) described a system which combined the two approaches in a design system and possessing the advantages of both of them.

3.4.2 Expert Systems in Construction

Human experience plays an essential role in successful construction planning and management, and because of this factor, construction, as Ashley and Levitt (1987) stated, is perhaps at the forefront of testing the applicability of ESs technology. Levitt (1986) summarised ES applications in construction engineering and construction management which include: 1) planning and engineering of temporary facilities for construction sites; 2) management of the construction process; 3) rehabilitation, repair and maintenance of engineered facilities. Adeli (1988) edited a book introducing ESs in construction and structural engineering. Allwood (1989) categorised the applications in six groups i.e., diagnostic, selection, advisory, data interpretation, monitoring and control, and design. The following examples are typical applications in this field:

1) Construction Management and Engineering - such as, intelligent construction time and cost analysis (Gray, 1986), project control systems (Logcher, 1987), construction project organisation design (Ashley et al, 1987), project planning and control (Levitt et al, 1988, 1990), strategic planning for house building projects (Formoso and Brandon, 1990), selection of contracts and advice on claims based on construction contracts (Kim and O'Connor, 1987), crane selection and location system (Gray and Little, 1985), layout of temporary construction facilities (Tommelein et al, 1987).

2) Maintenance and Rehabilitation - such as, diagnosis of dampness in buildings (Allwood et al, 1988), fault diagnosis of centrifugal pumps (Reinschmidt and Finn, 1986), maintenance advisor for old elevators (Ashley and Levitt, 1987), cost-time forecasts for housing refurbishment using intelligent simulation (Marston and Skitmore, 1989), a knowledge-based system for predicting building maintenance (Watson, Brandon and Basden, 1991).

3.4.3 Expert Systems for Value Management

In contrast to the relatively large number and wide area of applications of ESs in the design and construction fields, throughout the literature, there is little research work in the field of using ES techniques to facilitate the implementation of VM in the design and construction processes. Until recently, VM studies have been mainly a manual process with little computer assistance. Brandon and Shen (1988) took an early step forward in this field. They presented a paper at the International Conference on Expert Systems in Engineering Applications in 1989, within which the suitability and principles of using ESs to facilitate the implementation of VM in the design of construction projects were discussed. A prototype system developed using Leonardo was also introduced. Following this they presented another paper in the SAVE (Society of American Value Engineers) Annual International Conference (1991), which has been reprinted by "Value World", the official journal of SAVE.

Gibbs (1989) described an ES called P/VEX which, as claimed, can perform value engineering and producibility analysis. The system was developed by the U.S. Army Missile Command, and for confidentiality reasons, it is not possible to obtain further information about this system.

There are a few other reported computer systems which could partly facilitate VM studies, but can not be categorised into ESs. For example, the U.S. Department of Defense (DoD) Industrial Productivity Support Office developed a software for data tracking and programme management, which can facilitate the collection of VM project data and the compilation of the VM summary statistics (Paulson and Simpson, 1989). It is, however, not an analytical tool, it doest not provide the facilities for functional analysis, cost estimating, selection of the best alternatives, and other aspects of the VM.

3.5 SUMMARY AND CONCLUSIONS OF THE CHAPTER

Within this chapter, the fundamentals and the current state of the art of ESs have been introduced. ES applications in building designs and constructions are illustrated. The recent developments of ES applications in the field of Value Management have been examined. It is clear that, until recently, VM studies are mainly a manual process with little computer assistance. There a few conventional computing programmes which were developed in the USA, France and Japan. The functions of the systems are quite simple which can only support simple calculation and presentation formulation. There is little literature which introduces how computer systems could help the VM profession in their practices. This gap has been identified during the research and a system was proposed to improve the VM implementation in the design of office buildings. The detailed analysis of the VM domain and the development of the system will be discussed in the following chapters.

CHAPTER 4. DOMAIN EXPERTISE MODELLING

This chapter illustrates how VM methodology and principles are implemented in the design process to assist the designers in making better decisions. Because of the limited number of UK companies which actually employ VM in the design process, and the confidentiality issues of VM expertise regulated by different companies, it was very difficult to access companies' expertise regarding the use of VM, which is required in the system. To overcome this problem, every accessible source containing practical VM expertise has been explored, such as text books, papers presented at various conferences and seminars, and training materials.

Following the action research methodology stated in Chapter 1, a large UK company, the Imperial Chemical Industries (ICI) Plc, which represents the current state of the art of using VM in the design process has been successfully chosen, and the expertise of several VM specialists within the company has been acquired and became the most valuable input to the research. The knowledge and expertise inside the proposed system are therefore a combination of various publications and ICI VM specialists. The current cycle of project realisation in ICI is introduced and suggestions on improvement are discussed. A formal method for allocating project cost to required functions is also introduced.

4.1 WHY ICI ENGINEERING DEPARTMENT WAS SELECTED

In practice, like all other techniques and methodologies, VM has been personalised. As Brandon (1991) suggested, the actual process of achieving value will vary and each will be trying to solve the same problem from a different standpoint and technique. Different value specialists undertake VM differently, although the basic concepts and methods employed are the same. For instance, functional analysis as a principle has been practised by all VM specialists, but someone may prefer to use the Functional Analysis System Technique (FAST), while others may simply prefer to use the basic function analysis technique. Among those who prefer to use FAST diagrams, some may prefer to use task-oriented FAST diagrams, others may favour technically-oriented FAST diagrams (Snodgrass and Kasi, 1986). Since models are representations of reality (Brandon 1991), and the purpose of them is to provide better understanding of the decision-making process and to improve the result of the decision, it is therefore necessary to select appropriate value specialists and represent their VM knowledge and expertise in the proposed system.

As stated in Chapter 1, VM is not widely used in the UK, except in several large companies such as ICI, British Aerospace, and Whitbread (This view is supported by a recent survey conducted by the Commission of the European Community DG XIII, 1991, which revealed that large industrial companies are main VA users both in terms of number of companies using the method and average number of VA actions per year). Most companies that provide VM services or use VM, however, treat their VM related documents as confidential. Because the knowledge and expertise within a proposed knowledge-based system should be validated by the expert(s) from whom they were elicited or by a third party, it is even difficult to access more than one firm to collect the data and acquire the expertise which, once obtained from several sources, must be coordinated and implemented in the system.

Based on above discussions, it was decided to choose one large company where VM has been actively practised for a long period so that the expertise accumulated could be a valuable input to the research. The company should be willing to participate in the process of exploring the feasibility of using a knowledge-based system to facilitate VM implementation in their design process, and provide access to their previous VM studies and documentation. Fortunately, Professor Brandon was informed that ICI was quite willing to participate in the research. Following subsequent contacts with the company, a decision was made based on the following facts:

(1) ICI is one of the largest companies in the chemical industry in the UK. The Engineering Department is one of its major departments, employing 1200 permanent staff and 500 contract staff , responsible for the designs of office buildings, chemical plants and all other types of buildings and structures initiated within the company. VM has been successfully used in ICI for four decades to explore whether a design possesses good value for money. Gregory (1984) states that functional analysis was first developed and used in the practice of work study in ICI in 1947, and was proved to be a useful technique in providing cost savings and enhancement of performance.

(2) ICI Engineering Department has conducted many VM studies, and accumulated a large amount of valuable experience in using VM in various types of buildings and structures. This represents the current state of the art of using VM in the UK construction industry. VM techniques, for example, have been extended in ICI to include Conceptual Analysis (CA), based on the realisation that the earlier one can apply this technique, the better results can be expected, as major design decisions that have great influences on a project are usually made in the early design stages.

(3) ICI has a genuine need to apply VM. The Engineering Department has realised that usually only 35% of the money spent on a chemical plant was used for producing

chemicals, whereas the rest was spent on aspects such as environmental issues. This suggests that large saving potentials exist in the design process of a chemical plant. The costs of providing other types of buildings, e.g., office buildings, have a similar pattern. However, because design is a labour-intensive and time-pressured process, normally there is not enough time to investigate whether there is a better or optimum design, and if there is, how to achieve it. The initial design, therefore, has to be accepted as the best solution.

(4) A considerable amount of design work is aborted each year in ICI Engineering Department. This is simply because the scope of the project has not been clearly defined before project engineers actually start to design it. Although CA/VM can be used as a powerful tool to solve the problems mentioned above, occasionally the technique cannot be properly applied to the projects, because qualified VM specialists in ICI are considerably scarce. Currently, expertise in CA and VM resides with only Mr. John Roberts and two retired consultants in the Corporate Service Group, namely Mr. T. W. Burgess and Mr. J. W. Crabtree.

(5) In order to make the scarce expertise more widely available and to maintain the valuable VM knowledge and expertise in some ways that may otherwise be lost through staff movement or retirement, the ICI Engineering Department intends to develop an expert system with CA/VM domain knowledge to support the decision-making process at early design stages of office buildings.

Because of the reasons stated above, the ICI Engineering Department was selected to participate in the research and to provide valuable information concerning the expertise in using VM in the design process. The initial feasibility study was conducted jointly by the author and Mr. G.C. Dalton, a knowledge engineer from the Department of Corporate Management Services in ICI, between June and September 1989. The study established the feasibility of developing a KBS to facilitate the implementation of VM in the building design process.

4.2 THE CURRENT PRACTICE OF PROJECT REALISATION IN ICI

Following several sessions of interview with various relevant persons (including two value specialists, a building manager, a project engineer, and a manager in system support) in the Engineering Department of ICI, the current practice of project realisation in the organisation was examined and clarified. As shown in Figure 4-1, it contains several activities including Business Analysis (BA), Conceptual Analysis and Value Analysis, Building Cost Estimation, and Building Design and Construction. These activities are presented in a number of bold rectangles. The contents within the ellipses are the products generated by the activities e.g., "building requirements" is the product of "Business Analysis".

The arrows which link different activities represent the time sequence, e.g., after a BA programme is completed, its product "building requirements" is input into the CA process, of which the product "project definition" is passed into the process of BCE. The activities and products surrounded by a dotted square are the scope of the research, which contains three activities (BA, CA, BCE) and four products (building requirements, project definition, functional costs and elemental costs). It is these contents that are involved in the proposed system.

4.2.1 The Conceptual Analysis

VM has been used successfully in ICI over many years on various construction

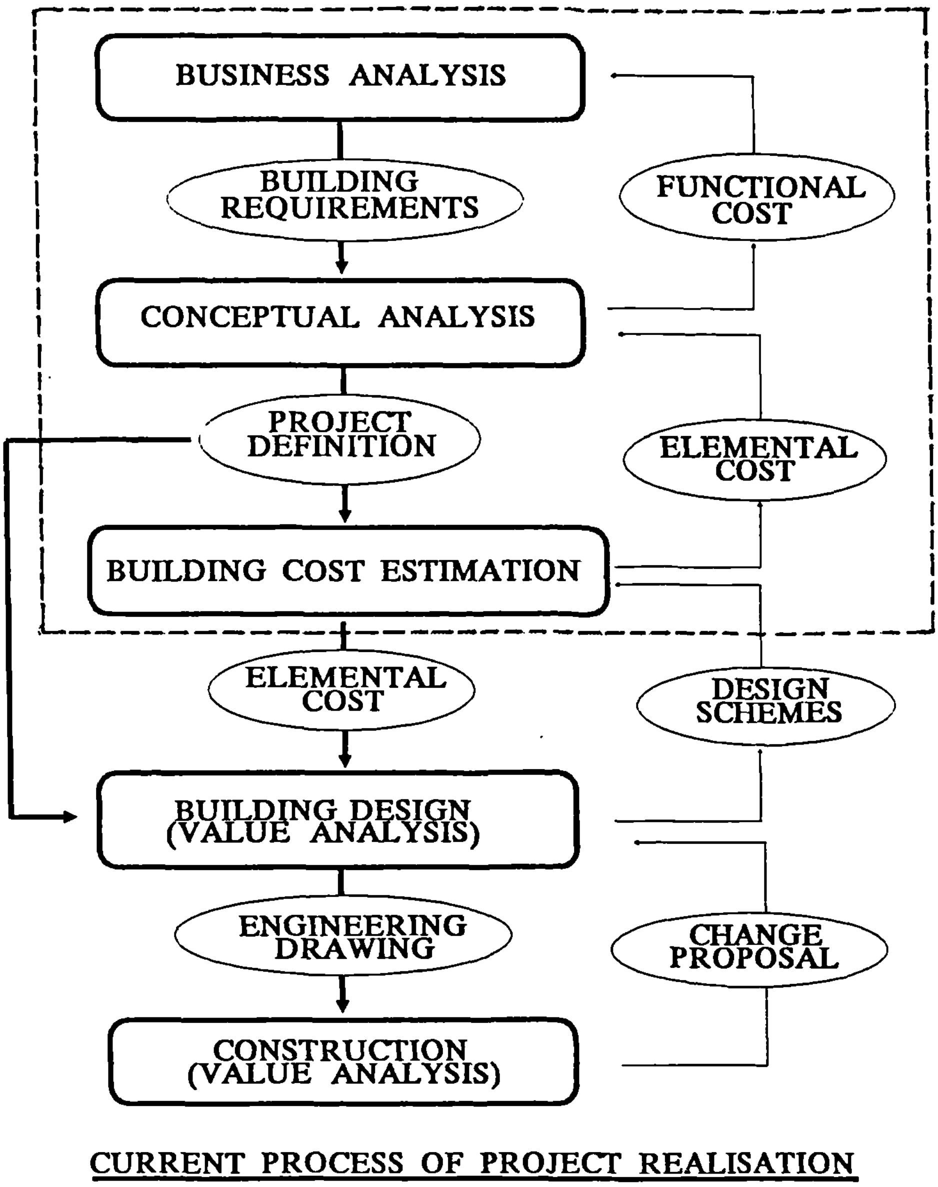


Figure 4-1 Current Process of Project Realisation in ICI

projects to assess value for money in providing projects to meet specific functions required by the client (A client is the body that initialises the project and has the authority to approve expenditure on the project, the form that the project has to take, and its timing). As a result of these studies, it has become clear that the major changes brought about by a VM study come from changes in concepts rather than the detailed engineering design. Late VM applications have caused frustration among engineering staff because of the abortive design work, and the possible delay to the project completion. Some projects have not been optimised because changing the concepts at a late stage could not be tolerated.

In order to avoid the problems stated above, VM methodology has been extended in ICI to include CA. The objective of a CA is to clarify project definition at an early design stage by establishing the factors which have (and have not) to be provided. A CA not only serves to unite a project team towards a clear and agreed objective and facilitates the preparation of preliminary estimates - it also avoids a considerable amount of abortive design work. This is because much design work proved to be abortive is due to unsolved or unrecognised conflicts of interests or objectives within the client system before the building process has been initiated (Walker, 1989). A CA is a tool that helps project engineers in clarifying client's requirements through functional analysis and comparisons of alternatives, and setting up a clear and precise project definition at early design stages, rather than to evaluate project engineers' design work when considerable amounts of design work have been undertaken. An ICI report (Dalton, 1989) shows that the potential savings on capital projects brought by a CA are of the order of 30%, compared with 10% for conventional VM.

Project engineers tend to start developing projects assuming that the client has: a) identified the best means of achieving his objectives, b) carefully analysed the spatial, technical and performance requirements associated with the objectives. The data provided by the client are therefore frequently accepted without question as the basis for developing the design (Walker, 1989). Unfortunately, no matter how efficiently resources are applied in devising and executing designs and construction, if they are not achieving realistic objectives, the inevitable result is waste. The benefits of adopting a more positive and creative approach in defining the client's objectives and needs have been illustrated by other researchers such as Allen (1984) and Cherns et al (1984). A successful project, as Walker (1989) argued, "inevitably means that both the client and the project team leader have to work in a spirit of trust, openness, collaboration and creativity to identify the appropriate objectives for the project and so give it the greatest chance of success".

Within a CA, all those who have an impact on the scope of the project to be undertaken are called upon to identify their needs in order to clarify project definition at an early stage. By setting out these needs in the form of a Conceptual Functional Diagram (CFD), a clear and concise picture of the project is made available to all parties. Alternative means of achieving the same function are usually displayed, which serves as a stimulus to resolve differences early in the project even though the information may not be complete.

The client's brief is treated as a starting point for investigation and is expected to be revised, or evolved during the divergent search in the design process. The instability of the requirements is perhaps the biggest difficulty in design (Jones, 1983). The main advantage of a CA is that it begins with formal ways of researching the problem more widely than the client's brief suggests, so that the inter-dependency of problem and solution can be properly explored and understood. As with the VM methodology, the CA uses a systematic approach and proceeds through the following steps:

(1) Select Team Members and Generate Terms of Reference

As shown in Figure 4-2, a number of people may have an impact on the scope of a project to be undertaken. It is vital to the success of a CA study to identify the key decision makers - everyone who is capable of influencing the scope of the project, and it is essential that the key individuals (not their representatives) take part in the study. Failure to include such key people may not only retard progress, but may also negate the validity of the whole study. The optimum size of the team is 4-8 people, so that active participation and a good rate of progress can be ensured.

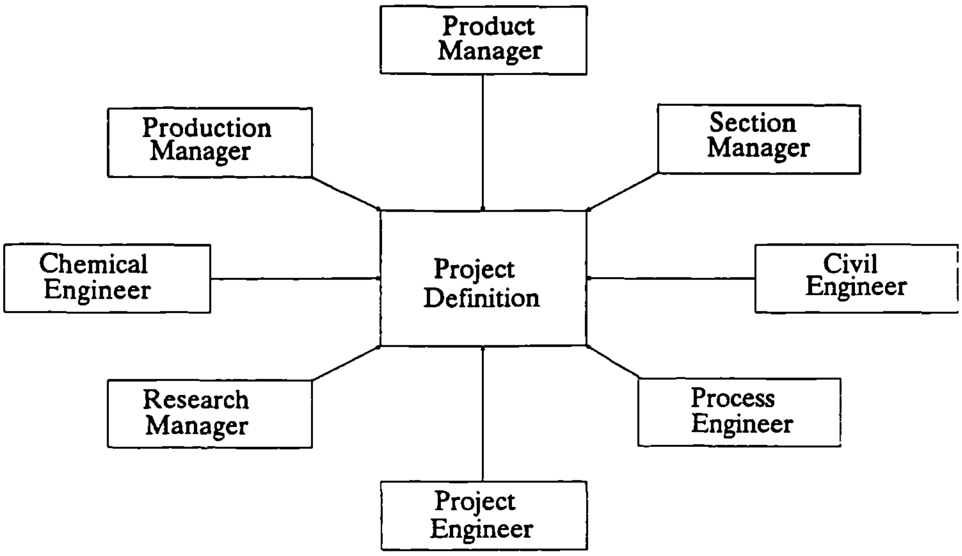


Figure 4-2 The Key Personnel Involved in Project Definitions

A terms of reference document should be drawn up for all projects to help the team to clarify symptoms and constraints, to set up objectives, and establish success criteria, as well as actions to be taken.

(2) Develop A CFD and Ensure All Options Displayed

After setting up the terms of reference, a CFD with all options/alternatives of achieving those required functions should be prepared. A CFD is very similar to the FAST diagrams used in VM studies, which obeys the "Why-How" logic with the higher level functions appearing on the left. Its content, however, differs considerably because it is a declaration of intent rather than a retrospective analysis. Also, because it reflects early thinking, there are usually a number of alternative means of achieving functions displayed. The advantages of using a CFD are the breadth of thinking and the depth of understanding of the design scope.

The preparation of a CFD usually starts with a standard list of major project functions given by a CA consultant. The CA consultant then ask team members to determine whether those functions are appropriate for that project being analysed. If not, the team will modify it under guidance of the consultant. After an agreed list of major functions is obtained, the consultant will organise the team to expand the CFD with alternative solutions by asking "how" questions, such as, "how can this function be achieved?". The consultant keeps reminding the team that there may be alternative ways of achieving a particular function. Thus a CFD can be gradually built up. It is the role of the consultant to organise and guide the team through the CA processes, and to make sure the team thinks of the project in functional terms, rather than in elemental items. The team can therefore set up the project in a structured and systematic way. A typical CFD for office buildings is shown in Figure 4-3 which was given by Mr. Burgess, a CA consultant to the ICI Engineering Department.

(3) Evaluate Alternative Solutions

A number of evaluation techniques will be used to evaluate those alternatives generated during the previous stage. By analysing and evaluating those options, the

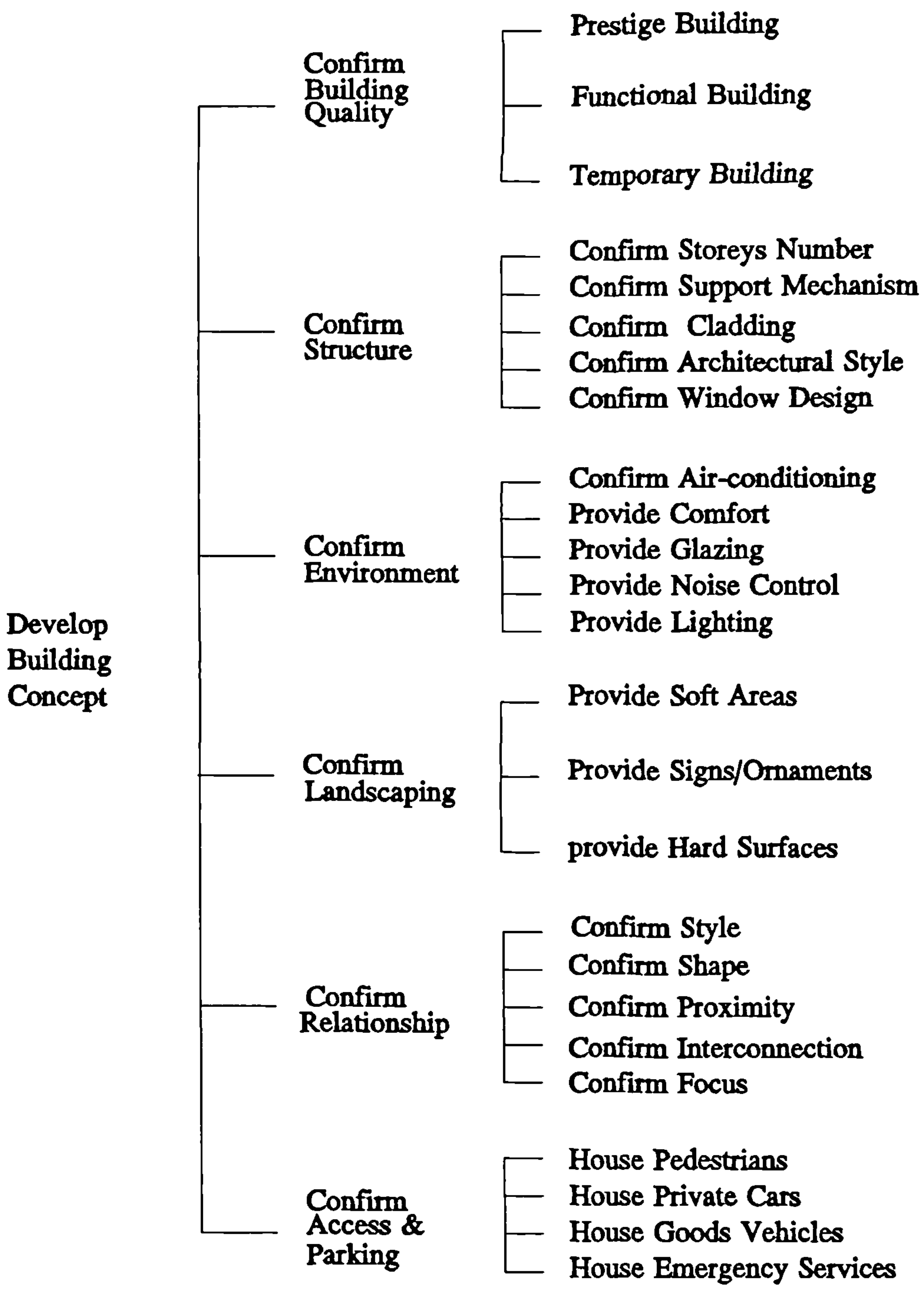


Figure 4-3 A Typical Conceptual Functional Diagram for Office Buildings

best alternatives for each function can be chosen. A conclusion concerning how the project should be done, rather than how it could be done, can be obtained. This is usually undertaken by means of the Weighted Evaluation technique, which is also known as the Evaluation Grid in ICI. There is, however, a tendency in ICI to use cost information as one important criterion, which was not easily available in the past, but could be generated by a computer system very quickly now. A copy of the ELSIE expert system was bought by ICI and was developed further to include buildings such as research laboratories.

(4) Allocate Actions and Responsibilities

Having evaluated the alternatives and selected the best solutions, a project definition will be available, which has the same format as a CFD, but with confirmed solutions, rather than alternatives. In order to proceed to the final form of the CFD, which effectively defines the project, the team is required to review the CFD and responsibilities for further actions concerning individual functions is allocated to team members or people outside the team who may provide the information required.

(5) Agree Recommendations and Report

In order to maintain the momentum of the study a series of review dates should be arranged and progress against individual actions should be reported. It is the duty of the CA consultant to summarize this information on behalf of the team and circulate the information to team members. A report should also be prepared by the consultant on behalf of the team to summarise the study. A series of review dates should also be arranged and progress against individual actions should be reported.

4.2.2 The Decision-Making Process in ICI Building Design

The process of building design and decision-making in ICI is shown in Figure 4-4, where the "Crude Estimate" is mainly based on the client's brief, although some sketches may be used. The "Grade C Estimate" is based on the Concept Design or Sketch Design. The "Sanction Estimate" or "Grade B Estimate" is based on a pre-sanction design which may last from 3 to 9 months.

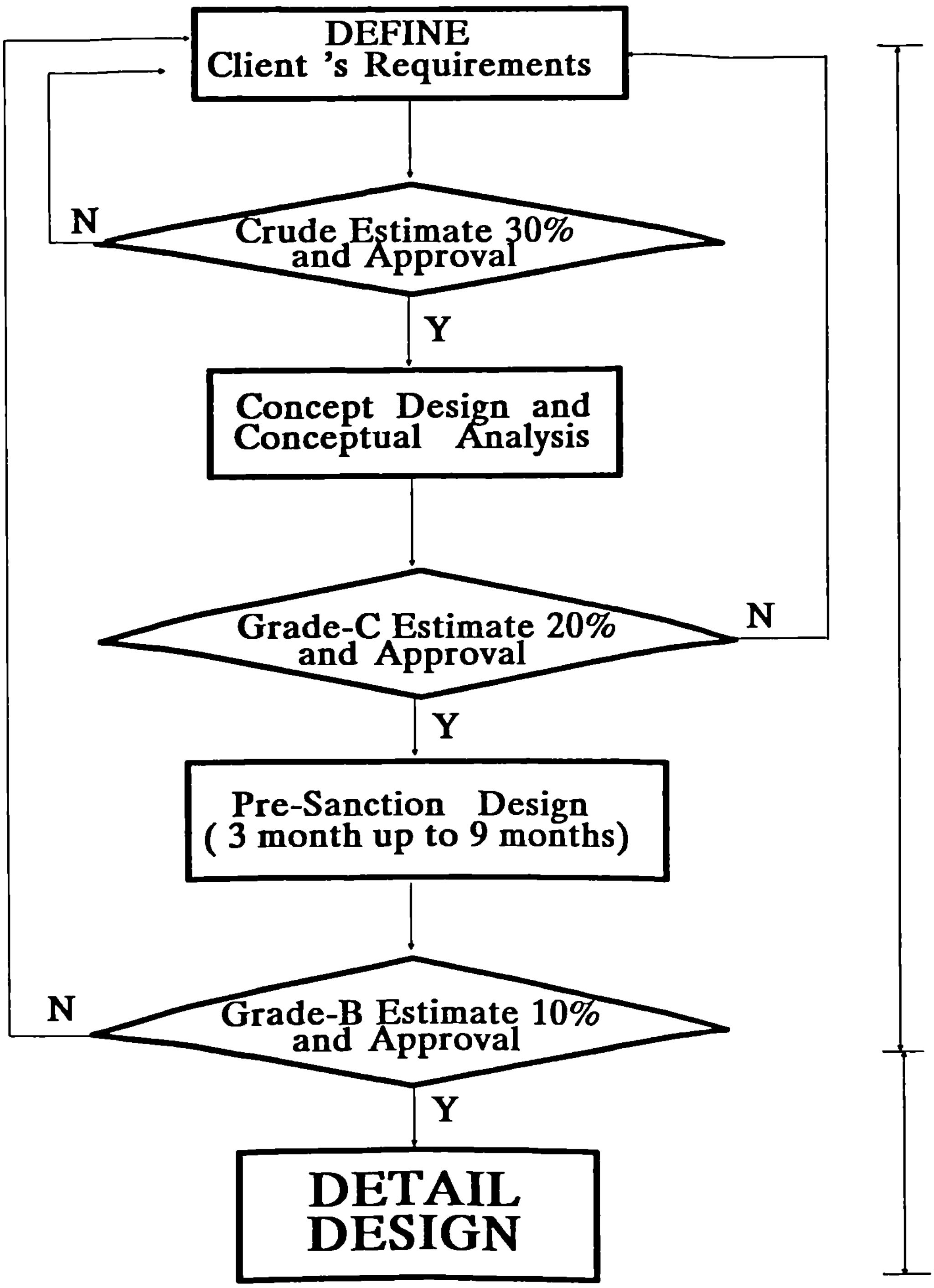


Figure 4-4 The Decision-Making Process in Building Design in ICI

At each stage of the estimates, decisions related to: a) approval of concept and preliminary design, or b) approval of design development or detail design have to be made by the directorate to determine whether the design of the project is acceptable, and if not, how to change the direction. Decisions concerning how to satisfy client's requirements within each design stage also need to be done by project engineers. Experience has shown that major decisions are made during the concept design stage, and the CA can facilitate and expedite the decision-making process.

The design decisions are usually made by the team members from various disciplines, such as, marketing, production, research and development, and engineering. It is the whole group of people who are instrumental in making the overall decisions, and it is very rare for only one person to make the decisions. The business guidelines, market needs etc. can all influence the decisions. It is important to look at things in overall terms, listen to various points of views, and make a precise project definition.

It is not a CA consultant's duty to make those decisions. In fact, s/he does not possess the detailed knowledge to make the decisions. What the consultant can do during the CA study is to organise and facilitate the decision-making process. Getting the key personnel in making decisions together, letting them see each other's points of view, making sure that they think of the project in functional terms, and guiding them through the study are the main roles of a CA consultant.

The top level decisions remain in the business session during which decisions on whether a project is needed will be made. The process at this level is largely independent of the departments involved, and to a great extent it depends on the personalities of the business-people involved. Some of them just tell the project engineers what they want, some might like to sit down with designers and talk through the project. If the client wants to design a chemical plant, s/he usually discusses the project concepts with project engineers. Whereas for buildings, this is not the case. There is a tendency in ICI that many people start their building projects themselves within the business stage. They tend to look around themselves and find out what they want. A fair amount of work has been undertaken before the project engineers are actually involved. Unfortunately the majority of recent design works in the Engineering Department are buildings such as laboratories, office buildings etc., rather than chemical plants.

What the project engineers ideally like to do is to sit down with the client, as soon as s/he has some ideas about what s/he wants. The engineers can then talk through with the client about what s/he wants and what s/he really needs, trying to make a better project definition with the help of CA, before producing a sensible cost estimate. This is because major design decisions are usually made in the early design stages, and it can be very expensive and sometimes impossible to change the concepts in the detail design stages.

In practice, a project engineer can not directly influence the decision-making process within the business stage. The CA, as a link between the engineering and the business, is therefore very important and welcomed by project engineers. During the CA, all those who have an impact on the scope of the project to be undertaken are called upon to clarify their objectives and needs in order to set up a clear project definition at an early design stage. Thereby project engineers have the opportunity to talk to the client involved directly, a clearly defined project therefore can be set out, and a considerable amount of abortive design work can be avoided.

The posts of business-engineering managers in ICI are established to strengthen the links between business-people and project engineers. They (there are currently about 30 in the Engineering Department in ICI) are responsible directly to the engineering director or the principle executive officers in ICI. A very important role for them is to provide help to the business-people at early conceptual stages.

4.2.3 The Integration of Conceptual Analysis and Cost Estimation

In practice, a CA programme is usually separated from the Building Cost Estimation process. The cost estimation is usually undertaken by external companies, which may take one to three months to complete. The separation of the CA and BCE may cause at least two problems:

1) Inefficiency -- A cycle usually exists between the CA and BCE processes, i.e., the cost estimates are derived from the project definition, which is the end product of a CA programme, whereas the costs generated by the cost estimation process could cause a re-definition of the project. For example, for a number of reasons, the client may not be able to afford the high cost of the external glazed curtain walls; the project should therefore be redefined to use other materials. Since the cycle might be repeated several times during the analysis of a project, and each cycle might take one to three months to complete (information was given by the experts in ICI), the time spent on these two processes could therefore increase dramatically. The inefficiency and delay caused by the separated CA and BCE processes could be unacceptable, if the project was to be completed within a limited time.

2) Inconvenience -- As most of the cost estimates are undertaken by external

companies, by the time the building cost estimate is available, a number of key personnel have to be called again to form the CA team. Since most team members of a VM study play major roles in their disciplines, it would be very difficult for them to find the same blank date(s) on their diaries to continue the VM process. This unavailability of key personnel directly influences the results of the VM study.

With the help of the ELSIE Budget Module (BM) (Brandon, 1988), a quick estimate for office buildings can be available. The BM is mainly designed to help experienced quantity surveyors to set up a budget for the development of an office building at the early stage of the project (usually before the design starts), based on the brief obtained from the clients (Castell and Basden, 1992). It is therefore very attractive to integrate the processes of CA and cost estimation together. Figure 4-5 gives a clear view of the model of the integration, which illustrates the differences and interactions between the two processes. The decisions made during the CA will provide a clear briefing information to the ELSIE BM, so that the BM can give a quick reliable cost estimate. On the other hand, the cost information generated by the budget module may to some extent change the initial definition of the project.

4.3 ALLOCATION OF PROJECT COST AGAINST REQUIRED FUNCTIONS

Function-Cost Analysis as a principle of the VM methodology has been used for many years in the construction industry (O'Brien, 1976, Macedo et al, 1978, and Dell'Isola, 1982). It is an extremely valuable tool in associating costs with functions, cutting unnecessary costs and thereby enhancing project value. VM practitioners in ICI have found that allocating costs against functions is a time-consuming task in VM

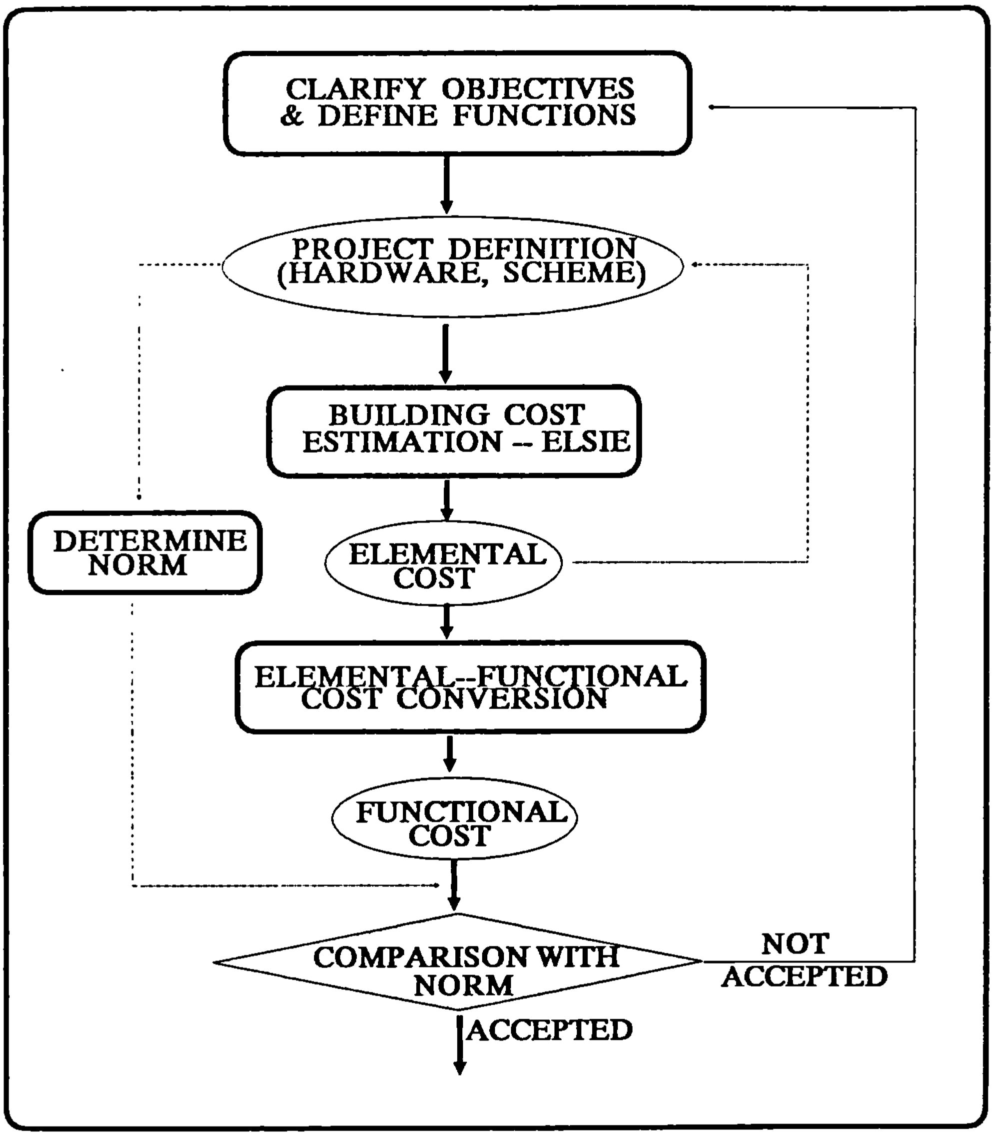


Figure 4-5 A Model which Integrates the CA and Cost Estimation

studies. Unlike the elemental cost analysis, however, functional cost analysis did not receive enough attention from researchers. There is little literature that introduces the methods or techniques of allocating project cost against functions. A method of allocating project cost against functions requested by the clients is therefore developed during the research. The methodology can be valuable to researchers and practitioners who are pursuing good value for money in the construction industry as well as in other sectors of the economy.

4.3.1 Difficulties of Functional Cost Allocations

In spite of the continuing success of VM, there are still some gaps within the VM methodology, of which functional cost allocation is a significant one. The difficulties of functional cost allocations are as follows:

1) The classification of functions for buildings is not standardised. For example, in the elemental cost analysis of an office building, the cost of a project is divided against elements, such as substructure, frame, roofing, heating and ventilation. In a functional cost analysis, however, such kind of standard classification is currently not available. This is because on the one hand, each building has its own specific functions to perform that may be quite different from others, and on the other hand, people tend to build their own functional structures during a VM study. The lack of standardisation is a serious problem to the function-cost analysis.

2) Though function analysis is regarded as one of the most important principles of a CA study, occasionally, one may find that some issues listed in a CFD are not functions of the building being analyzed, but the tasks that should be done during a CA study. For example, items like "Identify overall staff requirements", "Establish building requirements", "Identify site selection issues" are not functions of a building, but tasks that should be undertaken during a CA study. It would be wrong to allocate the cost of a project against a mixture of these tasks and functions.

3) The main problem of functional cost analysis, as Pahl and Beitz (1988) stated, is

to disentangle functions from components, since a single component may carry several functions or a single function may be fulfilled by several components, which leads to an ambiguous distribution of costs. If the functions of a product are directly associated with the components of the product, then it is relatively easy to allocate the cost of the product against each function, as the costs of functions are simply the costs of pertinent components. In most cases, however, a component may contribute to several functions, and several components may contribute to the same functions. For example, the functions of a load-bearing external wall are: a) support loads, b) exclude elements (e.g., rain, wind, and snow), and c) enclose spaces. How can the cost of the external wall be divided against these three functions? Should we say 30% of the cost contribute to support load, and 40% of the cost could be located to enclose space? If so, what is the basis for making this allocation?

4) Usually, alternative ways to achieve functions are listed in the fourth or fifth level of a completed CFD. Once the best alternatives have been chosen and the specifications of the alternatives have been defined, the costs to realise those alternatives could be determined. The costs of the functions relating to the alternatives are therefore available, the functional costs of upper level functions can be obtained by summing all functional costs of their sub-functions. This backward summation can be used until the first level functional costs are derived. However, we still face the problem of splitting elemental costs into functional costs. Suppose one alternative solution has been chosen to fulfil several functions in the fourth level, the costs for each function must be a proportion of the cost of that solution. The problem therefore stays the same as previously stated.

4.3.2 Current Approaches of Functional Cost Allocation

Because of the difficulties stated above, the number of available methods in functional cost allocations is very limited. The following approaches are only feasible in certain circumstances. It is sometimes necessary to use a combination of them.

Method 1 -- Component Measurement

If the functions of a product are directly associated with the components of the product, then it is easy to allocate the cost of the product against each function. For example, as shown in Figure 4-6, the functions of a bulb, i.e., convert energy, protect filaments, hold filaments, are directly related to the components of the bulb, i.e., filaments, glass and inert gas, and filament holders. The costs of the functions are simply the costs of pertinent components. In most of the cases, however, one component may contribute to several functions, and several components may contribute to the same functions. This method is therefore very limited.

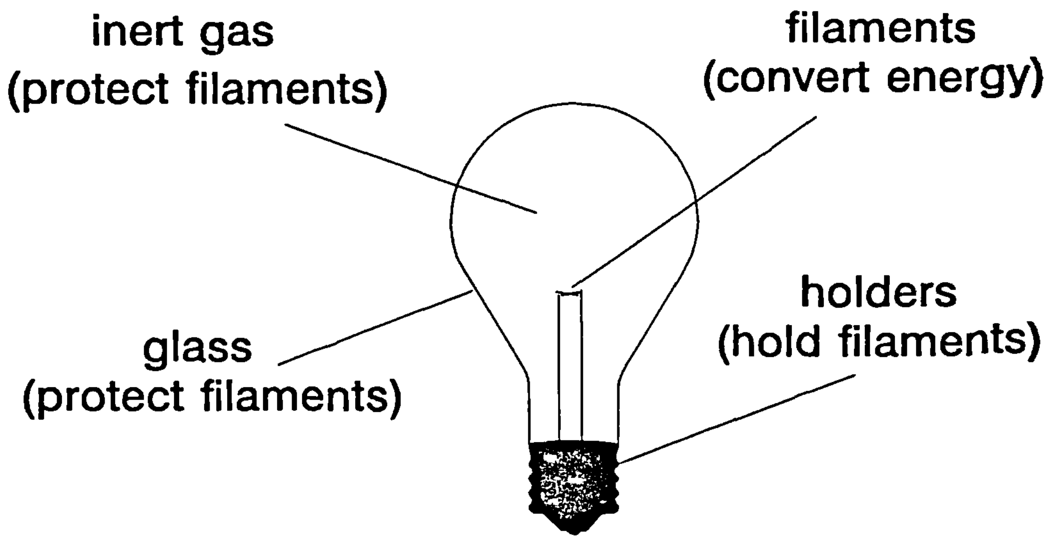


Figure 4-6 Functions and Components of An Incandescent Lamp

Method 2 -- Section Measurement

This method is based on measuring and/or calculating the actual sections (by length, area, or volume etc) which perform pertinent functions, and asserting costs to each function by splitting the total cost into different sections accordingly. As shown in Figure 4-7, for instance, the bridge deck includes three sections: parapets, barrier curb, and slab. The functions of the bridge deck are: support vehicles, support cyclists, support pedestrians, protect vehicles, protect cyclists, protect pedestrians, prevent accidents, prevent skidding, accommodate disabled vehicles, enhance appearance, extend life, improve ride-ability. The costs of each function of the bridge deck are directly associated with the parts that perform the functions, which therefore can be easily determined.

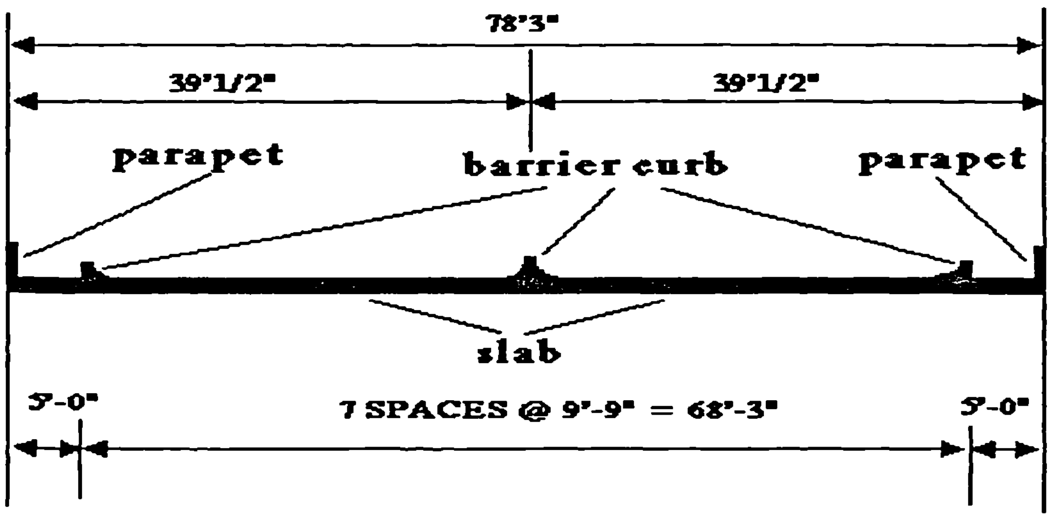


Figure 4-7 The Deck Section of A Bridge Under Analysis

Method 3 -- Material Substitution

This method is usually used in the manufacturing industry where the costs of materials and labour are relatively easy to determine. For example, the functions of an oil tank can be: a) store liquid, and b) prevent corrosion. Suppose the original design chooses stainless steel as the material to build the tank, which costs £8,000 per tank. The cost of storing liquid can be determined by the cost of building a tank which uses cold rolled steel, which is say £6,000 per tank. The cost for preventing corrosion can therefore be determined as £8,000 - £6,000 = £2,000 per tank.

Method 4 -- Subjective Judgement

This is a method of allocating project cost against required functions, by giving a subjective proportion figure to each function concerned, based on the experience of the value specialists obtained from previous similar projects. As the term suggested, this is a subjective and arbitrary method. Occasionally, an elemental - functional cost conversion matrix may be used, which, however, is applicable only to building elements, not the building as a whole. According to the specialists in ICI, for a single building element, this method can be applied successfully, but it would be impractical when applied to a building as a whole, because the matrix might be too big.

Method 5 -- Base Cost Plus Additional Cost

This method tends to split the cost of an element into two parts: base (or target) cost and additional cost. The method of determining the base cost was introduced by Dell'Isola (1982). A base cost, as the author stated, is the idealised elemental cost for providing the basic functional requirements. It represents the minimum cost believed possible for an element, based on team experience with similar buildings, cost files on similar buildings, or previous study results. Each elemental target cost is determined by several cost affecting factors. For example, the factors that affect the target cost of site improvement are: a) parking density, b) landscaping, c) facility access, d) security requirements, e) site area.

Dell'Isola, however, does not mention the specifications based on which the cost figures are derived. For example, the target HVAC *cost for an office building is* $1925 per installed ton, based on *the following information: required HVAC scale* is 300 a/c sf/ton, designed winter temperature is 10°F, and basic system is all air-packaged. It is not clear what sort of HVAC system it is talking about, nor the basic functions it is based on. The term "minimum functional requirements" is not clear, as there is no definition available in the book. It is not known where it comes from, client's specifications or building regulations or somewhere else.

The classification of elements within the *Cost Adjustment Guidelines is based on* American Uni-format, which is different from the classification in the U.K.. The cost figures are not appropriate for use in the UK, and further research work is needed here to prepare the Guidelines. The cost figures in the Guidelines may vary with relevant parameters in different projects, but the differences may hold true.

4.3.3 Functions of Office Buildings and Building Norms

To allocate project cost against functions, it is essential to define the functions of the project correctly. The functions specified for a project must not overlap each other, otherwise the costs allocated to them cannot be logically right, not to mention the accuracy. Unlike the classification of elements in an elemental cost analysis, unfortunately, the classification of functions within buildings is not standardised. For example, the cost of an office building can be divided against several elements, such as foundation, frame, roof, heating and ventilation. No such kind of standard classification is currently available in a functional cost analysis. Based on the research undertaken, the functions that may be required by a client in developing an office project are shown in Figure 4-8.

Basic Functions:	
1. Accommodate Activities	2. Accommodate Personnel
Supporting Functions:	
1. Provide Flexibility	6. Ensure Reliability
2. Ensure Buildability	7. Satisfy Regulations
3. Improve Company Efficiency	8. Maintain Security
4. Project Corporate Image	9. Ease Maintenance
5. Assure Convenience	10. Conserve Energy

Figure 4-8 Basic and Supporting Functions of Office Buildings

Besides the basic functions, clients tend to require all the supporting functions. However, they usually do not realize how much they are going to pay for what they have requested. As Kelly and Male (1988) suggested, "the nature of the briefing process is such that the requirements tend to be maximised without thought for the overall budget." It is the responsibility of a VM team to inform the clients about the costs related to the required supporting functions. The information about elemental costs is considered not very helpful by value specialists, because it does not illustrate how the costs are directly related to functions. A practical method of allocating project cost against those functions required by the clients is therefore valuable to both the designers and a VM study team. Thus during a CA/VM study, the client can understand how much s/he is going to pay for what has been requested.

Every building element has a number of alternatives; the number of combinations of alternative building elements is almost infinite. For example, as shown in Table 4-1, the total number of alternatives for window design is: 3 * 2 * 6 * 3 * 6 = 648. The cost of establishing a building therefore varies dramatically. Even for the same project, different design teams may produce different design schemes with great differences in project costs. Apart from the designer's experience, the functional performance required by the clients probably is the main factor that causes the difference in costs.

Table 4-1 Alternatives for Window Design

Material	Glazing	Type of Window	Quality	Finish
Timber	Single	Top hung	High	Spray painted
Steel	Double	Side hung	Medium	Brush painted
Aluminium		Bottom hung	Low	Galvanised
		Pivot		Polyester coasted
		Horizontal sliding		Silver anodised
		Vertical sliding		Colour anodised

It is likely that the cost of a building with glazed curtain walls would be much more than the cost of a building with brick cladding as its external walling. Suppose the costs of the two schemes are £ 500,000 and £ 480,000 respectively. The difference is therefore £500,000-480,000 = £ 20,000. To understand where this extra cost goes, i.e., why the scheme with glazed curtain walls costs so much more than the scheme with brick cladding, and how the cost associates with functions, it is necessary to have a standard design as a yardstick with which to compare. The concept of "norm" is therefore introduced. ***A norm is the specific mode, selected from a set of alternatives for implementing a building element, which satisfies the basic functional requirements of that building element and satisfies, to a minimum acceptable level, the supporting functions specified by the clients.*** The important characteristic of a norm is that it is dependent on where and when it is used. For instance, different organisations may have different norms for the image of their buildings. Personal Computers have become the norm for data processing in most companies, which was certainly not the case ten years ago. In the above example, we assume that brick cladding is the norm for external walling, because it satisfies the required basic functions and reasonably satisfies the supporting functions among the following alternatives: brick cladding, brick/stone mix, natural stone, prestigious stone, pvc coated metal, exposed aggregate pc, grp/grc, and glazed curtain wall.

The cost of the first scheme is therefore £ 20,000 higher than the norm, which may contribute to other functions such as *project corporate image* and *ease maintenance.* The question is "does the client really need these functions?". If the answer is yes, a further question will be asked to the client: "The functions you required will cost you £20,000 more than the norm building, do you still want them?". This process clarifies the client's requirements and reduces the risk of abortive design. The norms for other elements can be determined similarly, e.g., as shown in Figure 4-9, the norm for the plan shape of office buildings is assumed as "rectangular shape".

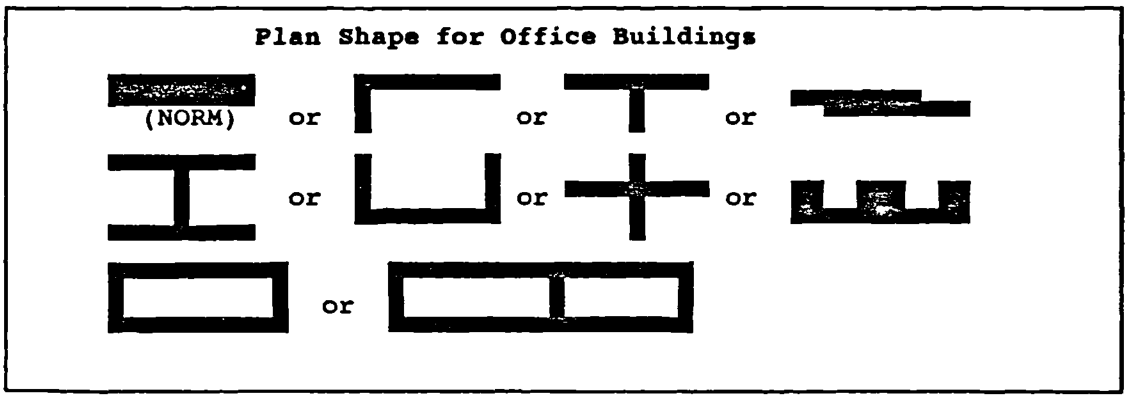


Figure 4-9 Alternatives and the Norm of Office Plan Shape

4.3.4 Allocating Extra Project Cost Against Functions

In addition to basic functions, the selection of an alternative is more or less to achieve one or more supporting functions listed in Figure 4-8. For example, the reasons for selecting glazed curtain walls as external walling might be to achieve functions "Project corporate image", "Ease maintenance", and "Provide flexibility". It is usually difficult to decide what percentage of the cost is devoted to "Project image", how much of the cost goes to the function of "Ease maintenance", and how much of the cost is actually contributing to the function "Provide flexibility".

If each function of a product (element) is directly associated with the components of the product, the cost for achieving each function is simply the cost(s) of pertinent component(s). In most cases, however, one component may contribute to several functions, and several components may contribute to the same functions. It is therefore difficult to split the extra cost against each function i.e., to give the percentages to which the total extra cost will be distributed. A formal method has to be deployed to allocate the extra elemental cost against the functions the element performs within a building. This area of functional cost allocation, however, has not received enough attention from the researchers, and no practical method can be found in the literature to solve the problem mentioned above. The method developed during the research is introduced as follows:

The first step of the method, as shown in Table 4-2, is to determine the dominant scores of each function required by the client. On the first row and the first column, all functions required are listed. Compare each function in the first column with functions in the second, third and fourth columns, and answer the question "which function is the dominant factor based on which this selection was made". If the function in the first column is more dominant, then put "1" in relevant column, otherwise put "0". If two functions have equal importance in selecting the alternative, then put "0.5". This is to avoid neglecting the lowest dominant function (in this example, the function is *provide flexibility*). The percentages for each function can then be calculated by dividing each score with the summation of the scores. Once the percentages for each function to which the selection is made have been determined, the costs for each function can be simply calculated as follows:

Table 4-2 The Method for Ranking Building Functions

	project image	ease maintenance	provide flexibility	total score	%
project image	.5	1	1	2.5	56%
ease maintenance	0	.5	1	1.5	33%
provide flexibility	0	0	.5	0.5	11%

Cost for projecting image = £ 20000.00 x 56% = £ 11200.00

Cost for easing maintenance = £ 20000.00 x 33% = £ 6600.00

Cost for providing flexibility = £ 20000.00 x 11% = £ 2200.00

To simplify the process and prevent repeating the same procedure, an assumption has been made for the proportions, based on which extra cost is allocated against each supporting function. The assumption, shown on Table 4-3, can be altered by the user according to the specific situations. The numbers listed in the first column of the table are questions asked by the ELSIE Budget Module. As listed in Table 4-4, they represent the key factors affecting the cost of an office project.

Table 4-3 Assumed Percentages for Allocating Cost to Supporting Functions

BM No.	ALTERNATIVES (Norms are described inside the brackets)	Percentage of Cost Allocated for Supporting Functions (%)									
		f1	f2	f3	f4	f5	f6	f7	f8	f9	f10
14	Height limits (no limit)							100			
20	Car park places (0)				50	50					

	Brick (norm)										
	Brick/Stone Mix				30		30			40	
	Natural Stone				30		30			40	
	Prestigious Stone				30		30			40	
30	PVC coated metal	50			50						
	Exposed aggregate PC	40			60						
	GRP/GRC	30			70						
	Glazed Curtain Wall	20			80						
	Any style (norm)										
	General traditional			20	80						
	Traditional - high level			20	80						
32	Prestigious traditional			20	80						
	Ribbon windows			20	80						
	Prestigious modern			20	80						
	To make a statement			20	80						
50	Fitting (shell/core only)			80	20						
52	Need large space (0)	40		20	30					10	
53	Need column-free (0)	70			30						
54	Keep ext. air out (0)			90				10			
55	Air conditioning (no ac)			50	40			10			
140	Aesthetic/Amenity (3)			40	60						
141	Performance Quality (3)			60	40						
142	Flexibility (norm: 3)	100									
	Tempered Air (norm)										
	Reverse cycle pump						50				50
	Fan coil						50				50
150	Inducting						50				50
	VAV						50				50
	Local packaged units						50				50
151	Raised floor (sp. area)				50			50			
174	Shape (Rectangular)	10		40	50						
181	Structure complexity (3)	40		20	40						
191	Detail of ext walling (5)				100						
	Pitched (norm)										
193	Mansard				20		30			50	

	Flat (Slab)						30	20		50	
	Flat (Wood)			50	50						
194	Roof Complexity (1)			80	20						
200	Frameless (norm)										
	Steel Frame	30	20		20		30				
	In situ Concrete	30	20		20		30				
225	Installation complex (4)						30	30		40	

Within a design scheme, there might be several factors which are above their norms. The influence of each factor to the cost of a project can be determined by changing the options of the factor from its current alternative back to its norm, and calculating the difference of the project costs accordingly. Once the process of allocating each individual extra cost (due to one factor above norm each time) to pertinent functions is completed, the total extra costs for achieving each supporting function of the project can be derived by summing every individual contribution to the functions. For instance, there might be four factors (e.g., front elevation, plan shape, quality level, and performance quality) that contribute to the function "project image". The total cost for projecting image would be the sum of each individual contribution.

Suppose there are n factors and the differences are $\Delta 1$, $\Delta 2$, ... Δi, ...Δn respectively. Is the sum of them identical to the cost difference between the initial design and the norm building, i.e., is the following equation always true?

$$\sum_{1}^{n} \Delta i = \Delta 1 + \Delta 2 + ... + \Delta i + ... \Delta n = \Delta = Cost_{project} - Cost_{norm}$$

The answer is: if all the factors selected are independent and the cost function is a multi-variable linear function, then the two sides will be identically equal. This conclusion can be proved as follows:

Table 4-4 Questions Asked by the ELSIE Budget Module (Partial)

No 14.	Is there a height restriction on this building? (1...80 or Unknown)
No 20.	How many car park places are required? (0...2500)
No 30.	Can you say what treatment the designers will give to the "Main or Front" elevation?
No 32.	Can you say what architectural style the main/front elevation will have?
No 50.	Is the building to be fitted out? (1...3) (1. Shell and core only; 2. Partial fit-out; 3. Fully fitted out)
No 52.	To what extent will you need any large spaces that might mean the width of the building has to be greater than the standard 45ft (0...10) (0. Not at all; 2. Some possibility; 7. May need a wider building; 10. Many large open spaces)
No 53.	Does the client need column-free space? (y/n)
No 54.	To what extent is it necessary to keep external air out? (0...10) (10. Important, everywhere; 7. Important over part of the building; 5. Preferable; 2. No real need; 0. Not at all)
No 55.	Do you wish to specify the amount of Air Conditioning in the building? (1...5) (1. No AC; 2. Only in special areas; 3. Also in executive suite office space; 4. In all office space; 5. The whole building)
No 140.	What level of Aesthetic and Amenity quality do you require? (0...10 or U for Unknown) (0. Vary basic; 3. Medium; 6. High; 10. Prestigious)
No 141.	What level of Performance Quality do you require? (0...10 or U for Unknown) (0. Basic; 3. Medium; 6. High; 10. Very high)
No 142.	What level of flexibility for internal space do you want in the building? (0...10) (0. None; 3. Moderate; 6. High; 10. Very high)
No 150.	Do you wish to specify the type of Air Conditioning in the building?
No 151.	How much Raised Floor do you want (as part of this building contract)? (1...5 or U for Unknown) (1. None; 2. In special areas only; 3. In high quality areas too; 4. In normal areas too; 5. In all areas)
No 174.	Can you indicate the approximate Plan Shape for the building?
No 181.	What is the level of complexity of the building structure (frame etc)? (1...10) (10. Extremely complex; 7. Complex; 3. Average; 1. Very simple/repetitive; 0. Extremely simple and no site problems)
No 191.	How visually complex and detailed will the external walls be? (0...10) (1. Simple and plain; 2. Medium level of detailing; 3. High level)
No 193.	What type of roof construction would you like? (1...4)
No 194.	Please give a figure on a scale of 0 to 10 for the complexity of the roof? (0...10) (0. Simplest roof of its type; 3. Roof has one or two steps in it; 7. Many pieces of roof; 10. Multi-level roof with many pieces)
No 200.	Which type of construction would you like? (1...3 or U for Unknown)
No 225.	What level do you want to specify for Installation Complexity? (0...10 or) (10. Extreme; 7. High; 4. Medium; 1. Simple)

The project cost, as a multi-variable linear function, can be presented as:

$$Cost=f(x_1,x_2,...x_i...x_n)=a_1x_1+a_2x_2+...+a_ix_i+...a_nx_n=\sum_1^n(a_ix_i)$$

where x_1, x_2, ... x_i, ... x_n are the factors that affect the cost of the project. Suppose that (x_{12}, x_{22} ... x_{i2}, ... x_{n2}) are the values of those factors (x_1, x_2, ...x_i ...x_n) in the original design scheme, whereas (x_{11}, x_{21} ... x_{i1}, ... x_{n1}) are the values of those factors which are equal to building norms. The *following equations are therefore true:*

$$\Delta = f(x_{12}, x_{22}, ...x_{i2} ...x_{n2}) - f(x_{11}, x_{21}, ...x_{i1} ...x_{n1})$$
$$= (a_1x_{12}+a_2x_{22}+ ...a_ix_{i2} ...+a_nx_{n2}) - (a_1x_{11}+a_2x_{21}+ ...a_ix_{i1} ...+a_nx_{n1})$$

$$\Delta 1 = f(x_{12}, x_{22}, ...x_{i2} ...x_{n2}) - f(x_{11}, x_{22}, ...x_{i2} ...x_{n2}) = a_1x_{12} - a_1x_{11}$$
$$\Delta 2 = f(x_{12}, x_{22}, ...x_{i2} ...x_{n2}) - f(x_{12}, x_{21}, ...x_{i2} ...x_{n2}) = a_2x_{22} - a_2x_{21}$$
$$\Delta i = f(x_{12}, x_{22}, ...x_{i2} ...x_{n2}) - f(x_{12}, x_{22}, ...x_{i1} ...x_{n2}) = a_ix_{i2} - a_ix_{i1}$$
$$\Delta n = f(x_{12}, x_{22}, ...x_{i2} ...x_{n2}) - f(x_{12}, x_{22}, ...x_{i2} ...x_{n1}) = a_nx_{n2} - a_nx_{n1}$$

$$\Delta 1 + \Delta 2 +... \Delta i +...\Delta n$$
$$= (a_1x_{12}-a_1x_{11}) + (a_2x_{22}-a_2x_{21}) + ...(a_ix_{i2}-a_ix_{i1}) + ...(a_nx_{n2}-a_nx_{n1})$$
$$= (a_1x_{12}+a_2x_{22}+...a_ix_{i2}...+a_nx_{n2})-(a_1x_{11}+a_2x_{21}+...a_ix_{i1}...+a_nx_{n1})$$

Therefore $\Delta = \Delta 1 + \Delta 2 +... \Delta i +...\Delta n$, the conclusion is proved.

In practice, because the factors selected usually affect each other, i.e., some of them are dependent on each other, the conclusion derived above is therefore not always true. In these cases, the percentages of the functional costs over the sum of individual extra costs will be used to calculate the real functional costs by taking the same percentages of the total extra cost.

An example has been illustrated below to demonstrate the method in detail. Table 4-5 shows the differences between the original design scheme and the norm defined. As shown there, the costs for establishing them are £5030477 and £2308369 respectively. Figure 4-10 shows the elemental costs of the original design. Figure 4-11 presents the elemental costs of the norm building. Figure 4-12 demonstrates how the cost of the project changes due to one factor above its norm each time, Figure 4-13 exhibits how the extra costs are allocated to each supporting function. Table 4-6 displays how the extra costs are allocated against each supporting function. Where Ci is the total cost of the project when one factor (i) changes back to its norm, for example, "Brick Cladding" is used for external walling, instead of "Prestigious Stone". Di is the difference between estimated Project Cost C and Ci, i.e., Di = C - Ci. FCij is the extra cost allocated to supporting function j (j = 1 to 10) because of factor i does not equate to its norm. It is a fraction of Ci. Figure 4-14 shows the extra costs for achieving supporting functions.

4.4 SUMMARY AND CONCLUSIONS OF THE CHAPTER

In this chapter, the current process of project realisation and the design decision-making process in ICI have been examined. Modelling of the integration of the CA and BCE has also been discussed. Functional Cost Analysis is an extremely valuable tool in cutting unnecessary costs and enhancing project value. Current approaches towards the analysis have been introduced. Based on the method introduced above, the total cost of a project can be divided into two parts i.e., the cost of achieving the

Table 4-5 Differences Between The Original Design and The Norm Building

No. ITEM	SCHEME VALUE	NORM VALUE
20. No. of cars	250	0
30. Wall appearance	4: Prestigious stone	1: Brick
50. Level of fitting	2	1
53. Column free ?	True	False
55. AC where ?	4: Office Space	1: No AC
140. AA Quality	0------|----10	3: 0---|------10
142. Flexibility needed	0---|------10	3: 0---|------10
150. AC type	5: VAV	1: Tempered Air
174. Plan Shape	2: L or T Shape	1: Rectangular Shape
181. Form Complexity	0-------|---10	3: 0---|------10
191. Wall Detailing	0--------|--10	3: 0---|------10
200. Building Frame	3: In situ concrete	1: Frameless
225. Install complexity	0---|------10	3: 0---|------10
TOTAL COST	£ 5030477	£ 2308369

Note: The numbers in the first column are the question numbers as shown in Table 4-4.

norms and the cost above the norms. The latter part can be allocated against each supporting function specified earlier by the clients. A clear functional cost distribution can be therefore available to both the client and the designers of the project. This useful tool will be extremely beneficial to VM studies on office projects.

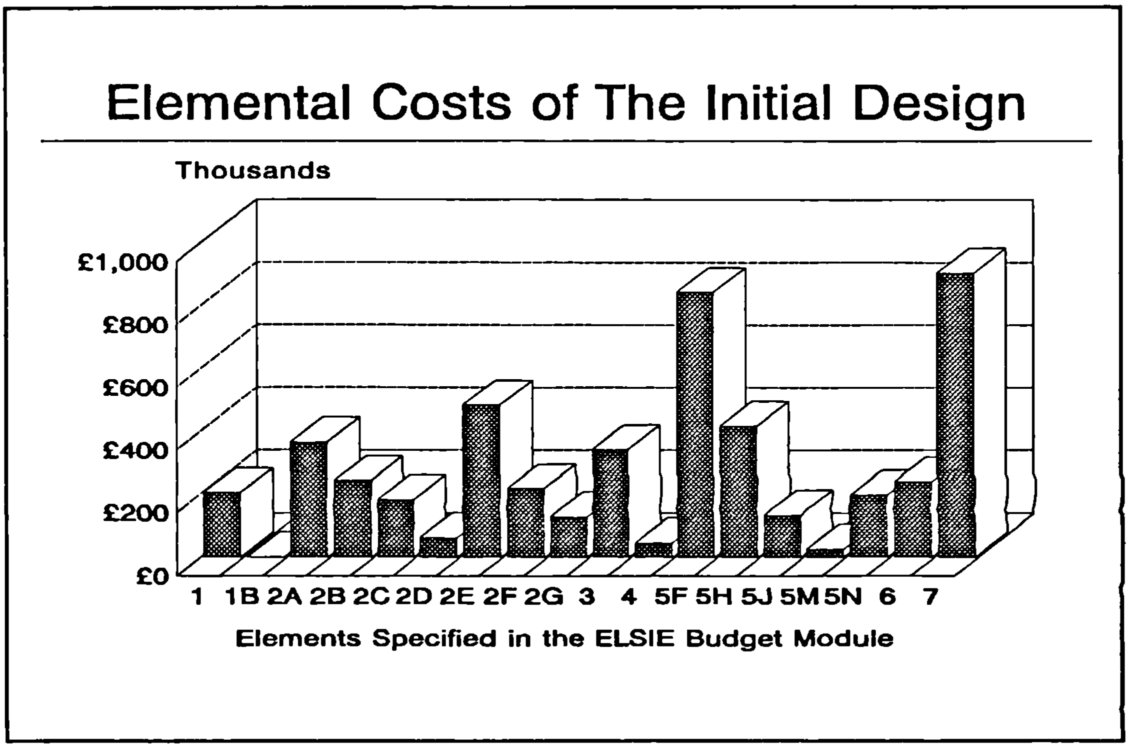


Figure 4-10 Elemental Costs of The Initial Design

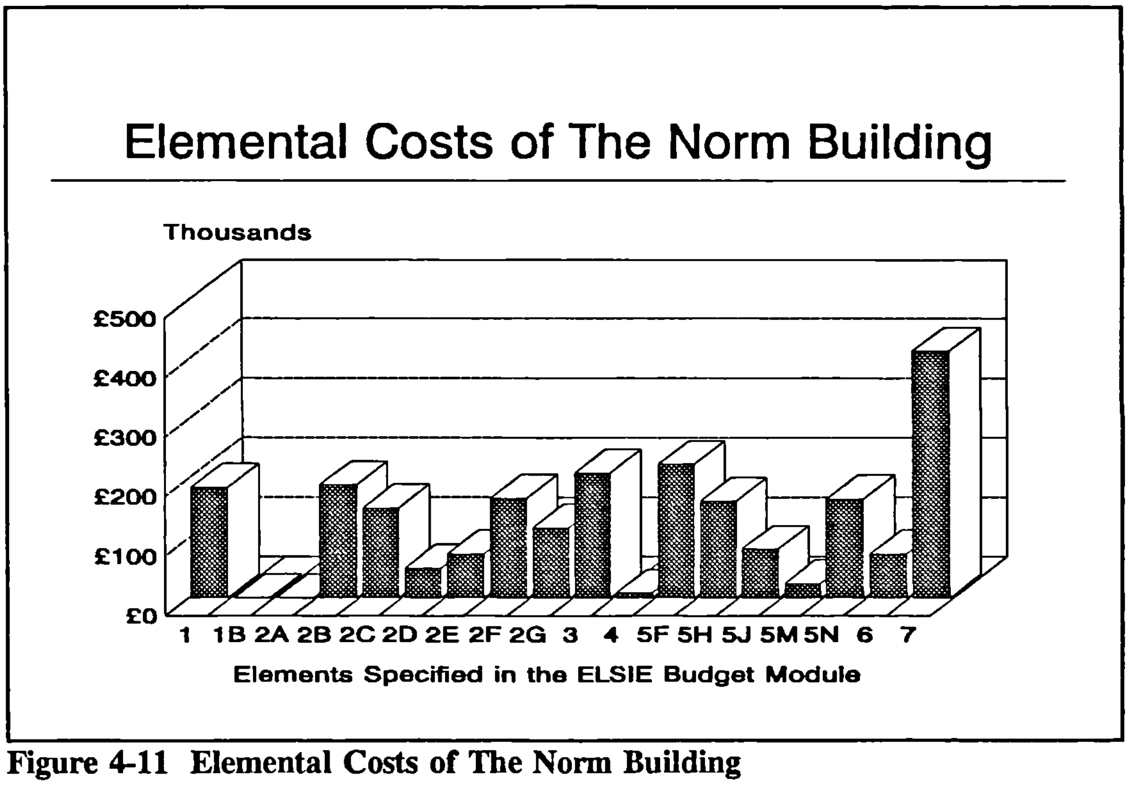


Figure 4-11 Elemental Costs of The Norm Building

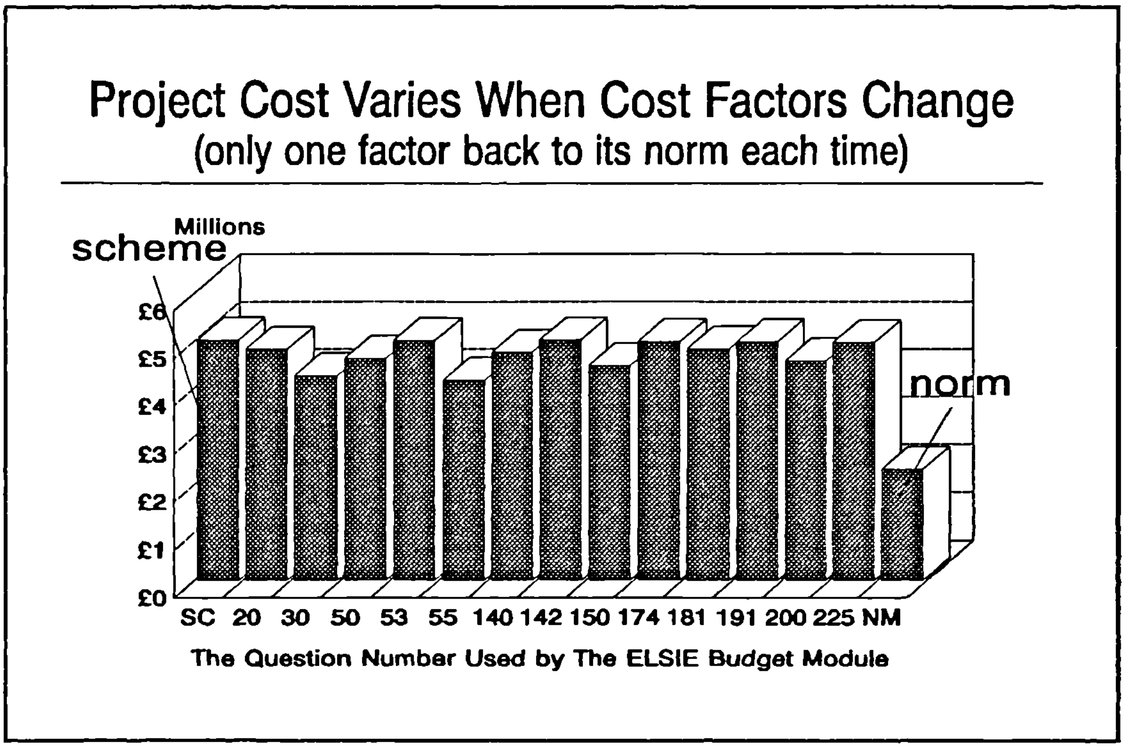


Figure 4-12 Project Costs When Cost Affecting Factors Above Their Norms

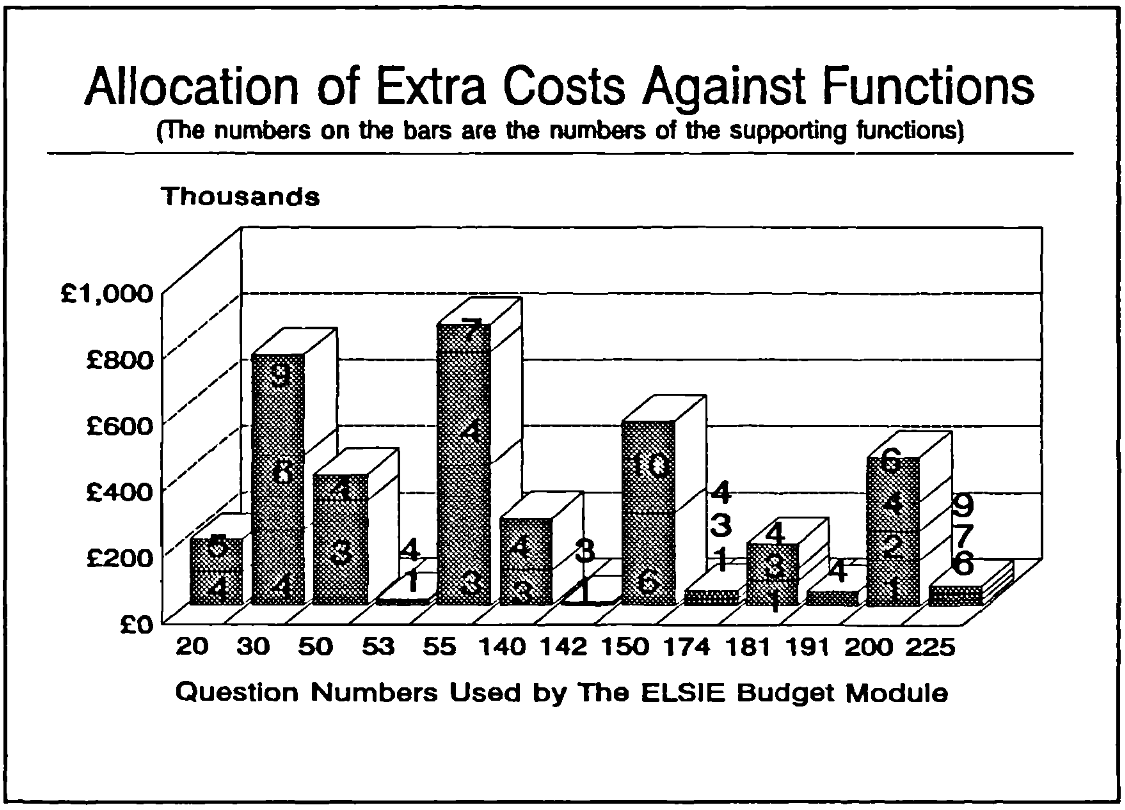


Figure 4-13 Allocation of Extra Cost Against Functions

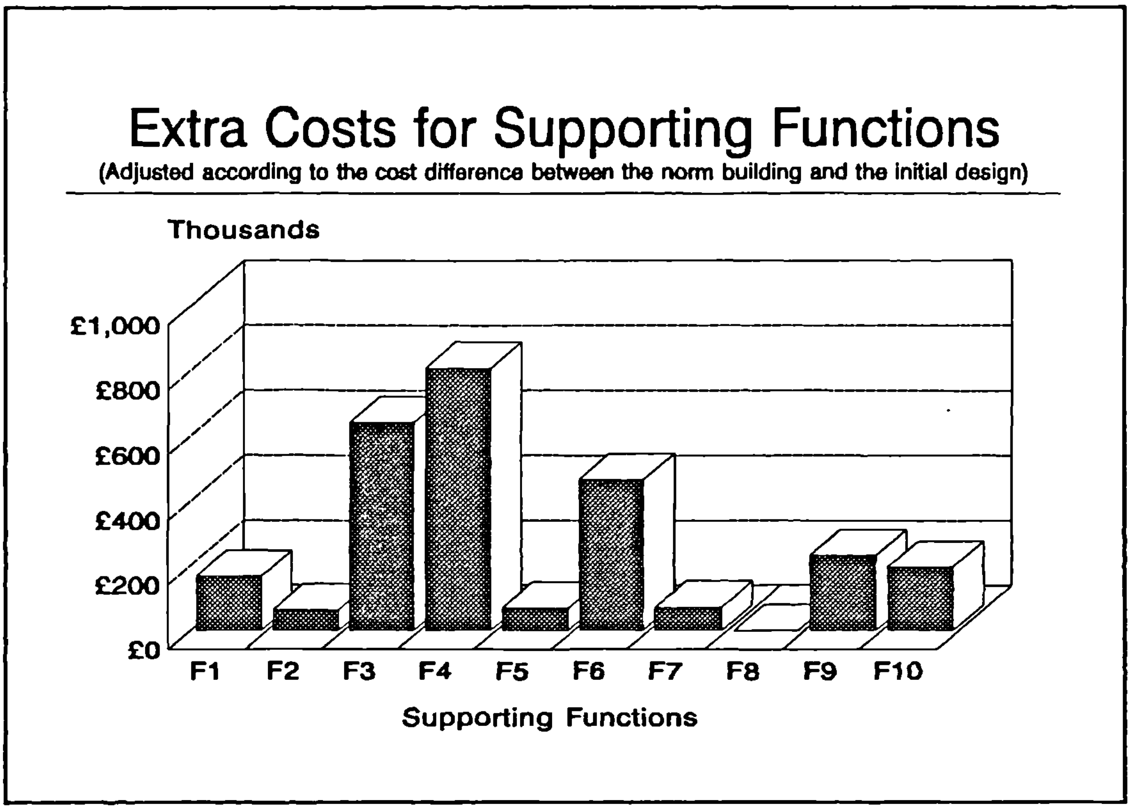


Figure 4-14 Extra Costs for Supporting Functions

Table 4-6 Allocations of Extra Costs To Supporting Functions

ELSIE No	Ci	Di=C-Ci	FCi1	FCi2	FCi3	FCi4	FCi5	FCi6	FCi7	FCi8	FCi9	FCi10
#20	4833785	196692				98346	98346					
#30	4275303	755174				226552		226552			302070	
#50	4636766	393711			314969	78742						
#53	5013486	16991	11894			5097						
#55	4182376	84810			424050	339240			84810			
#140	4767916	262561			105024	157537						
#142	5021092	9385	9385									
#150	4476687	553790						276895				276895
#174	4987626	42851	4285		17140	21425						
#181	4843926	186551	74620		37310	74620						
#191	4988388	42089				42089						
#200	4583509	446968	134090	89394		89394		134090				
#225	4971537	58940						17682	17682		23576	
SUM Σ		3813805	234274	89394	898493	1133042	98346	655219	102492	0	325646	276895
Percentage (Pj)		100	6.14	2.34	23.56	29.71	2.58	17.18	2.69	0	8.54	7.26
Functional Cost (FCj) Σ=2722108			167137	63698	641329	808738	70230	467658	73225	0	232468	197625

Total Project Cost Cproject = £ 5030477 Norm for this project Cnorm = £ 2308369 Difference D = Cproject - Cnorm = £ 2722108

CHAPTER 5. SYSTEM DESIGN AND IMPLEMENTATION

In previous chapters, the design process and the applications of VM in the design process have been introduced. The expertise of the VM domain in the Engineering Department of ICI has been modelled. The purpose of this chapter is to discuss how the VM domain and domain expertise in its implementation in designs could be linked with expert system applications, and to introduce the detailed processes involved in the design and development of the system for facilitating VM implementation into the design of office buildings. It begins with a discussion of the desired characteristics of the proposed system and the domain suitability for ES development (Section 5.1 and Section 5.2), followed by a description of the methodology employed in the development of the proposed system (Section 5.3). The methods and techniques used in the processes of knowledge acquisition and knowledge representation are introduced in Section 5.4 and Section 5.5 respectively.

5.1 DESIRED CHARACTERISTICS OF THE SYSTEM

It has been known in ICI that Conceptual Analysis can provide great cost savings when applied in the early concept design stage of a building project. It helps project engineers in clarifying the client's requirements in functional terms and specifying the project through creative design thinking and thorough comparison, so that the project can be clearly and precisely defined. This technique is welcomed by the project engineers when applied in the early design stage of a project. However the expertise in this technique is confined to only 5 ICI staff and 2 retired ICI staff. A feasibility study with the objective of exploring the feasibility of building an expert system to assist project engineers in their decision-makings in the early Concept Design stage of a building project is therefore proposed.

As stated in Chapter 1, the overall objectives of this research are: (1) to explore the possibility of using expert systems techniques in the domain of Conceptual Analysis and Value Management to make scarce expertise more widely available; (2) If it is proved to be feasible, then a demonstration system will be built to illustrate facilities that would be available in a fully developed system i.e., to demonstrate how an expert system with VM domain knowledge could support project managers in their decision- makings within the early design stage of an office building; (3) To discover how expert systems can be applied to "open-ended" decision-making problems in which new options may be generated during each session with the system.

5.1.1 Scope of The Proposed System

Every expert system has its own domain boundaries beyond which the system can not perform well. The scope of the proposed system should therefore be clearly defined. Since a group of individuals from different disciplines usually participate in a VM study, it would be ideal to design a system containing knowledge and expertise of experts in all disciplines (including the expertise of the VM specialists). It was, however, proved unrealistic to undertake the intensive amounts of work involved in the knowledge acquisition and representation process, because of the limited time available. The system was designed to represent the knowledge and expertise of the value specialists by performing in a similar way to them, i.e., it organises users' creative thinking and records the alternative ways of achieving the functions given by the users. It also gives some suggestions about alternative ways to achieve the same functions, based on the generic knowledge of building design.

The proposed system does not intend to replace human experts, neither does it intend to undertake a complete VA study. It is known that the most time-consuming task in a VM study is to assemble the data concerning cost, performance, and quality. The system was therefore designed to facilitate these processes. Although the system can use a checklist to stimulate users' creative thinking, it will leave the task of creative thinking to the users, because current technology has not reached the stage where expert systems can think creatively. Since major design decisions are usually made in the early design stages, and later VM applications could cause delay to the project and are unlikely to be accepted by the designers and the clients, the proposed system is designed to demonstrate how VM can be used in the early design stages i.e., concept design and sketch design.

The potential users of the proposed system include: project managers, project engineers, and novice value engineers, since all of them are deeply involved in the design of a project, and the success of any VM studies depends on their awareness of VM and their commitment to the use of the VM methodologies and techniques in the design process. The system provides assistance to the potential users in their VM studies by introducing and utilising VM techniques, concepts, principles, and the domain expertise of human value specialists. As is the case with a VM study organised by a human value consultant, the success of the study depends on the cooperation of the consultant and the team members from various disciplines.

Unlike conventional expert systems which are usually one-way systems (i.e., by asking the user(s) to give answers to their questions, the systems generate solutions for the user(s)), the proposed system is a two-way system; its success depends on both sides of the consultation, i.e., the user(s) and the system. The system can be used in the following ways:

(1) Individual Analysis -- This is to assist a potential user in clarifying client's requirements, identifying client's objectives, and preparing a clear and precise project definition of an office building in functional terms. By doing so, the risk of producing an abortive design is reduced.

(2) Preliminary Analysis -- The system could be used for a preliminary analysis of the project to be designed by a potential user, who may subsequently call for a formal VM study to analyse the project in more details, if the initial analysis shows that the project has a big saving potential and it is too complex for the system to accomplish the complete analysis.

(3) Analysis Assistant -- The system can also be used by an expert or novice value consultant during the actual VM studies as an assistant tool. The facilities provided in the system such as functional cost analysis, project information storage and retrieval, life cycle costing analysis, weighted evaluation can all be used to speed up the pace of the study, and save participants' time to concentrate on more creative issues involved in the design.

(4) Training Device -- Because of transparency of the reasoning process provided by expert systems, the proposed system can be used to train relevant staff and encourage its implementation. Potential users can learn a considerable amount of expertise and familiarise with the concepts and principles of the VM domain. Quantity surveyors,

for example, can become VM specialists by learning VM concepts, methodology and techniques, because they are very similar to the VM profession in the USA.

5.1.2 Requirements of The Proposed System

In order to achieve the research objectives stated above, especially to test how expert system techniques can be applied to the VM domain within the specified research scope, and to satisfy the needs of the expertise providers, the following characteristics were expected to be included in the proposed system:

1) The prototype system should successfully represent the knowledge and expertise of the value consultants in organising CA studies by using the CFD structure as an intelligent checklist to clarify client's requirements and remind the project engineers not to overlook any important issues concerning the design of office buildings.

2) The proposed system should be able to provide functional cost information and suggest alternative ways to achieve required functions. The alternatives suggested by the system may not be the best solutions, but could stimulate user's thinking and widen their thinking. Since alternative ways to achieve functions usually appear in a CFD, it was considered valuable to integrate the proposed system with the ELSIE Budget Module to generate a quick cost estimate. Some assumptions should be made in order to avoid asking too many trivial questions.

(3) The system should be able to identify clients' objectives, and clarify their requirements which are usually an intuitive expression, rather than simply accept what the clients want. It should help the user to expand the objectives into an overall

CFD through a user-friendly interface. The system should be developed in a way which allows the user to easily modify the contents of the hierarchical diagram provided by the system, and express their own options (alternatives) for achieving some functions, i.e., the system should deal with open-ended problems.

(4) The use of the system should also enrich the store of knowledge and expertise in the VM domain. The system should consider the possibility of taking the user as an integral part of the system and letting users extend and customise the knowledge base. Each time when the system is used, the user with his/her expertise in a specific domain, such as structural engineering, may add new knowledge to the system. The knowledge base inside the system can therefore be gradually expanded and refined by adopting the user's specific knowledge and expertise.

(5) The system should be able to provide guidelines for base costs (or target costs). A base cost is the minimum cost for providing the basic functional requirements. The methodology was introduced by Dell'Isola (1982) in his book "Value Engineering In Construction Industry". The figures for base costs were determined based on the past experience of value consultants, which may vary with pertinent parameters in different projects, but the differences possibly hold true.

(6) The system should facilitate the applications of supporting techniques used in VM studies such as a creativity stimulating checklist, weighted evaluation and Life Cycle Cost (LCC) analysis. An LCC analysis model, for example, should be used in the system which includes: initial capital cost, annual maintenance cost, operation cost, intermittent maintenance/alterations/replacement cost, sundries, running cost, additional tax allowance, salvage and residuals. The LCC data such as life-spans of

building elements and the calculation formulae should be provided.

5.2 DOMAIN SUITABILITY FOR AN ES APPLICATION

As discussed in Chapter 3, ESs can only be applied to a number of clearly-defined narrow domains. Several researchers such as Hart (1988), Pederson (1989) and Brandon (1990), suggested a number of criteria for selecting domains suitable for ES applications. They are summarised as follows:

- The knowledge should involve a small number of concepts.
- The knowledge should already be well organised and formalised.
- The majority of the knowledge should be well documented.
- There should be a consensus on domain knowledge.
- The knowledge should be stable and well tested.
- An explicit methodology or model should be available.
- The problem should be well constrained and defined.
- Large problems should be able to be split into sub-tasks.
- The problem solving strategies should be well known/documented.
- The problem should provide a return on investment.
- Experts should be able to explain the steps to arrive at solutions.
- The problem solution should not depend on common sense.
- The majority of problem-solving strategies should not depend on sense data.

Applying ES to the VM domain is a new concept. To prove that ES technology could be successfully applied to the domain of value management to support the decision-making processes within the early design stages of office buildings, a careful analysis of the VM domain against the above criteria should be undertaken, and the following issues should be addressed: (1) what the decision-making process within the design of buildings is; (2) how VM can support the decision-making process; (3) how an expert system can facilitate the use of VM/CA in the design of buildings.

Directed towards analysing functions and eliminating or modifying anything which adds costs to a project without contributing to the required functions, VM is an effective method of reducing the overall cost without sacrificing client's functional requirements. As described in Chapter 2, the five principles which comprise the VM domain are: VM job plan, function analysis, function-cost analysis, team approach, and environment for creativity. In order to discuss whether the VM domain is suitable for ES applications and what roles an expert system with VM domain knowledge and expertise can play in the design decision-making process, it is necessary to briefly review these principles to observe how they can be represented in a knowledge base. Initial analyses of the VM domain and how the knowledge and expertise can be represented in a knowledge-based system is illustrated in the following sections. The final conclusions about the domain suitability depend on the success of the system designed.

5.2.1 Representation of the VM Job Plan

The standard VM job plan has already been well established which usually contains the following stages: 1) Information, 2) Speculative, 3) Analysis 4) Proposal, and 5) Final Report. This kind of step-by-step procedural knowledge (information regarding the application of facts, concepts and relationships in a particular domain) can be represented in a knowledge base by meta-knowledge i.e., knowledge about knowledge. As shown in Figure 5-1, a production rule can be written to control the process.

If	Information is gathered
and	Speculation is done
and	Analysis is undertaken
and	Proposal is proposed
and	Final Report is presented
then	The VM study is completed

Figure 5-1 Rule for the VM Job Plan

5.2.2 Representation of Function Analysis

Through systematic function analysis, a VM team can efficiently identify and remove unnecessary costs i.e., costs which provide neither quality, use, life, appearance, nor client required features. The techniques which have been used in the VM studies are function description/classification and the function analysis system technique.

Object name:	provide_image
Functions:	provide image
Function code:	2.1.1
Functional cost:	£20,000

Figure 5-2 Frame for Building Functions

Functions of a building can be categorised into two groups: functions of the building as a whole, and functions of building elements or components. The functions of an office building, as illustrated in Chapter 4, section 4.3, can be represented by a frame with a number of slots to describe the physical and functional characteristics. Both attributes tend to be hierarchical descriptions, for instance, a building has a number of rooms, where every room has its physical dimensions such as length and width. The functions of a building can be organised hierarchically through the internal "Why-How" logic. As shown in Figure 5-2, a function at any level of the hierarchy can be represented in the frame designed.

The design process is characterised as a search for a description that matches some intended meaning within a space of designs defined by generative knowledge (Coyne (1990). Design includes interpretive and generative (or syntactic) knowledge. It delves into how design solutions can meet the constraints such as client's requirements, laws and regulations. The reasoning inside design includes deductive, inductive and abductive. A design is comparable with a language, the syntax of a design is similar to the grammar in a language, whereas the interpretation of a design is similar to the meaning of a language. Within a design, client's requirements are translated into design schema/solutions by using the interpretive and syntactic knowledge possessed by the designers.

Functions of building elements or components can be determined during a VM study, based on designers' and value specialists' experience. They can also be represented in the frame facilities provided by some commercially available development tools. As shown in Table 5-1, the functional and physical attributes of three elements of office buildings i.e., foundations, columns and floors can be represented in frames.

Table 5-1 Functions of Building Elements Represented in Frames

	Foundation	Column	Floor
Functions	Support live and dead loads	Support live and dead loads; Transfer loads to foundations	Absorb live and dead loads; Transfer loads to columns and stability elements; Separate rooms horizontally; Provide horizontal areas
Shape/System	piles, stripe, box...	square, rectangular, round...	flat with or without beams underneath the floor
Materials	concrete, brick, rock...	reinforced concrete, brick	reinforced concrete...
Construction	in-situ, prefabricated	in-situ or prefabricated	in-situ or prestressed

Design activities involve prototype generation, prototype refinement, and prototype adaptation (Coyne et al, 1990). A prototype has two classes of attributes, i.e., physical and functional attributes, which answer the questions of "what is it?" and "what does it do?" respectively. Other questions asked during a VM study, such as, "what must it do?", "how much does it cost?", "what else will do the job?", "how much will the alternative cost?", can be represented in a frame with several attribute slots. For instance, the representation of physical and functional attributes of a pencil is shown in Figure 5-3.

Physical Attributes:		**Functional Attributes:**	
Length:	20 cm	Object:	Pencil
Shape:	Round	Basic Functions:	Mark Clearly
Thickness:	R=0.3mm	Supporting Functions:	Looks Pretty
Paint Colour:	Blue	Cost:	£ 0.10
Material:	Wood	Alternatives:	Anything
Weight:	10 Grams	Alternative Costs:	£ 0.0 – 1.0

Figure 5-3 Physical and Functional Attributes of A Pencil

The descriptive knowledge such as glossary and explanations of functions can be represented by the Hypertext facilities provided by some commercially available ES development tools. (Hypertext is generally defined as the provision of non-linear textual documentation on a randomly accessible basis, with selection being keyed on works and phrases). Users may select different issues with great flexibility and different users may not follow the same route of consultation.

5.2.3 Representation of Function Cost Analysis

Function cost analysis is usually undertaken by a VM team through the conversion of elemental costs into functional costs. Cost estimation for office buildings has been proved to be a suitable domain for expert system applications by the ELSIE Budget Module (Brandon, 1988). The method of converting elemental costs into functional costs has been introduced in Chapter 4, section 4.3, and it seems unlikely to be a problem in terms of representing the knowledge into a system.

Target costs (a target cost represents the approximate minimum cost for achieving a required function) are the bases and guidelines towards selecting areas for in-depth analyses and generating of alternatives. The method for the determining of target costs, introduced by Dell'Isola (1982) is very similar to the method used for cost estimation. It is mainly based on cost data of past similar projects, up-to-date design and construction technology, and new building materials. For instance, the expertise that determines the target cost of HVAC can be represented in a rule as shown in Figure 5-4. It is not necessary to give an exact value for a target cost, as it is only used to compare with functional cost and to locate the areas where in-depth analysis should be made. The determination of target costs is therefore unlikely to be a problem.

```
Target Cost for HVAC of Buildings
If    building is office
and   building is low-rise
and   areas > = 30,000 SF
and   system type is air/water
and   design temperature is 40 F
then  target cost = £ 1925*0.88/ton
```

Figure 5-4 Rule for Target HVAC Cost

5.2.4 Representation of the Team Approach

As described in section 5.1.1, the scope of the proposed system has been defined to representing the knowledge and expertise of the value specialists only. The system does not intend to imitate the team approach practised in VM studies. One of the advantages of the team approach is that each member's thinking can be stimulated by others under the rules of brainstorming. This approach can only be represented when the system possesses all the knowledge and expertise of individuals from various domains. Interactions between rules from different knowledge sources can be controlled through the blackboard architecture.

5.2.5 Representation of Environment for Creativity

As Lawson (1980) suggested, throughout much of the literature on productive thought a variety of closely related binary divisions may be found between on the one hand rational and logical processes and on the other hand intuitive and imaginative processes. They are known as convergent and divergent production (thinking). Typically the convergent thinking, which has been associated with ability in science, needs deductive and interpolative skills to arrive at an identifiable problem. Whereas divergent thinking, which has been associated mainly with the arts, demands an open-ended approach seeking alternatives where there is no clearly correct answer.

Although there is no consensus about the stages of creative thinking, according to Lawson (1980), most researchers seem to agree on a five stage process (as shown in Figure 5-5) consisting of the following steps:

First insight
--> Preparation
--> Incubation
--> Illumination
--> Verification

Figure 5-5 Stages Involved in Creative Thinking

- First insight: It involves recognition of an existing problem and commitment to solve the problem. This period itself may last for many hours, days or even years. The formulation of the problem may often be a critical phase in design situations, as design problems are "rarely initially entirely clear and much effort has to be expended in understanding them thoroughly" (Lawson, 1980).

- Preparation: It involves much conscious effort to develop an idea for solving the problem. There might be many cycles between this and the "first insight" phase as the problem is reformulated or even completely redefined (Lawson, 1980). Many researchers emphasise that this period of preparation involves deliberate hard work and is then frequently followed by the periods of "incubation" and "Illumination".

- Incubation: It involves no apparent effort, and it is often terminated by the sudden emergence of an idea ("illumination").

- Illumination: As MacKinnon (1976) explained, this is an unconscious cerebration during the incubation period. The thinker is unwittingly reorganising and reexamining all his previous deliberate thoughts. According to him, that by withdrawing from the problem the thinker is then able to return with fresh attitudes and approaches which may prove more productive than continuing his initial thought development.

- Verification: Once the idea has emerged all writers agree upon a final period of conscious verification in which the outline idea is tested and developed.

Coyne et al (1990) outlined the term creativity in relation to both product and process, i.e., creativity can be assessed by the quality of a product, or by the process through which the product is produced. In terms of creativity according to product, three features can be said to be creative: innovation, value, and richness of interpretation. In terms of creativity according to process, entropy, efficiency, and richness are thought to be the three aspects of creativity.

Rickards (1980) reviewed nine different sources (Parnes et al, 1977; Stein, 1974; Koberg and Bagnall, 1972; Jones, 1979; Rickards, 1974; Schlicksupp, 1977; Bakker and Buijs, 1979; Jaoui, 1979; and McPherson, 1969) and concluded with four main families of techniques for creativity. As shown in Table 5-2, they are: Brainstorming, Morphological Analysis, Synectics and Lateral Thinking. Besides those techniques stated above, Kirk (1988) summarised three other approaches to group creativity: Delphi method, Manipulation and Pattern analysis. Because of the limited space, they will not be discussed further in the thesis.

Although ESs have achieved high-level performance in problem-solving in some specific domains, their intelligence in general is quite limited. Psychologists have observed a regular demonstration of certain personalities and traits possessed by creative people (Mansfield and Busse, 1981; MacKinnon, 1970). They include above-average intelligence, extensive training, openness to experience, autonomy, and aesthetic sensibility. These personalities are necessary for creativity, but it does not suggest that a person who possesses them could be creative. No computer can do many of the simple tasks that a person with average intelligence can (Coyne et al, 1990). Though the knowledge base in an ES contains theories, methods, techniques, as well as experience and required data in a particular domain, all these are not sufficient for creativity. Many knowledge-based design systems do not produce very creative designs (Maher, 1984; Rosenman et al, 1987). Aesthetic sensibility is

Table 5-2 Four Main Families of Techniques for Creativity

Techniques	Operational Mechanisms
Brainstorming	- Generate many ideas. - Avoid evaluation while generating ideas. - Seek new combinations (hitchhike/freewheel).
Synectics a. Gordon	- Seek ways of making the familiar strange, the strange familiar. - Use metaphor/analogies to assist the process.
b. Prince & Gordon	- Identify a range of problem definitions. - Separate process tasks (group leader) & content decisions (client). - Encourage positivity to ideas via "itemised response".
Morphological Chart	- List all possible dimensions that present a system being studied. - List alternatives in each dimension. - Examine as many combinations of sub-combination as possible. - List any promising and unusual new ideas suggested.
Lateral Thinking a. Random Stimulus	- Sample any rich set of random stimuli (walk in science museum). - Seek relationships with your problem needs.
b. Concept Challenge	- Consider in depth important statements usually taken for granted. - Challenge in all ways possible.
c. Interned Impossible	- Move from a realistic idea to an imaginative impossible one. - Treat as stepping stone to new realistic idea.

another extremely difficult aspect for computer programs to cope with.

The above discussion shows that, like environmental aspects, creativity is a difficult task for expert systems to tackle. To a large extent, it still depends on human input. The proposed system therefore does not intend to substitute human VM specialists and other team members. Instead, it uses several creativity-stimulating techniques such as a checklist to inspire the creative thinking of VM team members. By means of providing technical information regarding materials or methods, and facilities to assist creative thinking, alternatives for achieving functions can be developed by human participants of the VM studies.

5.2.6 Conclusions of The Domain Suitability

There are a number of supporting techniques which have been used in VM studies including: life cycle cost analysis, weighted evaluation technique, and cost/target-cost ratio analysis. They are used as tools to support the decision-making process. The content of the majority of them is mechanistic, and there are a number of steps to follow, which can be represented mainly by procedural languages.

It is generally agreed by AI researchers that conventional computing is suitable for processing structured information, whereas human thinking has a unique advantage in dealing with unstructured information. Expert systems are suitable for solving problems which are in between the structured and ill-structured information, although in theory all ESs could be built with conventional computer languages. In this sense, VM can be regarded as a domain with semi-structured information. This is because: VM is an experience-based domain. A survey undertaken by Venkataramanan (1984) showed that among 39 individuals cited as instrumental in the accomplishment of significant VM savings, there was an average of 20 years of industrial experience. This kind of expertise is not well structured information; (2) The VM job-plan, on the other hand, is well organised and structured.

Having analysed the VM domain knowledge, expertise and supporting VM techniques with respect to how they can be represented in a knowledge-based system, an initial conclusion was therefore derived: building an expert system with VM domain knowledge to support the decision-making processes within early concept design stages of an office building project is feasible, *although the problem of creative* thinking needs to be addressed. The behaviourial and interpersonal aspects of the expertise possessed by human experts are difficult issues for an expert system to handle. In fact, no computer can replicate these skills. The final conclusions about the domain suitability will depend on the designed system itself.

5.3 SYSTEM DEVELOPMENT METHODOLOGY

A methodology provides the framework for the transfer of collected wisdom which may be taught in a structured and formal manner, thereby reducing the need to learn through apprenticeship. Despite recent achievements in other areas of expert system development and applications, methodologies for ES development are still an area where further research work is needed. The lack of development methodology leads to a situation where even the developers themselves do not know what methodology is available and which is appropriate. A recent survey conducted by the Department of Trade and Industry (DTI) in the UK confirmed that nearly 1/4 of the respondents have no answer or do not know the methodologies they used in developing their systems (DTI, 1992).

When the research started in late 1988, only a few well-cited methodologies were available. In addition to the widely-used rapid prototyping approach, two other approaches are of increasing popularity. They include KADS (Wielinga and Breuker, 1984, 1986; Hickman et al, 1989), and the Phased Development Methodology (Based on which a client-centred approach was subsequently developed (Brandon et al, 1988; Watson, Brandon and Basden, 1991, 1992).

Despite being criticised as paying particular attention to technical issues but providing very little in the way of support for management issues (which are thought to be crucial to successful project control), the rapid prototyping approach still remains the most popular KBS development methodology. The DTI survey shows that 45% of the respondents are using rapid prototyping and another 7% of them use both the rapid prototyping and structured methodologies (DTI, 1992).

KADS is the result of two ESPRIT (European Strategic Programme for Research in Information Technology) projects. The foundation of the KADS methodology is the epistemological structure of the model of expertise (Wielinga and Breuker, 1986). According to Hickman et al, KADS in many ways resembles conventional software development methodologies. It prescribes phases, stages and activities, models, documents and deliverables. As a model-driven approach, it provides specialised techniques, project metrics and quality assurance procedures for KBS development. It is also a result-oriented approach, and differs from other methodologies in that it pays special attention to the special characteristics of KBSs and the particular problems inherent in their development.

The phased development methodology combines conventional functional approaches and the rapid prototyping approach. It was first introduced by Brandon et al (1988) and used in the ELSIE project, from which four expert systems were successfully developed and subsequently commercialised. As shown in Figure 5-6, the methodology includes the following stages:

STARTING UP: At this stage, knowledge requirements should be identified i.e., the following questions should be considered: Who will be the likely users? What will

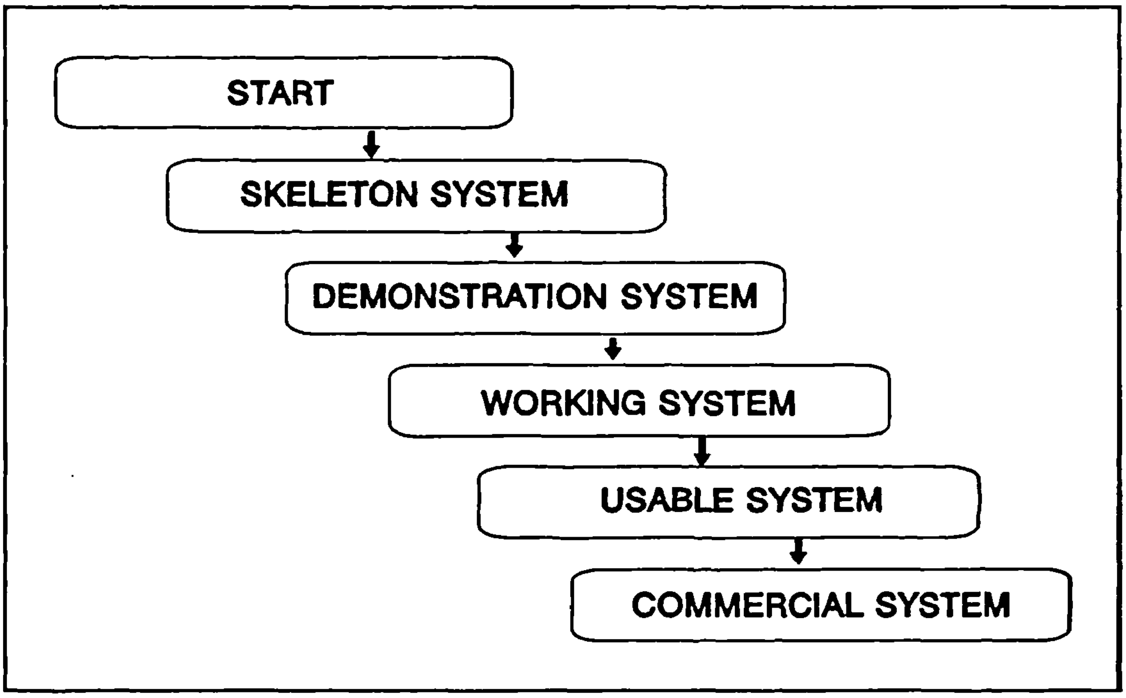


Figure 5-6 Methodology Used in the Development of the Proposed System

be the likely requirements and expectation of the system from the users? In what situations is the ES to be used? The answers to these questions will strongly influence the research direction in later stages.

SKELETON SYSTEM: This system is built only to act in approximately the right way, and accurate answers are not necessary at this stage. It contains little domain expertise, but serves the following purposes: to provide a clear picture of the overall functionality of the proposed system; to help knowledge engineers familiarise with the domain and the types of information to be handled; to give the potential users an idea of what the expected ES will look like.

DEMONSTRATION SYSTEM: During this stage, a significant amount of work in knowledge acquisition, knowledge representation and validation should be undertaken. Although the accuracy is still poor, this system can provide broadly acceptable results by asking a set of questions. It can be used as a basis to determine whether to continue, change direction or abandon the research.

WORKABLE SYSTEM: This is a refined demonstration system achieved through validating and debugging, which should be able to provide more accurate results than the demonstration system in unexceptional conditions, but some questions and parts of the report may still need to be refined. Gaps in the existing expertise may be found during the intensive amounts of work in validating the expertise.

USABLE SYSTEM: This is the working system made usable by providing usability features such as help, explanation, what-if and screen-altering facilities, easy methods of data entry, and integration with other systems. Although it still lacks perfect wording in questions and explanations, it can be used by the users, and real business benefits can be expected. This stage may overlap with previous two stages.

COMMERCIAL SYSTEM: This is the system when it provides a professional operation manual and perfect wording in the questions and explanations, the whole system has been put into a run-time system, and good Help facilities, installation procedures and tutorials have been provided. The purpose of this stage is to prepare for wide distribution of the system to the potential customers.

The DTI-sponsored EDESIRL (Evolutionary Development of Expert Systems in Real Life) research project currently being undertaken at the Department of Surveying, Salford University, adapted the above approach and developed it into a client-centred approach for small and medium-sized enterprises. The methodology includes two main elements: a life-cycle method - concerned with managing the whole life of an expert system from the initial conception, through development and use, to its demise as a useful tool; and a knowledge acquisition method - a method concerning obtaining a structured and understandable expression of the expertise that can be encapsulated in the computer to form the ES. (Watson, 1991; Watson et al, 1992).

Unlike building a conventional computer program, in building an expert system, the designer's concentration is on the knowledge of the problem and ways this knowledge can be used in solving the given problem (Durkin, 1990). The designer is mainly concerned with obtaining and structuring the knowledge which emphasizes the importance of problem understanding. The solution in this sense becomes a by-product of the understanding.

The development of the system followed the methodology introduced by Brandon et al (1988). The reasons for using this methodology were: (1) as described above, only a few well-cited methodologies for developing expert systems were available when the research first started; (2) the methodology introduced by Brandon is well-documented, and the expertise of applying the methodology was easily available.

Because of the limited time available for the research, however, it was difficult to develop the prototype system into a commercial system. The facilities and the potential benefits of the fully developed system were however illustrated in the workable system. The following steps were included in the development of the proposed system, although some of them may have overlapped.

5.3.1 Information Gathering

This stage included identification of problems i.e., identify the problem areas and define research objectives and scope. For instance, what kind of problem is to be solved, what are the results expected?. A profile of the problem domain should be established through discussion with potential user and domain experts, i.e., What is the primary role for the proposed ES?; What are the primary benefits of the system expected by the clients?; Who would use the system?; Why would they use the system?; Can the problem be easily identified?; Can a less than perfect result be tolerated?; Does the problem have clearly defined boundaries?; Will the problem still be relevant in several years time?; Is the problem stable?; Can the problem be broken down into separate sub-problems or stages?. The main objective of this step is to assemble VM documents, review VM-related literature e.g., papers and books which may contain valuable VM specialists' expertise, understand and familiarise with VM concepts, methodology, and principles.

5.3.2 Development of The Skeleton System

Based on the knowledge and expertise which has been gathered in the information gathering stage and the understanding of the VM domain, a skeleton system was developed. The development of the skeleton system includes conceptualisation and formalization of the domain knowledge and expertise. The conceptualisation process identifies those concepts which represent knowledge, clarifies the key concepts and their relations, and determines information-flow characteristics needed to describe the problem-solving process. The formalization process designs the structure to organise acquired knowledge and expertise and formulates 'if-then' production rules to be embodied in the knowledge base.

The coding strategies adopted in the development of the skeleton system were: (1)

write rules which are easily understood, (2) build structured knowledge base, and (3) use clear, efficient and easily-modified control structures. (Details about the system structures will be introduced in Chapter 6). The skeleton system contains most of the facilities to be provided by the fully developed system. It can work approximately in the right way as expected, and has been modified continually as expertise from VM specialists has been elicited. The skeleton system was proved to be very helpful in obtaining and maintaining the interest of human experts on the project.

5.3.3 Further Development Towards Demonstration and Workable System

To develop the skeleton system further towards a demonstration and subsequently workable system, further knowledge acquisition and representation were undertaken. During this stage several human experts in the VM domain have been located and their specialised knowledge and valuable expertise in VM have been acquired through knowledge elicitation. As stated in Chapter 4, the Engineering Department of ICI Plc has applied CA/VM to their design processes for many years, and the experts there have accumulated large amounts of practical expertise. The following persons in the Engineering Department of ICI were located and several sessions of interviews with them were arranged: Wilfred Burgess - a retired value specialist, John Roberts - Manager of the Engineering Services Group, Stuart Lord - Manager of the Design Systems Group, Peter Kennedy - a project manager in the building section, and Clive Richardson - a project engineer. The process of knowledge acquisition lasted throughout the development of the proposed system, details of which will be described in Section 5.4

Along with the process of knowledge acquisition, further knowledge representation was undertaken when more knowledge and expertise in the VM domain was obtained (Details about this representation process will be reported in Section 5.5). This implementation process overlapped with the knowledge acquisition process. As the system was continuously developed, verification and validation of the designed system needed to be undertaken. This is a process of evaluating the performance of the proposed system and revising it until it reached the standards of excellence for a workable system defined by experts. The details about the validation and verification of the system will be described in Chapter 7.

5.4 THE KNOWLEDGE ACQUISITION PROCESS

Knowledge Acquisition is the extraction and formulation of knowledge derived from extant sources, especially from human experts. It has long been recognised as the major bottleneck in the development of an expert system (Durkin, 1990).

Two important issues have been addressed in the knowledge acquisition process: 1) identification of knowledge requirements, i.e., to answer the following questions: who will be the likely users? what will be the likely users' requirements and expectation of the system? in what situations is the expert system to be used? 2) selection of the most appropriate acquisition methods. The following methods have been found useful in the development of the proposed system: text analysis, interview analysis, and observational studies.

Text analysis is the acquisition of knowledge without recourse to an expert but through the use of text books, reports or user manuals. It was used as a starting point to gain basic understanding of the domain which the expert system is concerned with.

The danger of this method is that the resultant system is less likely to be successful, as it is usually difficult for the knowledge engineer to evaluate and validate the system, and the system may not address many of the domain problems. Although this is probably the least successful method and should be only sparingly used (Cleal, 1988), it was proved useful in developing an interesting skeleton system which could be used as a tool to demonstrate to industrial specialists and potential users in order to attract their input and commitment to the research.

Interview analysis is extracting knowledge by means of talking to the expert directly during an interview. By interviewing the expert, the knowledge engineer gradually builds a representation of the knowledge in the expert's terms. To ensure the accuracy of observation, the interviews have been tape-recorded and subsequently transcribed. Although there are some advantages such as the relative ease of analysing and interpreting the information into the proposed system, and explicit knowledge can be elicited quickly (Slatter, 1987), the following are seen as the drawbacks: firstly, it is difficult for the knowledge engineer to ask detailed questions; secondly, the questions may be restrictive to the answers given by the experts, some crucial expertise may be overlooked; thirdly, it may prove difficult to uncover underlying information used by the expert.

Observational studies requires the knowledge engineers to observe and make notes when the expert is working. The advantages of this group of methods are that: they do not require the expert to repeat the same task many times, so that the amount of expert time used can be kept to a minimum; good quality data are likely to be obtained which cannot be gained in any other way; and the knowledge engineer can examine what the expert said in relation to what he has actually done, as experts may have difficulties in expressing their expertise; and if involved, user's contribution can be identified. The author benefited from participating in a number of VM studies including a 24-hour SAVE approved VE training workshop (MOD II) organised by Barlow Associates in the USA, and a value practitioner's training workshop organised by John Roberts of the ICI Engineering Department. This group of methods, however, may be obtrusive and intimidating to the domain expert, and the knowledge engineer has to deal with large amounts of information, of which the majority are of little or no importance.

As a result of the interviews with a number of specialists in the Engineering Department of ICI Plc, especially sessions with the value specialists i.e., W Burgess and J Roberts from Engineering Services Group, the following types of knowledge possessed by the value specialists have been identified: (1) the knowledge about the processes of a Conceptual Analysis/Value Analysis, i.e., the procedural knowledge of how to organise a CA/VA; (2) the knowledge of preparing a conceptual functional diagram for the project to be analyzed; (3) the knowledge about how to stimulate team members' creative thinking and record important information; (4) generic knowledge about building design. The domain knowledge and expertise modelled in Chapter 4, for example, were acquired through the acquisition process.

5.5 THE KNOWLEDGE REPRESENTATION PROCESS

5.5.1 Software for Expert System Development

Until recently, developing an expert system has been very costly in terms of time and money (Nguyen et al, 1987). The situation has changed over the last several years by the utilisation of commercially available ES development tools. Although theoretically speaking, every expert system can be built by using conventional computer languages (Basden, 1989), the effort involved in the programming may vary dramatically. It is generally known that the use of development tools can reduce the programming labour to a factor of ten (Nguyen et al, 1987). Three classes of such tools have been used in system development. They are: shells, knowledge engineering environments, and rule-induction software.

Expert system shells, as the name suggested, are emptied expert systems which could house knowledge bases from other domains. The fundamental basis for the research on shells is that the knowledge base of an expert system can be separated from its inference mechanism. Early works on shells started from MYCIN, an expert system that diagnoses infectious diseases of the blood (Buchanan and Shortliffe, 1984). The empty MYCIN, EMYCIN, was used to build SACON (structural analysis consultant), one of the early expert system applications in civil engineering (Bennett and Engelmore, 1979).

Shells are often inexpensive and easy to use, and because they make it possible to build experimental prototypes quickly and without extensive coding, they are convenient for rapid prototyping. There are however, a number of drawbacks concerning the use of shells. Firstly, system developers are generally unable to modify a shell's control mechanism (Ortolano & Perman, 1987). Secondly, a shell's sole reliance on production rules for representing inferential knowledge is often inefficient and awkward. Thirdly, explanation facilities provided by shells are often inflexible and sometimes yield verbose outputs (Jackson, 1986). Finally, shells distinguish between the tasks of building and running an expert system by using different software for each task, and this is often inconvenient for system developers.

Knowledge Engineering Environments, as Ortolano and Perman (1987) explained, are programming tools that include languages, editors, interfaces, multiple knowledge representation techniques, and established routines that facilitate the development of expert systems. Sometimes they are known as Knowledge Representation Languages (KRL). Unlike shells, they have hybrid knowledge representation methods such as frames, rules, and procedures; controllable reasoning mechanism; flexible editing, debugging and graphical facilities. There is little doubt about the power of such hybrid knowledge engineering environments. It is especially useful when a system developer requires sufficient flexibility in knowledge representation and reasoning control, ease of rapid prototyping, and ability to provide a sophisticated user interface for a system designed to be used in real life.

Rule-induction software is programs that assist in knowledge acquisition by identifying rules on the basis of case studies. Research work on rule-induction is based on the result observed that specialists transmit their inarticulate skills to trainees by examples, rather than by using explicit rules (Michie, 1984). There are many different ways to induce general rules from specific examples. The approach used to induce rules is one of the features that distinguishes one induction software package from another, for example, EXPERT-EASE, an IBM PC-based rule-induction package, induces the simplest possible "decision tree" for assigning the case study attribute data to outcomes consistent with the data used to derive the tree.

In comparison to shells and knowledge engineering environments, rule-induction software has not received substantial attention from expert system developers. This situation may be changed as new expert system shells and knowledge engineering environments are introduced with rule induction capabilities as a feature. Rule-induction software was however not used in this research for the following reasons: (1) The learning aspect of rule-inductions i.e., the machine learns "how to do it" from experts who supply examples, belongs to the category of machine learning, which is still at its early stages; (2) Rule-induction software requires large amounts of examples in order to generate reliable rules, which is unlikely to be available in the research; (3) One of the research objectives was to understand the VM domain, and the best way to achieve this goal is through knowledge acquisition and representation. As the old proverb says "I hear and I forget, I see and I remember, I do and I understand". The use of rule-induction software may however weaken this process.

Since the objectives of the research are to explore the feasibility of modelling the knowledge and expertise of the VM domain and the potential of using expert systems to facilitate the decision-making process within the design of buildings, a balance has to be maintained between modelling the expertise and programming. The Use of conventional computer languages such as FORTRAN and BASIC or AI languages such as LISP or PROLOG would involve intensive programming for the inference mechanism and user interface, in addition to the representation of the domain knowledge and expertise, which may require a large proportion of the research effort and therefore has the danger of putting the cart before the horse. Although the use of object-oriented languages such as SMALLTALK and C++ may provide flexibility to the developer, they are low level languages, and they too tend to require large amounts of programming. The decision was therefore made to use a shell to facilitate the development of the proposed system.

5.5.2 Selection of Knowledge Representation Languages

There are now over 20 software companies in the UK and over 60 in the USA, which provide ES development tools. When the research project started in 1988, however, there were only a few KRLs available in the UK market, such as Savoir, Crystal, Leonardo, Xi Plus, GoldWorks. The danger in selecting a KRL is that all too often developers purchase a KRL which can accomplish their first diagnostic or advisory system, only to find that they have reached the product's limitations. The selection of an appropriate KRL is therefore essential to the success of the design and development of the proposed system.

As a result of the increasing performance and decreasing price, Personal Computers (PC) became a very popular device in academic research institutions and industrial organisations over the last few years. In fact, according to a survey conducted between October 1987 and June 1988, the majority of the respondents favoured PC-based tools and languages (O'Neill and Morris, 1989). It was therefore decided to select a PC-based development environment, based on the practical consideration of the ready availability of these computers to most potential users.

5.5.2.1 Selection Criteria

Based on previous discussions about the VM domain and the characteristics of the proposed system, the criteria for selecting a KRL tool were set up as follows:

- The inference mechanism should be flexible with controllable forward and backward chaining facilities.

- The knowledge representation facilities should have a hybrid architecture which integrates rules, frames, and procedural programming.

- The explanation facilities and user interfaces should allow users to ask "why" and "how" types of questions. The shell should also include a good facility for user interface design.

- The interfaces with other languages and software packages such as Fortran, C, Pascal, databases and spreadsheets should be flexible, robust and easy to use. The capacity of integrating with other existing systems is also expected.

- The requirements for hardware and software environments should not be too expensive in consideration of the potential users of the system.

- If possible, technical support should be provided by the software vendors, so that, to a large extent, abortive development effort due to the defects of the shell can be avoided.

- The shell should provide relatively easy-to-use facilities in system debugging and development.

5.5.2.2 Comparison and Evaluation of Candidates

CRYSTAL (Version 3.20) was developed by Intelligent Environments Ltd, written in C. It is an entirely menu-driven system with relevant on-line help at any point, and is a fairly easy-to-use expert system development shell. No knowledge of computing or formal training is required to be able to use it effectively within a short time (Lydiard, 1989). The knowledge representation is however rather limited, in the form of production rules only. Descriptive knowledge e.g objects and static relationships can be difficult to represent in the shell. Because of this constraint, most Crystal-based applications are regulation-based systems, data entry and validation systems or as intelligent front-ends to databases or spreadsheets. The main users seem to be those who are already using packages such as Lotus 1-2-3 and dBase (Lydiard, 1989).

Despite its advantages in terms of ease of use, good interfaces with spreadsheet and database packages, and the availability at the time of developing the proposed system (the Department of Surveying bought a copy of Crystal in 1988), it was not selected for developing the proposed system. The reasons for this decision were that the knowledge representation facilities and reasoning mechanism in Crystal are too restricted to be used for complex applications like the proposed system. For example, knowledge bases can become extremely verbose in the absence of a class inheritance facility, and a restricted inference mechanism (backward chaining only) may obstruct the objective of building the knowledge base efficiently. Crystal was used by one of the PhD students in the Department to develop a system, and subsequently abandoned because the developed system soon reached the limits of the shell.

SAVOIR (Version 2.0) was developed by ISI Ltd, UK, written in PASCAL. It is a descendant of the early system PROSPECTOR, offering rules, facets and facilities for representing uncertainty (Allwood, 1989). It was a very popular shell in the UK market. The successful expert system, ELSIE, was developed using this shell. The shell runs on PCs and certain main frames.

This shell was certainly a very promising candidate for developing the proposed system. This is not only because of the flexibility of its knowledge representation facilities, but also because the proposed system was expected to link to the ELSIE Budget Module. At the time of developing the prototype of the proposed system, however, the company which developed this shell ceased further development, and no technical support was available. This caused a potential danger of lack of technical support (which may be required during the development of the system), and existing defects would have been left in the shell, which could have caused problems such as in inferencing. In addition to this danger, there are some other drawbacks such as the poor editing, debugging and on-line help facilities provided for the development environment, all of which finally led to a decision not to use this shell for the proposed system. The maintenance of the ELSIE system has proved that the memory restriction imposed by the shell is a serious problem for future development and expansion.

XI PLUS (Version 3.0) was developed by Expertech and is currently marketed by Inference Europe Ltd, written in C. This product is also limited by its rule-based representation capacity, but provides a richer knowledge representation facility than Crystal, allowing object-attribute-value triples to be defined. It has been used for fault diagnosis and classification systems. The users need to spend some time to learn about the shell and its features in order to use it competently. The external interfaces with other packages are however very limited, as the main emphasis of the developer has been to provide access to other packages by running them from Xi Plus itself (Lydiard, 1989).

Although two high level interface programmes i.e., Load and Roll Programmes, are provided to call large user programmes and other software packages directly from a knowledge base, which is very useful in terms of integrating the proposed system with existing systems written in other languages or shells, its restrictions in knowledge representation are not tolerable for the proposed system. Compared with Leonardo, the execution speed in Xi Plus is very slow, and it offers less flexibility and capacity to represent the declarative and procedural knowledge, which are two essential types of knowledge to be represented in the proposed system. It is therefore not a successful candidate.

GOLDWORKS (Version 1.0) was developed by Gold Hill Computers Inc, written in GCLISP. It is a large and complex system, based on very powerful and flexible definitions of frame objects, providing a comprehensive expert system development environment, but with a less than readable form of rule. As a result of this, it requires a certain proficiency in LISP programming in order to utilise all of its functionalities (Lydiard, 1989). It runs on PC's with 8 MB memory expansion or AI work stations. Its main users tend to be academic and research institutes, although a number of commercial and industrial companies have purchased the product.

GOLDWORKS as a powerful shell satisfies most of the criteria listed above. There are, however, several problems when considering it as the application tool for the proposed system development. Firstly, its less readable format of rules could affect the user-friendly interface expected for the proposed system. Secondly, the requirement for 8 MB memory expansion on a PC was very expensive at the time of development, and is unlikely to win popularity. Users of the proposed system would have to invest a large amount of money in order to use it. Finally, the slow speed during the development and running of the system was another concern, as the author was using an IBM AT with a clock frequency of 8 MHz.

5.5.2.3 Brief Introduction to The Successful Candidate

LEONARDO (Version 3.18) was developed by Creative Logic Ltd, UK, written in FORTRAN. It is a shell with a simple, readable form of production rules and frames, and with facilities for structuring rule sets and objects, and for representing procedural knowledge using internal easy-to-use procedural language. The main users of this product are scientific and engineering disciplines, as it is written in FORTRAN and communicates well with external FORTRAN programmes. It runs on PC's and VAX systems.

LEONARDO turned out to be the best candidate for this research, as it satisfies all the criteria stated above. A brief analysis of the shell against the criteria is as follows (Detailed information about LEONARDO can be found in its user's manual):

(1) Inference Mechanism -- The default inference mechanism within Leonardo is mainly backward-chaining, with opportunistic forward-chaining. The reasoning mechanism can be controlled by using a control command inside the knowledge base. This multiple inference mechanism makes the system very effective. Rules can be grouped under rulesets, and rules fire only when their ruleset is enabled. Thus, by controlling which rulesets are enabled at a given time, it is possible to control which rules fire during forward and backward chaining.

(2) Knowledge Representation -- Leonardo is a production rule based knowledge

representation language combined with structured objects (known as frames) and a built-in procedural language for representing objects and procedural knowledge. The syntax for the rules is relatively clear and readable, like a natural language. Its structured ruleset architecture provides a mechanism for breaking a large complex knowledge base into discrete chunks, and building the knowledge base in a very clear structure which is valuable for the implementation and the subsequent maintenance of the system.

(3) Interface Facilities -- Leonardo provides a good balance between ease of use and aesthetic appeal, both through the default user interface and user on-line help, and through Leonardo's screen designer, hypertext and graphics capabilities, which, to a large extent, facilitate the design of interfaces.

(4) Interfaces With Other Packages -- Leonardo has open interfaces to several other languages such as Fortran, C, Pascal, as well as high level interfaces to DOS and files generated by dBase, Lotus, Btrieve, DataEase. Particular care has been paid in developing 'hooks' to external routines and external data files. This facility makes some of the advantages of other languages available when one uses Leonardo.

(5) Explanation Facilities -- The straightforward representation syntax is also used in the explanation process when questions like "why is this question asked?", and "how are the conclusions derived?" can be answered. Its full explanation facilities make it easy to use and give better explanations during execution.

(6) Ease of Use in System Development -- Through the object/frame editor one can easily access each structured object/frame to set up defaults, inheritance and

quantification, which makes some applications much easier and simpler.

(7) Run-Time System -- A full protection of intellectual property has been provided in the run-time system. A single name can invoke several selected applications. This facility is very useful when the knowledge base is too large to be executed at current 640K base memory, because the knowledge base can be divided into several smaller ones with manageable sizes.

(8) Technical Support -- Creative Logic Ltd and subsequently Software Directions, the new vendor of Leonardo, have kept their promises to develop Leonardo further. Creative Logic used to provide a hot line technical support which was considered very helpful by users, because it dealt with user's specific problems occurring during system development.

No product is either perfect or suitable for every application. Leonardo has very good built-in "How" and "Why" facilities, but for real life non-trivial applications, like most existing tools, these were of little use to an end user, though useful in testing. The advantages stated above have demonstrated that Leonardo is one of the best expert system shells currently available in the U.K. market.

5.6 SUMMARY AND CONCLUSIONS OF THIS CHAPTER

Within this chapter, the desired features of the proposed system have been described, and the boundaries of the proposed system have been defined. The initial analyses of the VM domain, especially the five principles, have demonstrated that expert system techniques can possibly be applied to the VM domain to facilitate its implementation in the design process of office buildings. The methodology of phased development adopted in the research proved to be appropriate and useful, and the development of the skeleton system was especially successful in terms of attracting industrial input and maintaining the interest of the human experts. Because of the unique characteristics of the VM domain and the proposed system, three methods of knowledge acquisition, i.e., text analysis, interview analysis and observational studies, have been used in the research, and a knowledge representation language -- LEONARDO has been selected to represent the knowledge and expertise acquired from domain experts.

CHAPTER 6. AN OVERVIEW OF THE PROPOSED SYSTEM - CAVA

This chapter describes the structure of the proposed system CAVA - The Conceptual Analysis (CA) and Value Analysis (VA) System - implemented in Leonardo V3.24. Section 6.1 illustrates the architecture of the system which consists of a Conceptual Analysis Module and a Value Analysis Module. Detailed structure of the CA Module is introduced in Section 6.2 which includes the generation of a CFD, modification of the CFD and generation of alternatives, evaluation of alternatives and report generation, a framework for knowledge refinement within the CA Module, and the integration of the CA Module and the ELSIE Budget Module. Section 6.3 delves into the structure of the VA Module. Section 6.4 summarises and concludes this chapter.

6.1 THE OVERALL SYSTEM ARCHITECTURE

The proposed system includes two modules i.e., Conceptual Analysis (CA) Module and Value Analysis (VA) Module. They can be used in the stages of the Concept Design and the Sketch Design respectively. The reason why the system contains these two modules is that major design decisions that have great influences on cost, as shown in Figure 6-1, are made in these first two design stages. According to Ferry and Brandon (1980), about 80% of the cost of a building had been committed before even the sketch design had been produced. Past experience has shown that the earlier it is possible to apply VM techniques to a project, the better the results that can be expected (Dell'Isola, 1982; Kirk et al, 1988). Later VM applications could cause abortive design and delay to the project completion; the proposals recommended by the VM study team are therefore unlikely to be accepted.

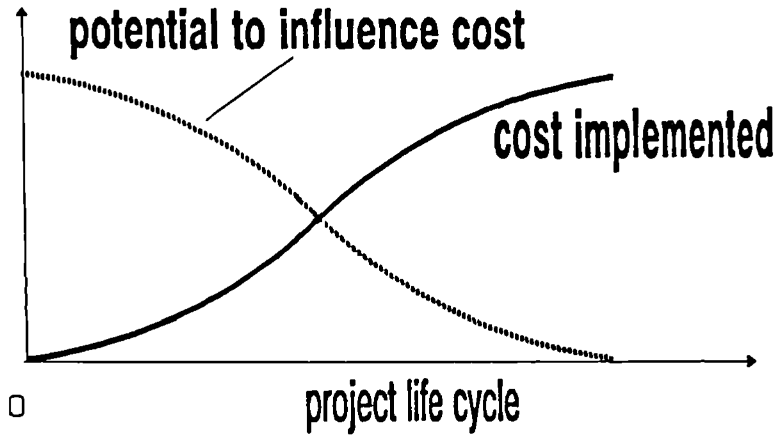


Figure 6-1 The Potential to Influence Cost Over Project Life Cycle

The Concept Design is the phase of a construction project that clarifies client's objectives, identifies client's requirements, conducts conceptual investigations on how the objectives and requirements can be achieved economically, and define the project accordingly in functional and elemental terms. It is an interactive process among the designers and the clients, which starts from the project inception and precedes the start of actual design work, encompassing the briefing process. Within the process, functional requirements of the client and the architectural programme within which the design is to be performed are described.

According to Walker (1989), the success of a construction project to a large extent depends upon the contributors of various disciplines to perceive the same objective for the project, and it is of paramount importance that the objective be identified and understood by all the contributors. The traditional design process, however, has been often performed on an intuitive basis, rather than through a systematic approach, which identifies needs but often fails to specify objectives. The importance and the greatest opportunity of applying VM to this design stage is recognised by the experienced clients. Inexperienced owners, either through optimism or failure to understand the total budget-design-build process, may omit this phase. The resultant cost in time and money is inevitably high (O'Brien, 1976).

Sometimes referred to as schematic design, the sketch design is the initial phase of the actual design work accomplished by the design team. At this point, the design concepts generally would have been developed during the previous development. The preceding work in the concept design can strongly influence the schematic design. If that work has been very well organised and thoroughly performed, the design team will have a strong base upon which to build a design. If, on the other hand, the work has been informal and somewhat ambiguous, the design team may proceed cautiously into the sketch design phase. The schematic design phase offers the best single opportunity for the design team to apply VM. In the prior phases, the design team did not actually exist, and project engineers' contributions would be principally as design advisors (O'Brien, 1976; Macedo et al, 1978; Kirk et al, 1988).

As shown in Figure 6-2, a blackboard architecture has been designed to organise knowledge sources within the system. According to Engelmore and Morgan (1988), a blackboard architecture is a generic term which covers applications that are often implemented with different combinations of knowledge representations, reasoning schemes and control mechanisms, and frameworks which are either a specification of the components of a blackboard model or an implementation of the specification. (Further information about blackboard systems can be obtained from Engelmore and Morgan's book "Blackboard Systems", Addison-Wesley, 1988.)

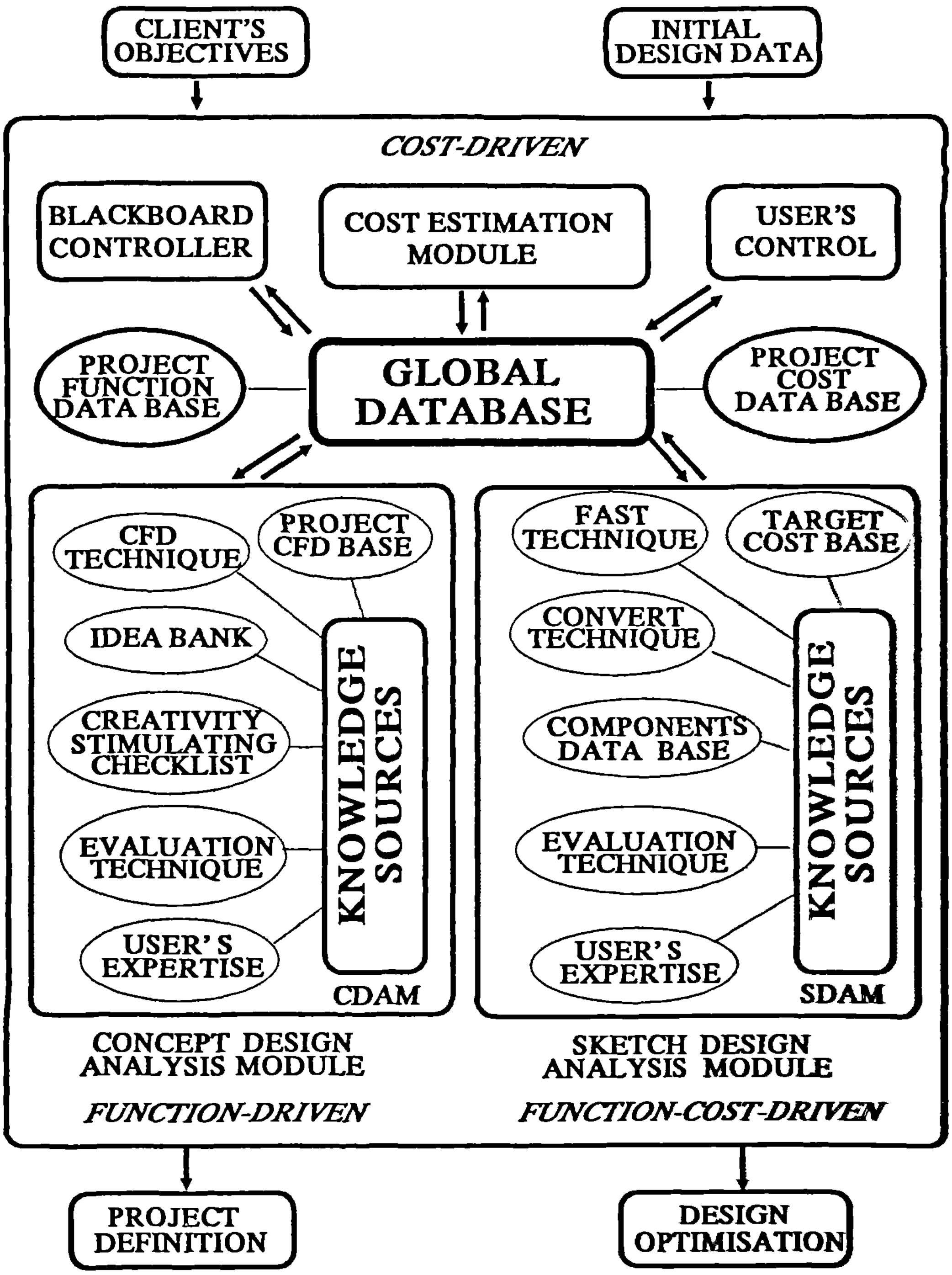


Figure 6-2 A Blackboard Structure of the Proposed System

Here the term "blackboard structure" is used in a loose way, and it is the concepts of the blackboard architecture that have been adopted in this system. Within the structure, the blackboard is a medium through which communications among different modules take place. It can be viewed as a global database; through its changes interactions among knowledge sources take place. Solutions may be built up incrementally onto the blackboard. The purpose of using this structure is to provide a means for storing information that is common to both modules, to facilitate communications and co-ordination among different modules and other systems that may be integrated into this proposed system, for instance, the Budget Module of the commercialised ELSIE expert system.

Each of the two modules (i.e. the CA Module and the VA Module) included in the system has its unique functionality. The function of the CA Module is to assist the user in clarifying client's objectives and setting up a clear project definition in the very early concept design stage. The function of the VA Module is to assist the user in allocating design areas of high saving potentials (by comparing estimated initial costs and target costs), and providing facilities for in-depth analyses. Both of these two modules are function-driven, i.e., detailed function analysis plays an essential role in these modules. The Cost Estimation Module is a cost-driven module, which is adopted from the ELSIE Budget Module. Its main function is to provide a reliable cost estimate based on the information provided by the other two modules.

6.2 STRUCTURE OF THE CONCEPTUAL ANALYSIS MODULE

The CA Module is designed to guide and help the end user -- project managers and project engineers to clarify client's requirements, identify client's objectives, and set up a clear and precise project definition of an office building project through the use of CA techniques. It utilises a CFD as an intelligent checklist to navigate users' thinking, to clarify client's requirements and to remind the users not to overlook any important issues concerning the design of an office building. A considerable amount of effort and time has been devoted to the development of a comprehensive CFD. Special attention has been paid to avoid restrictions imposed on the users which may limit their creative thinking.

Figure 6-3 gives an overview of the structure of the CA Module (Detailed illustration of the performance features of this module is given in the attached Appendix 5). The processes involved in this module are very similar to those undertaken by the CA consultant manually, i.e., suggestion of an appropriate CFD, guidance to the VM team members to modify the suggested diagram and generate alternatives, evaluation of alternatives, and conclusion and report preparation. It is not the intention of the system to direct the users in every single step, but to give clear and concise information regarding functional costs of available design options.

It is very important to distinguish between client's needs, wants and objectives. What a client wants is sometimes quite different from what s/he really needs in order to achieve his/her objectives. For instance, a client's objective might be to increase company's profit to a level of 30% more than the current figure. To achieve this objective, the company may need to employ an extra 300 staff, and a corresponding extra space of 3000 m2 to house them. The accomplishment of client's objective, however, as Walker (1989) argued, does not have to be achieved by the construction of a project. The system will suggest a number of ways of achieving the need for extra space, for instance, leasing new space and relocating staff for a short or long-term, remodelling and possibly expanding in currently leased space, splitting operations into two or more locations, adopting centralized (versus decentralized) services, rehabilitating and relocating staff to owned facilities, identifying temporary situations until more appropriate long-term solutions are feasible, developing a new facility specifically to satisfy space requirements. It is up to the user to decide which

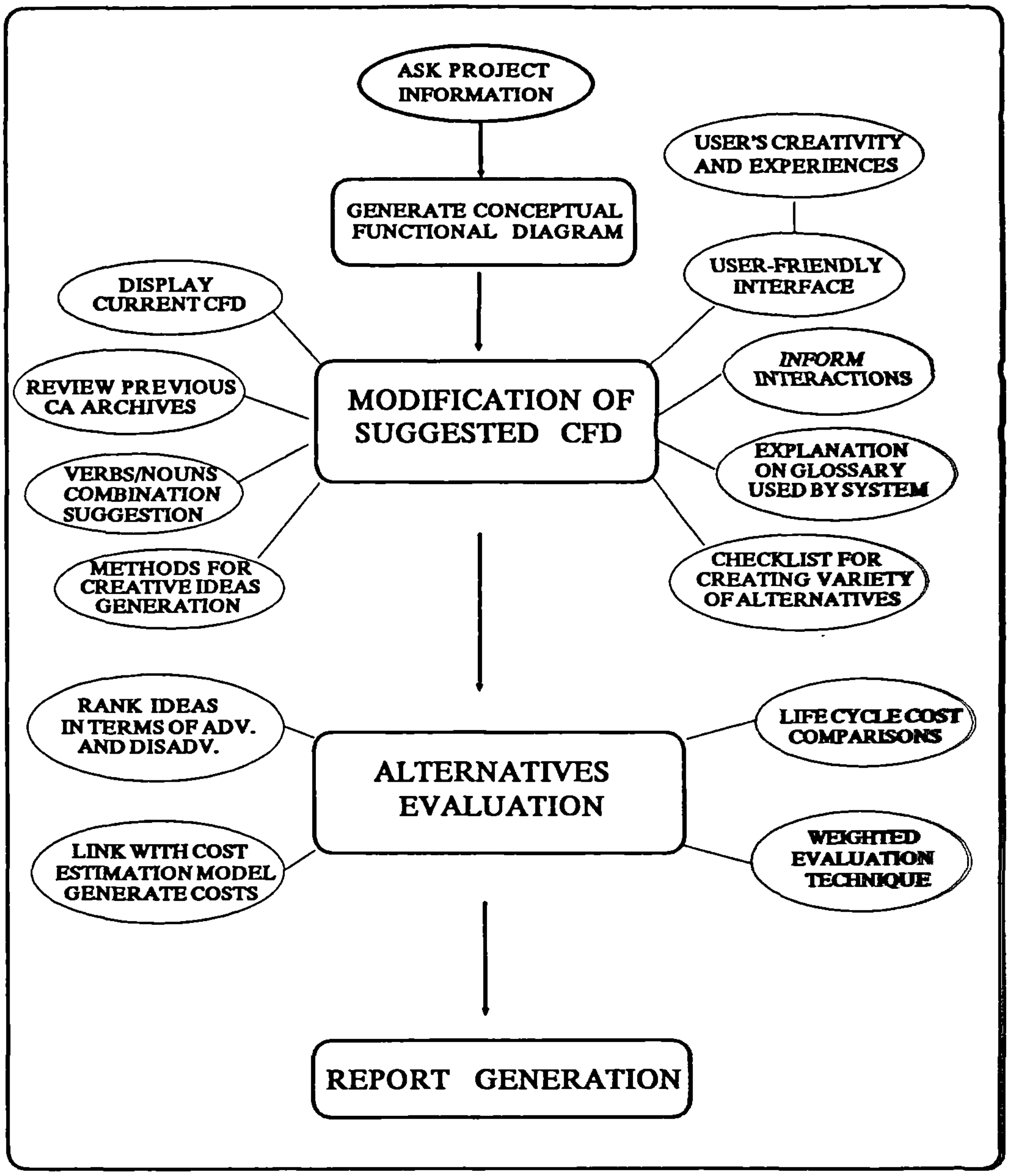


Figure 6-3 Structure of the Conceptual Analysis Module

alternative is the most suitable one.

6.2.1 Generation of a Specific Conceptual Functional Diagram

If a new building project is the best solution to the space needs, the CA Module will generate a CFD to organise user's thinking in a structured way, i.e., think the project in functional terms, rather than in elemental terms. Based on the type of the project being analysed (the research has explored office buildings, other types of buildings may be added in the future development) and the requirements from the client, the system will generate a generic CFD to define the project in functional terms which, as the value specialists suggested, could lead users into deeper thinking and better understanding of the project.

Since a CFD is usually structured to include four levels of functions, functions within this CA Module are divided into four classes, i.e., level1_functions, level2_functions, level3_functions, and level4_functions. The structural hierarchy of functions within the CA Module is shown in Figure 6-4. Each class of functions has its own specific "memberslots". As shown in Figure 6-5, for example, the memberslots defined for class level1_function include: function_name, function_code, include_status, sub-functions, and cost. Functions within a class are represented as the instances of the class. For instance, "establish office facilities" is a function in the first level of the CFD i.e., a member of the class level1_functions, its representation is also shown in Figure 6-5. This kind of representation makes the dynamic generation of functions during system execution possible, which is essential to the success of building an open-ended system to allow users to put in new options.

The inference process within the CA Module is through the management of functions and alternatives to achieve them. The generic rule for managing the inference is shown in Figure 6-6. It is this kind of rule which controls the flow of information during the execution of the system. For example, if "provide image" is selected as one major function of the building to be achieved, the system will ask the user "what kind of image are you talking about?"; "for what reasons do you want to provide this

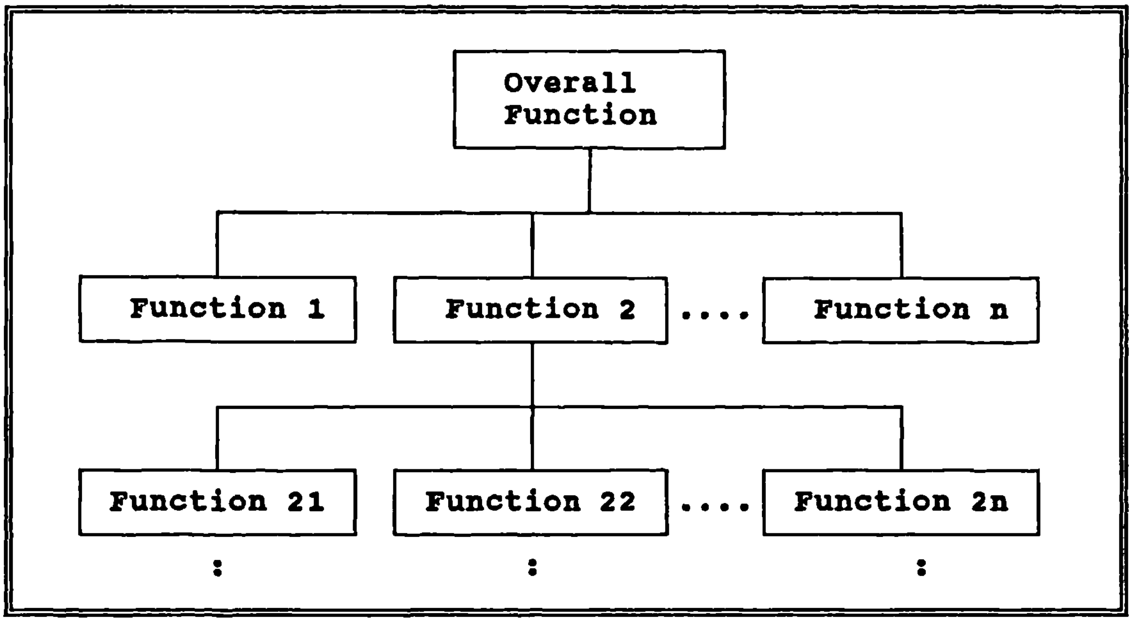


Figure 6-4 The Structural Hierarchy of Functions within CAM

```
         Name: level1_functions
     LongName:
         Type: Class
      Members: Satisfy_Client_Req, Identify_Site
               Establish_Building, Minimize_Risks
  MemberSlots:
 functionname: level1
         code: code1
 includestate: included
 subfunctions: none
         cost: 0

         Name: Establish_Building
     LongName:
         Type: Text
        Value:
    Certainty:
  DerivedFrom:
          IsA: level1_functions
  MemberSlots:
         cost:
 includestate:
         code: 3
 functionname: Establish_Office_Facilities
 subfunctions: Satisfy_Operability,
               Undertake_Building_Design,
               Create_Internal_Environment,
               Create_External_Environment,
               Provide_Furnishings, Provide_Services,
               Satisfy_Regulations
```

Figure 6-5 Frames for Level1_Functions and Establish_Building

image, is it for staff, or for customers, or for community, or for other?"; "what is the best way to provide this specific image?". The system will then provide facilities to help the user in generating a variety of alternatives, and if required, provide some suggestions on solutions. A weighted evaluation framework will be provided to help the user to evaluate all possible alternatives to select the best alternatives.

The Generic Managerial Rules:

if	the subfunctions of the overall function are determined
and	the value of its subfunctions are analyzed
then	overall function is analyzed
if	a function is a subfunction of a higher level function
and	the subfunctions of this function have been determined
and	the values of each subfunction are analyzed
then	this function is analyzed

Figure 6-6 The Generic Managerial Rules in Controlling Functions

After identifying that the client's objective is to "provide an office block", an introduction to rules and principles based on which the CFD is constructed will be displayed. Functions in the first level of the suggested CFD for office buildings are shown in Figure 6-7. This is because one major objective of the design staff is to provide good design solutions. To achieve this objective, they need first to "define the project properly", "generate alternative design solutions" and "optimise design solutions". To define the project properly, for instance, one needs to "clarify client's objectives" and "identify site conditions".

The design problem set by the client's brief is often vague. As Cross (1990) argued, it is only by the designer suggesting possible solutions that the client's requirements and criteria become clear. The designer's very first attempt to conceptualise and represent the problem and solution is therefore essential to the procedures that will follow, such as the alternatives that may be considered, the testing and evaluation of alternatives, and the final design proposal.

```
  Based on your answers to my questions, the following functions have
been suggested in the first level.

                        ┌── Satisfy Client's Requirements
   Provide Office       ├── Identify Site Selection Issues
   Facilities           ├── Establish Office Facilities
                        └── Minimise Development Risks

    (1) Add Functions              (3) Recover Functions
    (2) Deduct Functions           (4) Stop Modification

          Please put your selection here (1...4):

<F1> Display Current CFD  <F2> Quit  <F3> Review Archives
```

Figure 6-7 Representation of Functions in the First Level

A number of alternatives to achieve functions specified by the client are suggested by the system accordingly. For example, in order to achieve function "control access to the building", a function "limit vehicles' speed" is necessary. The following are suggested alternatives for achieving that function: 1) Using narrow driving lanes (10--10.5 feet); 2) Avoiding long tangents or unbroken segments; 3. Providing vertical definition close to the edge of the driving lanes. As far as the function "locate streets and drives" is concerned, as shown below, a generic rule can be used to arrange the locations of streets and drives. These alternatives, however, should be treated as a starting point by the user to generate more appropriate alternatives for the specific project undertaken.

```
if     ridge-lines are available on the site
and    ridge-lines are located in the right place
then   locate the streets and drives along the ridge-lines
else   locate streets at a diagonal to the contours where slope > 4%
```

6.2.2 Modification of Functions and Alternatives Generation

Having confirmed by the user the functions in level 1 of the CFD, the system will deal with those functions one by one through the process of giving suggestions and allowing the user to modify them, until the overall CFD has been suggested and confirmed. The user can modify the suggested functions using the facilities provided by the system. The main purpose of this process is to guide the user through the modification of the suggested CFD, to make it appropriate for user's specific project, and provide necessary help to the user. It is believed that the user can be stimulated by those ideas suggested by the system and use his own creative thinking and previous experience to add functions which have to be accomplished in his/her specific project.

Following the above procedures, a complete CFD with a number of alternatives to achieve those functions is available. A what-if facility is then provided to allow the user to modify the CFD until it is appropriate to represent that specific project in functional terms.

As stated above, a number of facilities have been designed in the system to help users in modifying the suggested CFD, making it appropriate for user's specific project, and generating a variety of alternatives. They can be activated by using a predefined function key <F1>. When the user hits the key <F1>, a menu containing all the supporting facilities will appear on the screen. They are as follows:

1) Display of Current CFD -- The initial display of the CFD is presented by using the hypertext facility within Leonardo V3.24. It makes the system more flexible, as the user may select the issues which s/he is not familiar with and therefore would like to have an introduction. Different users are not necessary to follow the same route.

A global database is used to record the CFD suggested by the system and any modifications subsequently undertaken by the user during the consultation. The database is therefore continuously updated as the consultation goes on and the latest version of the CFD structure is always available to the user.

2) Retrieval of historical CA archives -- the user can review previous CA documents on similar projects stored in the project database which have been well organised in a hierarchical structure. If necessary, a number of quite different projects will be retrieved to get cross-fertilisation. Currently the CA library contains the following types of projects: office block, computer centre, spillage control centre, chemical plant, and research laboratory. Figure 6-8 is a graphical presentation of functional costs generated by the system during a session of execution.

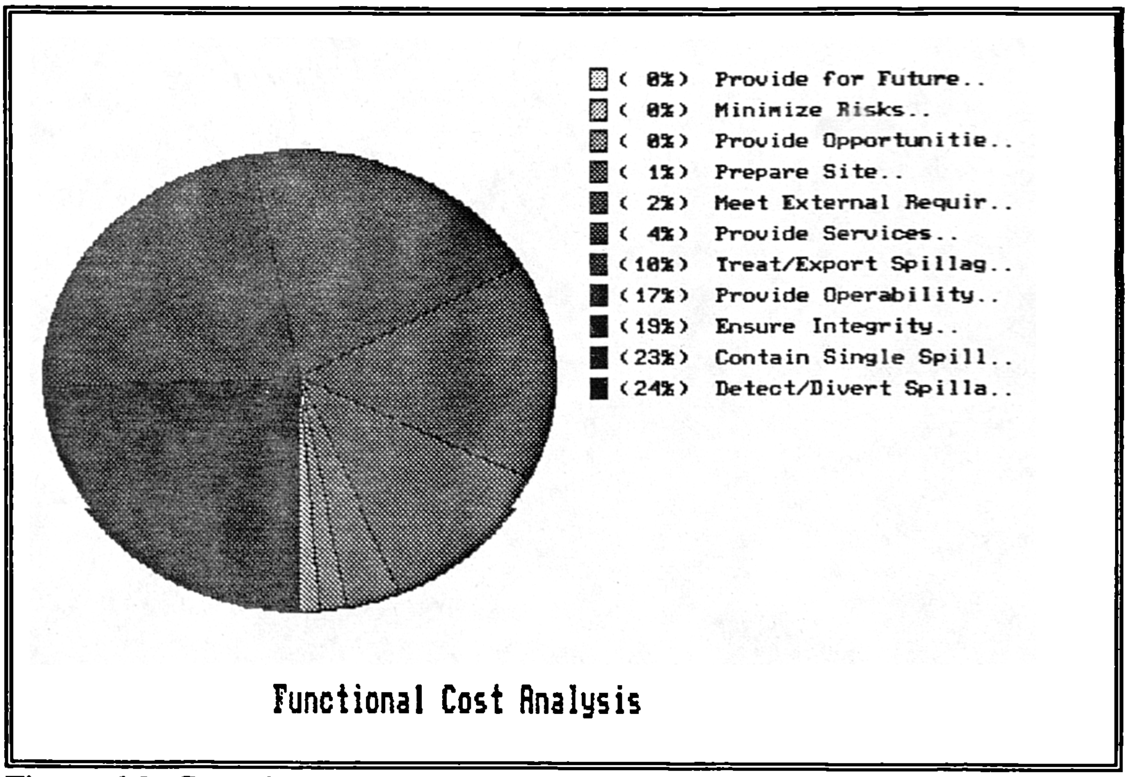


Figure 6-8 Graphical Presentation of Functional Costs Generated by CAVA

Functions of a previously studied project are stored in a project database (Appendix-4 gives an example of the database of a computer centre). Each function stands as a record consisting of five fields, i.e., code, level, name, number of subfunctions (nos), and cost (if available). The number of segments in a code (delimited by a period ".") for functions equals to the level of the function, for example, the code for function "convey people and goods" is "3.6.7", which means the function is in level three, and it is the 7th sub-function of function 3.6 which in term is the 6th sub-function of function 3, the 3rd function in the first level. The total length of each record is 62, and the lengths of each field are as follows:

code	level	function name	nos	cost
9	1	40	2	10

3) Stimulation of user's creative thinking -- At the end level (often the fourth level) of a CFD, alternative means to achieve the same required functions are usually provided. It is necessary to introduce the methods of creative thinking to the user. Creative thinking has three psychological bases (Zimmerman, 1982), they are: (a) similarity or like ideas, (b) contiguity or adjoining ideas, (c) contrast or opposite ideas. The system introduces methods of creative thinking and suggests alternatives to perform required functions. It has been recognised that the following methods are useful in generating a large quantity of creative ideas:

- Combine ideas -- combine several ideas that already exist.
- Modify ideas -- modify existing ideas e.g., to make it larger or smaller.
- Piggy-back ideas -- take an idea that already exists, e.g., from a checklist.
- Use checklists -- a list of questions as a reminder for creating new ideas.
- Think of ideal answers and encourage wild impractical ideas

The system encourages users to create new ideas by using these methods. It is at this stage that some trigger words are thought to be very useful to stimulate user's creative thinking and creative ideas. A checklist with expert suggested trigger words is therefore provided as shown in Table 6-1. The questions listed above can be grouped into eight categories of methods, as shown in Table 6-2. Whenever the user wishes to use a checklist to facilitate the process of generating ideas, the list can be called to pop up on the screen. This self-questioning method was proved by Osborn (1963) to be a useful technique in stimulating creative thinking, which can also encourage the user to think more deeply and systematically. If the checklist is well prepared (e.g., assisting divergence thinking), its potential disadvantages - inhibiting creativity by creating barriers and focusing areas of enquiry - can be overcome.

Table 6-1 A Checklist for Stimulating Creativity

Can it be eliminated?
Can a change in design reduce operation or maintenance costs?
Can construction methods or procedure be simplified?
Can specification requirements be eliminated or modified?
Can a standard part or commercial product be used?
Can we improve the sequence of construction?
Is there a less costly part, or method that will satisfy the function?
Can two or more parts be combined into one?
Do we need the present shape, size, or weight?
Are features that improve appearance justified?
Can less expensive materials be used?
Can we reduce the energy consumption?
Can less costly surface coatings or surface preparation be used?
Can soldering or welding be eliminated?
Would a coarser finish be adequate?
Can tolerance be relaxed?
Can a fastener be used to eliminate tapping?
Have you considered newly developed materials?

Table 6-2 Methods for Creating a Variety of Ideas

(1) Adapt? What else is like this? What other ideas does this suggest? Does past offer parallel? What could we emulate?
(2) Modify? Change meaning, size, colour, motion, sound, form, shape? Make other changes? Put to other uses?
(3) Magnify? What to add? Greater frequency? Stronger? Higher? Longer? Thinker? Duplicate? Multiply? Make it more elaborate?
(4) Reduce? What to subtract? Smaller? Condensed? Miniature? Lower? Shorter? thinner? Lighter? Omit? Split up? Understate? Less elaborate?
(5) Substitute? Who else instead? What else instead? Other material? Other process? Other power? Other place? Other approach?
(6) Rearrange? Interchange components? Other pattern? Other layout? Other sequence? Transpose cause and effect? Change schedule? Change speed?
(7) Reverse? Transpose positive to negative? How about up-ending? Should we turn it around? Why not up instead of down? How about reversing the roles? Why not have it upward instead of downward?
(8) Combine? How about an alloy, an assortment? Combine units? Combine purposes, appeals, ideas? Combine functions, equipments?

4) Provision of information about possible roadblocks -- Roadblocks are negative generalisations that intend to stop progress and keep things just as they are (Macedo et al, 1978). People are naturally hostile and resistant towards changes even remotely threatening their pattern of living (O'Brien, 1976). In order to develop large amounts of creative alternatives for previously identified functions, the potential roadblocks should be broken down to find ways to prevent them happening. As Kirk (1988) stated, a team member alert to them will be in a much better position to take positive and practical steps to overcome the blocks.

There are four types of self-imposed roadblocks: perceptual, habitual, emotional, or professional (Kirk, 1988). Blocking may result from any of these or a combination of them. The perceptual restriction is created by the failure to use all the senses, e.g., sight, hearing, taste, smell, and touch, to tackle a problem. Habitual blocks involve the continuance of what has always been done or thought before, which may be created internally or prescribed by an outside authority. Emotional blocks result from fears of suggesting something different from the way the problem would normally be solved, fears of making an unpopular decision, unwillingness to let one's guard down, or fears of what others might think. Some individuals play it safe by making adequate, but not creative, decisions. Professional blocks are caused by the academic, professional, educational, and working environment in which one functions. Some individuals are unable to branch out into concepts proposed by other disciplines. Some architects, for example, may believe that their profession proclaims the truth about design, to the exclusion of disciplines concerned with environmental problems. Other persons' attitude towards a proposal can also result in producing roadblocks to creativity. As shown in Table 6-3, O'Brien (1976) gave a detailed list of possible psychological reasons (including human abilities), due to which roadblocks to people's creative thinking are formulated.

In practice, the blocking can appear in many different forms, for example, by finding excuses in terms of time, quality, policy, practicability. A number of authors e.g., Dell'Isola (1982), Macedo et al (1978) and O'Brien (1976) have stated the possible roadblocks to VM studies. They are summarised in Table 6-4 and represented in the system which may be called at any stage.

5) Provision of information about interactions of building elements -- The system will also point out the interactions among the selections of building elements i.e., how the

Table 6-3 Psychological Reasons of Roadblocks (O'Brien, 1976)

- Fear of making a mistake or appearing to make a mistake.
- Unwillingness to change the accepted form.
- A desire to conform or adapt to standard patterns.
- Over-involvement with the standard conceptions of functions.
- Unwillingness to consider new approaches.
- Unwillingness to be considered rash or non-conservative.
- Unwillingness to appear to criticise, even constructively.
- Lack of confidence resulting from lack of knowledge.
- Overconfidence because of experience, however limited.
- Unwillingness to reject a previously workable solution.
- Fear of authority and/or distrust of associates.
- Unwillingness to be different.
- Desire for security.
- Difficulty in isolating the true functional requirements.
- Inability to distinguish between cause and effect.
- Inability to collect complete information.

selection of an element may influence the selections and subsequently costs of other elements. For instance, if the quality level of the building has been determined as prestigious, the selections of alternatives for other elements such as plan shape, external walling, architectural style, internal and external environment, and window design may be affected in order to achieve the quality level. The system will provide some suggestions on the selections of alternatives, but not fixed instructions. It is up to the user to make the final decisions on selecting suitable alternatives to achieve the functions required by the client of the project.

6) Suggestion of verb/noun combinations -- in CA, it is very important to think the project in functional terms, rather than in elemental terms. Therefore verb/noun combinations are often used to guide team members to think functionally. The system will provide some verb/nouns combinations to help users to describe functions;

Table 6-4 Possible Roadblocks During the CA/VA Study

Timing	- We don't have the time. - We're not ready for it yet. - It's too late to do anything like this. - It sounds okay, but we're not ready to progress it rapidly. - It sounds good, but we don't have time to implement.
Responsibility	- That's not our problem. - There is no money budgeted for this. - It might work, but it's not our responsibility
Quality	- It's too old-fashioned. - It is not good enough. - Somebody would have suggested it if it were any good.
Information	- We don't know anything about it. - You don't understand our problems. - Has anybody else ever tried it? - It has never been tried before. - We have never done it before. - We tried that approach before, and it didn't work. - It might work for someone else, but our problem is unique.
Practicality	- The risk is too great. - Let's be practical. - What will the customers think? - We'll be a laughing stock. - It looks like hell. - Let's get back to reality. - It's a good idea, but it would never work here. - We tried that before, but it doesn't work.
Management/ Policies	- It's against company policy. - Let's assign it to a committee. - It would be too hard to administer. - It would mean too much paperwork. - It will make our present system obsolete. - It may be okay, but management will never buy it. - Management may agree, but the union would be against it.
Excuses or Objections	- It won't work. - It needs more study. - You are wasting your time.

The following are the possible verbs/nouns combinations suggested by the system, users may use their own words not included in the list.

POSSIBLE VERB/NOUN COMBINATIONS:

support weight	reduce sound	attract users
transmit load	reduce losses	identify items
enclose space	collect heat	improveappearance
conduct current	divide space	enhance product
condition space	exclude elements	satisfy owner
protect people	move weight	allocate space

7) Explanation of key glossaries -- It has been found that the same words may have different meanings in different projects analysed by different persons. So it is necessary to have an explanation of those words being used in a CA, otherwise misunderstanding might happen during a consultation with the system.

8) User-friendly interface -- with a well-designed interface, the user can easily modify and adjust system assumptions for the major functions as well as functions in detail levels, until they are appropriate for the specific office building being analysed. The user can add major functions which s/he thinks suitable for his/her particular project, or delete some functions that are suggested by the system.

The user can then modify the functions suggested by the system through adding, deducting or recovering functions. Instead of repeatedly asking the same questions such as: "Do you think this diagram is appropriate for your specific project or not?", "Do you want to deduct some functions that are not appropriate to your project?", "Do you want to add some functions which, based on your own experience, are unique to this project?", the system provides a menu with the four options as shown above to simplify the modifying process.

With the help of the above facilities, the end user (who has large amounts of design expertise) may gradually develop an appropriate CFD with a variety of alternatives to achieve each function required by the client for the specific project.

6.2.3 Evaluation of Alternative Solutions

As far as the evaluation of alternative solutions is concerned, there are many occasions when there is no clear decision available and the matter rests on subjective judgement. In such cases the following facilities will be used to expedite the selection of alternatives.

(1) Weighted Evaluation

Simple decisions involving analysis of one or two criteria and a "yes/no" or "either/or" answer can be reached quite easily. More frequently, decisions require an analysis of several alternatives against a number of criteria, each having a certain degree of importance (weight) depending on the situations of a project. Weighted evaluation is one of the supporting tools for this kind of complex decision-making problem, which can facilitate the selection of alternatives against a number of criteria. It is also known as the "Evaluation Grid" in ICI Engineering Department.

In practice, the criteria for a project may include some of the following:

a. initial cost,
b. energy reduction,
c. maintenance cost,
d. performance,
e. aesthetics,
f. flexibility
g. re-design time/cost
h. building cost impact
i. *construction time*
j. others

The user can then select appropriate criteria from the suggested list. For different functions the criteria can be different. The criteria for evaluating alternatives for function "limit speed", for instance, include: a) initial cost, b) energy reduction, c) maintenance cost, d) performance, e) aesthetics, and f) flexibility. An analysis matrix is used to compare the relative importance among those selected criteria, so that weights can be allocated to each criterion. Based on the total satisfying factors of those alternatives, the best solution can be chosen for detailed analysis. Figure 6-9 shows the process of ranking the criteria and selecting the best alternative by giving satisfying factors to each alternative against each criterion. (For details about the weighted evaluation method, please refer to Dell'Isola's book, 1982).

The number of alternatives generated for each function can be considerably large, and it is sometimes difficult to judge which alternative is the best solely based on the satisfying factor. In this case, the first three alternatives should be chosen to undertake further Life Cycle Costing Analysis, so that the best solution can be chosen and analysed further into development proposals, based on the quantitative figures.

(2) Quick Cost Estimate

Occasionally, cost figures are not used during a CA study in ICI, due to the difficulty in obtaining an accurate cost estimate at the concept design stage. Recent CA studies undertaken in ICI have taken costs as an important factor in addition to functions. The ELSIE Budget Module, which has been proved to be reliable in giving a quick cost estimate for office buildings at very early design stage, is frequently used. A special interface between the CA Module and the ELSIE Budget Module is therefore designed to compare the costs factors among different alternatives. This facility is

	b	c	d	e	f
a	a-3	a-3	a-3	a-4	a-2
	b	b-4	b-2	b-3	b-4
		c	c-3	c-2	c-3
			d	d-3	d-3
				e	e-3
					f

How important

4- Major preference
3- Medium preference
2- Minor preference
1- Slight, no preference, One point each (Letter/Letter)

criteria	raw score	weight
a. initial cost	15	10
b. energy reduction	13	9
c. maintenance cost	8	5
d. performance	6	4
e. aesthetics	3	2
f. flexibility	1	1

	a/10	b/9	c/5	d/4	e/2	f/1	Total
S1	4	3	2	3	3	4	99
S2	5	1	2	4	2	3	92
S3	3	2	3	4	4	1	83

Excellent-5 Very good-4 Good-3 Fair-2 Poor-1

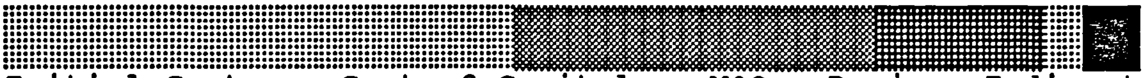
Figure 6-9 Criteria Ranking and Alternative Selection Processes

especially useful when several alternatives have similar advantages and disadvantages in achieving a function. The details about the integration between the CA Module and the ELSIE Budget Module are described later in Section 6.2.6.

(3) Life Cycle Cost (LCC) Analysis

The LCC analysis is a valuable tool for comparative analysis of design alternatives.

Instead of merely considering the initial cost of a building, it takes the overall costs of a building project over its life-span into accounts including costs of acquisition, maintenance, operation, alterations, and where applicable disposal. It can therefore give a more reasonable and reliable comparison. The importance of considering the LCC of office projects can be justified by analysing the breaking down of the total cost of ownership for a typical office building. As shown below, the initial cost represents only 43% of the total cost of ownership.



In a survey conducted by Picken (1990), respondents indicated that VM provides a vehicle for bringing LCC into the design process in an effective manner, and also provides for the consideration of intangibles. The survey also indicated that there is a desire and some constraints on the use and development of LCC techniques. Picken suggests that the use of LCC as a natural process of professional development and advancement would extend and improve their advisory services and provide clients with buildings whose design has been subjected to rigorous analysis.

A number of researchers (e.g., Langston, 1990; Betts and McGeorge, 1990; Heath et al, 1990) have indicated the performance problems in the existing LCC appraisals. Heath et al (1990), for instance, pointed three possible problems: 1) errors occurring in the normal physical life prediction for the component; 2) wrong assumptions being made with regard to the economic life of the project itself; 3) the effect of abnormal physical life resulting from malpractice or inefficiency arising during the production stage of the building. To address each of the problems fully is beyond the scope of the research currently undertaken. It was assumed that the users - project engineers and project managers - should possess the correct information concerning LCC data such as life spans of building elements or components. It would be unrealistic to expect a value specialist to possess this kind of detailed knowledge.

An LCC model is used in CAVA to compare alternative solutions and to choose the one with lowest LCC. As shown in Figure 6-10, costs considered in the LCC model include: initial capital cost, annual maintenance cost, operation cost, intermittent maintenance/alterations/replacement cost, sundries, running cost, additional tax allowance, salvage and residuals. The difficulty in building an LCC model is the lack of historical data, such as the life span of a facility, annual operation and maintenance cost, and alteration cost. This kind of data can be obtained in relevant literature.

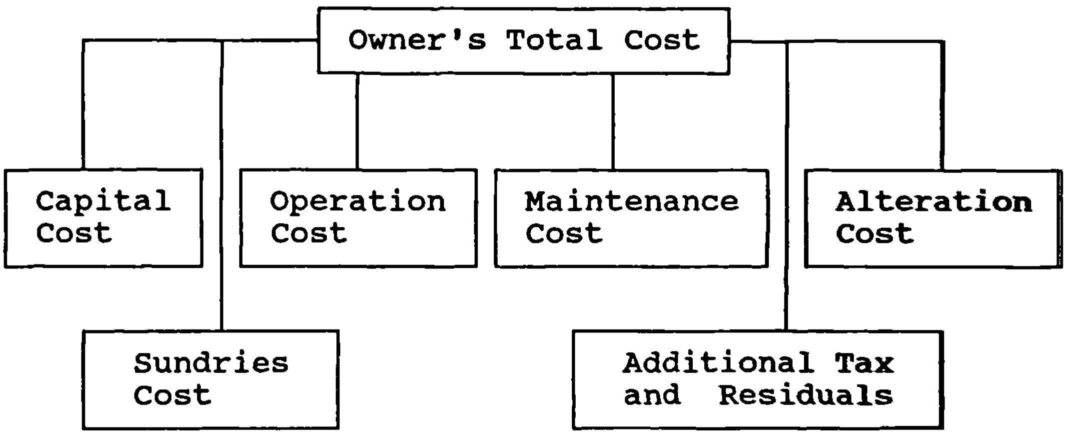


Figure 6-10 Model of Life Cycle Costing Analysis

As an example, the LCC analysis for an alternative is illustrated in Figure 6-11 through Figure 6-13. The figures in the following LCC analysis are purely used to illustrate the process of the analysis. The inflation rate for operation cost is 7%, for annual maintenance cost is 9%, for intermittent alteration/replacement is 8%. The LCC analysis for other alternatives will follow the same procedure, and their Net

Present Values or Annual Equivalent Values can be compared to select the one with lowest LCC. A sensitivity analysis can also be undertaken to observe how changes in the values of variables such as life span could affect the overall LCC results.

1) Operation Cost

Item	Cost
energy	4433
cleaning	3455
rates	345
insurances	3453
security & health	345
staff	45345
administration	3455
land charges	34555
Total operations costs	95386
Net Present Value	4561153

2) Annual Maintenance Cost

Item	Cost
heat source	4566
space heating/air treatment	456
ventilating system	6654
electrical installation	4566
gas installation	4566
lift installation	6788
Total maintenance costs	27596
Net Present Value	1123980

Figure 6-11 The LCC Analysis -- Operation Cost & Annual Maintenance Cost

3) Intermittent Maintenance/Replacement/Alterations Cost

Item	Interval	Cost	Present Value
plumbing & sanitary services	30	2344	7196
heat source	40	3455	15415
space heating & air treatment	35	2344	8673
ventilating system	50	4565	29601
electrical installation	50	6577	42647
gas installation	35	4456	16491
lift installation	45	3543	19057
Total Net Present Value			139081

Figure 6-12 The LCC Analysis -- Maintenance/Replacement/Alteration Cost

6.2.4 Report Generation on Conceptual Analysis

With the assistance of the above facilities, a final CFD with the best alternatives of achieving each required function can be produced. A clear, specific and precise picture of the project definition is therefore available to those who have impacts on the scope of the project. A report summarising the analysis will be prepared at the

4) Life Cycle Cost Analysis

Items	Cost	Present Value
1. Capital Cost	1953088	
2a. Operation Costs	95386	4561153
2b. Maintenance Costs(annual)	27596	1123980
2c. Intermittent M/R/A Costs		139081
2d. Sundries	23444	1322318
2. Running Cost (a+b+c+d)		7146532
3. Additional Tax Allowances	34555	1949015
4. Salvage and Residuals	23445	1322375
Total Net Present Value of LCC		12371011
Annual Equivalent Value Of LCC		219331

Figure 6-13 The LCC Analysis -- Net Present Value & Annual Equivalent Value

end of consultation. It includes participants of the study, functions specified for the project during the study, alternatives generated and the alternative evaluation processes (e.g., weighted evaluation).

6.2.5 Knowledge Refinement in the CA Module

It is impossible for a value consultant to possess specialised knowledge about each project for which s/he consults. For each project being analyzed, what the consultant can do is to provide a generic structure to define a project, and it is up to the team to modify the structure, to generate alternatives which can perform same functions but with lower overall cost and to select the best alternative for each function. The consultant can accumulate his experience through his CA practices, i.e., s/he can refine his knowledge. Next time when s/he organises a CA on a similar project, s/he can provide some options to the team to stimulate their creative thinking. This process is usually done through the cooperation between the consultant and the team members from different disciplines.

A framework of knowledge refinement was designed in the system to assimilate new

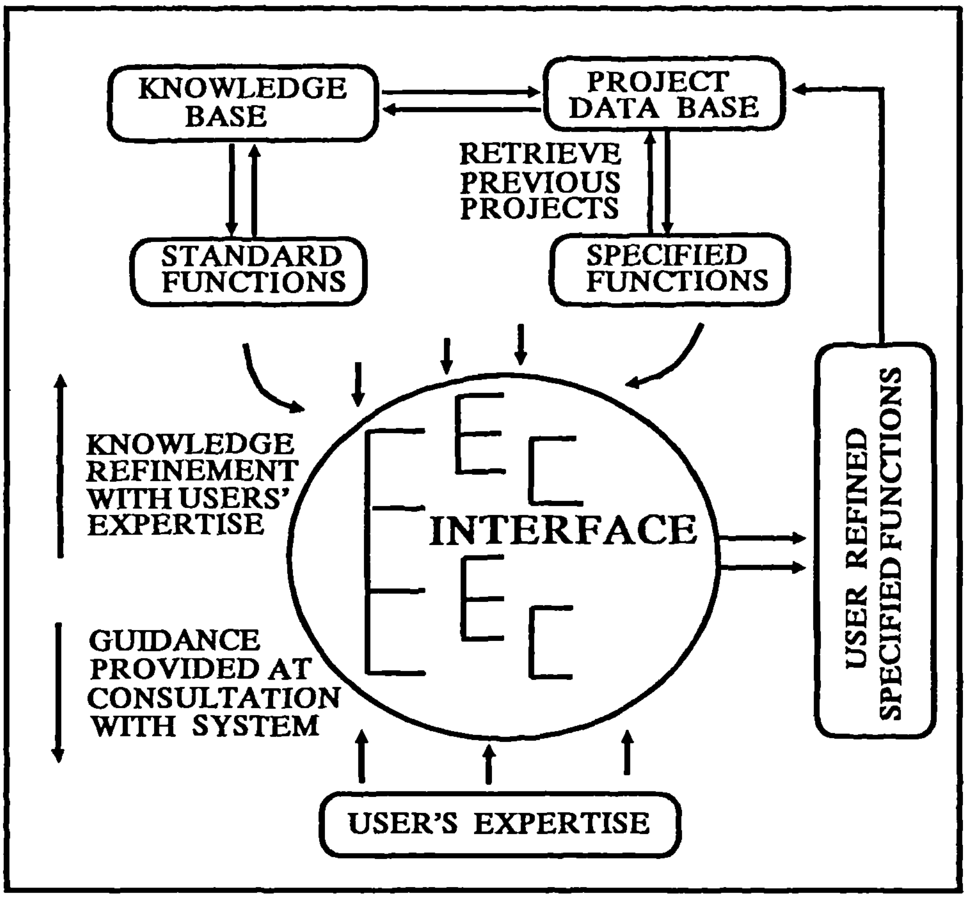


Figure 6-14 A Framework for Knowledge Refinement in CAVA

knowledge from the users during each consultation. The processes of knowledge refinement are diagrammatically shown on Figure 6-14. All information including functions and alternatives of achieving those functions etc. generated during each consultation with the system will be stored in a specially designed project database. This database can be retrieved by the system when requested by the users and the knowledge added during previous analyses will be displayed, so that when the system is used to analyze a similar project later, it can give advice from its own knowledge as well as from previous user's expertise. The user can input his/her expertise again which will constitute another source of knowledge. The knowledge base therefore can be gradually refined through its use, and begins to grow.

6.2.6 Integration of the CA Module and the ELSIE Budget Module

Once a project has been clearly defined through a CA, a cost estimate for the project should be available from the project definition. The cost information is essential in making the decisions on the selections of building alternatives. Before the commercial ELSIE system became available, the cost estimation was undertaken by consultancy firms outside ICI, and the process may take several weeks or even months before the information can reach the design and VM study team. The integration between the CA Module of CAVA and the ELSIE Budget Module is useful, because without it the information generated by the proposed system during a CA study has to be typed into the ELSIE Budget Module.

The benefits from the integration are two-fold: 1) it facilitates the process of costing the functions specified by the users; 2) it expedites the process of establishing building norms and allocating the extra project cost (above its norm building) against supporting functions. The facility of costing a CFD is potentially very beneficial in reducing the man-hours and the time required in producing the information that is likely to require high level Civil and Quantity Surveying thinking. ICI is therefore particularly interested in developing a method to allocate project cost to various functions on a CFD.

The interactions and differences between these two modules are shown in Figure 6-15. The decisions made during the CA study will provide a clear input of data to the ELSIE Budget Module. With the help of the budget module a realistic cost estimate of the project can be produced. Through a conversion of elemental costs to functional costs, the costs for accomplishing the functions previously defined can be determined.

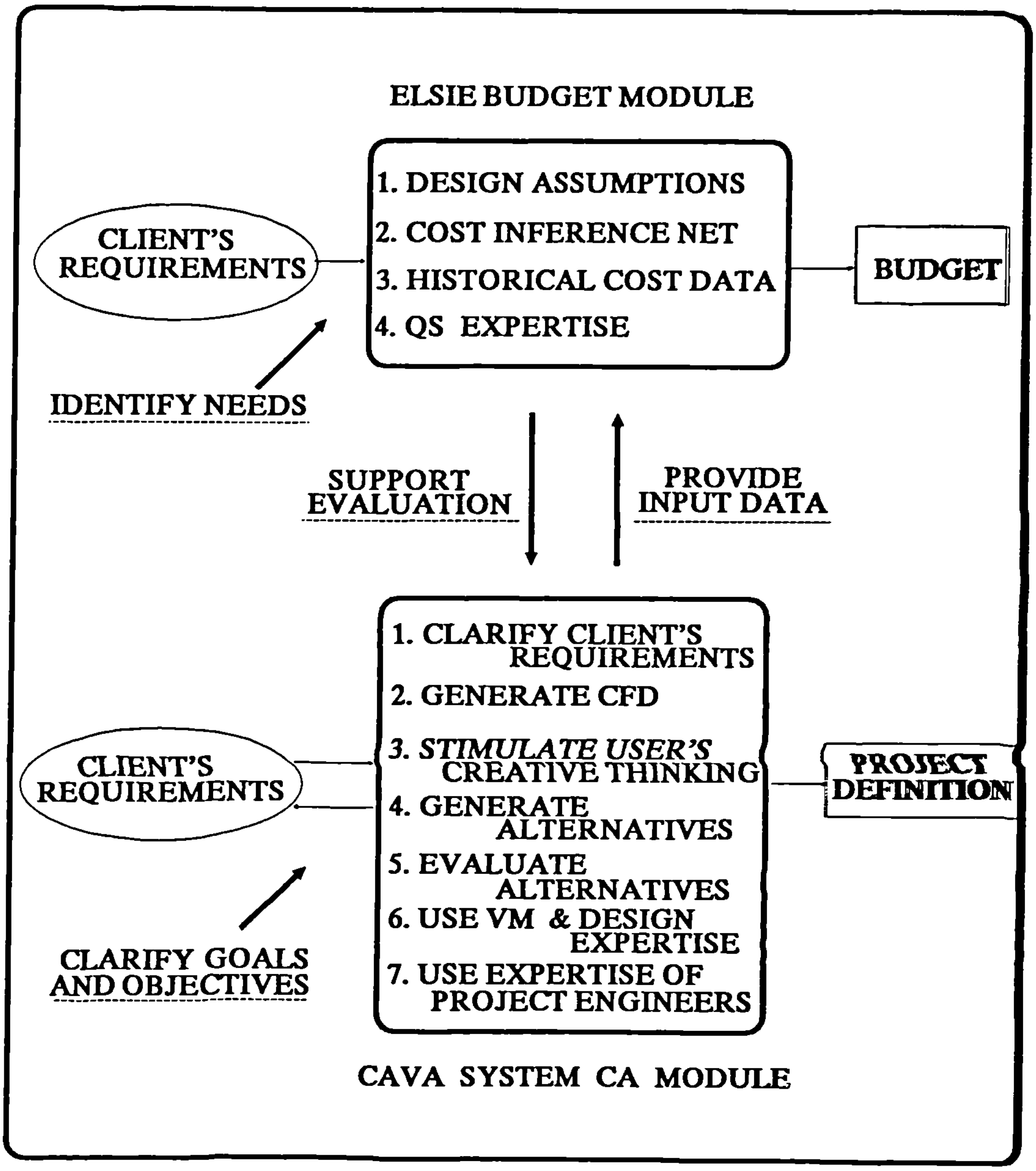


Figure 6-15 Interactions and Difference Between CAVA and ELSIE

Within the CAVA system, when appropriate alternatives for all the required functions have been properly selected, the information is stored in a project database - CAAPROJ.DB which has the same structure as the project database OV*PROJ.DB used by the ELSIE Budget Module (Here, "*" is a digital number representing the version of the system). Several assumptions that may be altered by the user will be made before the project database is used by the ELSIE system. For instance, the size of the building is assumed to be derived from clients' needs, and the use of the building is assumed to be industrial. The purpose of making these assumptions is to save user's time in answering questions which are usually unchanged for a specific organisation such as ICI.

Once all the relevant information has been stored into the caaproj.db database, the CAVA system then uses the "roll-out and roll-in" facilities provided by Leonardo to roll the current CAVA knowledge base out of memory and load in and execute the ELSIE Budget Module. The project database caaproj.db can be then used by the ELSIE Budget Module to give a quick cost estimate based on the information stored there. The cost estimate can feed back into the CA Module; and the user may wish to modify the project definition to adjust the costs. This cycle may be repeated several times until functions and costs of the project reach a satisfactory compromise. The project definition can then be used in the sketch design.

As introduced in Chapter 4, the overall cost for providing an office building can be divided into costs for basic functions and costs for supporting functions such as providing image, improving environment. The extra cost of a building above its norm building can be allocated against several supporting functions. By integrating with the ELSIE Budget Module, information concerning the costs of the project and the norm can be easily available, which may otherwise take much more time to collect. A comparison can therefore be made to allocate the extra cost against supporting functions. It is up to the user to make the final decision about whether the proposed design conceptualisation is justified and acceptable.

6.3 STRUCTURE OF THE VALUE ANALYSIS MODULE

The VA module is designed for use at the sketch design stage when some design work has been done. Because of the limited time of three years for the research, it was not possible to analyse all building elements in details; only several selected elements were analysed in detail. According to Kirk (1988), the following building elements are likely to be key cost issues and likely to have high saving potentials within an office building: (1) Heating, Ventilation and Air-Conditioning (HVAC); (2) Roofing System; (3) External Works. The purpose of selecting these three building elements is to take them as examples to show how the fully developed system could be used to guide end users through VA processes, and to illustrate what kind of knowledge or information is needed for further development.

It is known that the most time-consuming work in VA studies is to gather information concerning cost, performance and quality of building alternatives. The system is therefore developed to help the user in (a) Generating functional cost estimate, (b) Preparing base cost guidelines, (c) Undertaking LCC Analysis, (d) Suggesting alternatives to achieve required functions. The system leaves the task of creative thinking to the user, by providing several supporting facilities such as providing a checklist and introducing methods of creation.

A prototype VA Module coded in Leonardo (V3.24) has been built which will be refined gradually and eventually become a working system. Most of the knowledge within this module was obtained from books, papers, reports and documents on VM in building projects, because the traditional value analysis techniques were hardly used in recent studies in ICI and the majority of VM applications were Conceptual Analysis, rather than standard Value Analysis. The module was used to show what the expected system looks like, what type of facilities could be available in the fully developed system. As shown in Figure 6-16, the VA module currently includes the following functions:

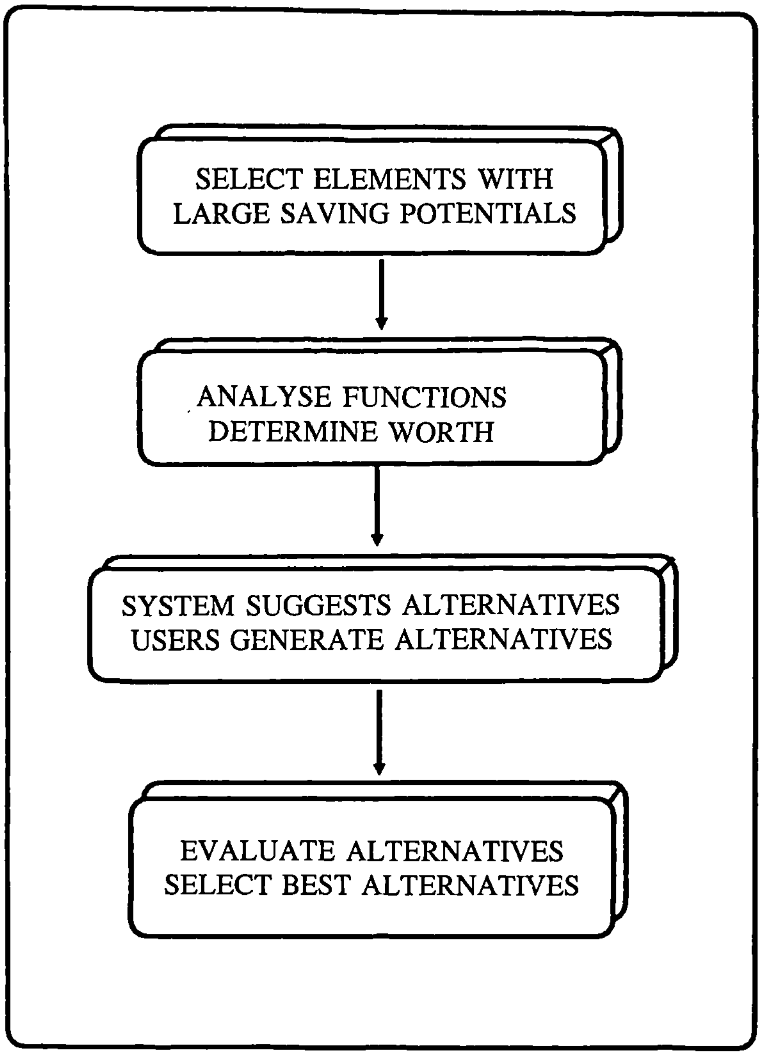


Figure 6-16 A Framework of the Value Analysis Module

(1) Select Elements with High Saving Potential

The VA Module accepts the estimate of the overall cost and elemental costs of a building project generated by the ELSIE Budget Module. When elemental costs are known, the system uses a cost model to compare estimated elemental costs with target elemental costs (A target cost represents the minimum cost of an element to perform required functions). Hence those elements with high saving potential can be located based on the ratio of estimated cost/target cost. A base figure for the ratio was set up as 3.0 in the system, and any elements with a ratio greater than 3.0 are considered as having high saving potentials and therefore selected for in-depth studies.

The figures for the target costs may vary in different projects, but the differences may hold true (Dell'Isola, 1982). As an example, the process of determining the target cost of external works is analysed here. Figure 6-17 is the inference net for external works, based on which the target cost of external works is derived. As the diagram suggested, the external works include four parts, i.e., site preparation, site improvement, site utilities and off-site works. The target cost of external works will be the sum of the costs of these four parts.

The cost for site preparation includes: cleaning, demolition and site earthwork. To estimate its target cost within certain constraints, the question series should be:

- Can you specify the soil conditions on your site? (common earth, hard clay, rock) (answer: hard clay)

- What is the average depth of excavation? (answer: 6 feet)

- Can you specify the site slope? (very severe -- slope >25%, severe -- 15% < slope < 25%, gentle -- 5% < slope <15%, even -- slope < 5%) (answer: severe)

Based on the answers to those questions, a target cost of £1.05/sf excavated area can be determined, which approximately represent the lowest cost to prepare site in the

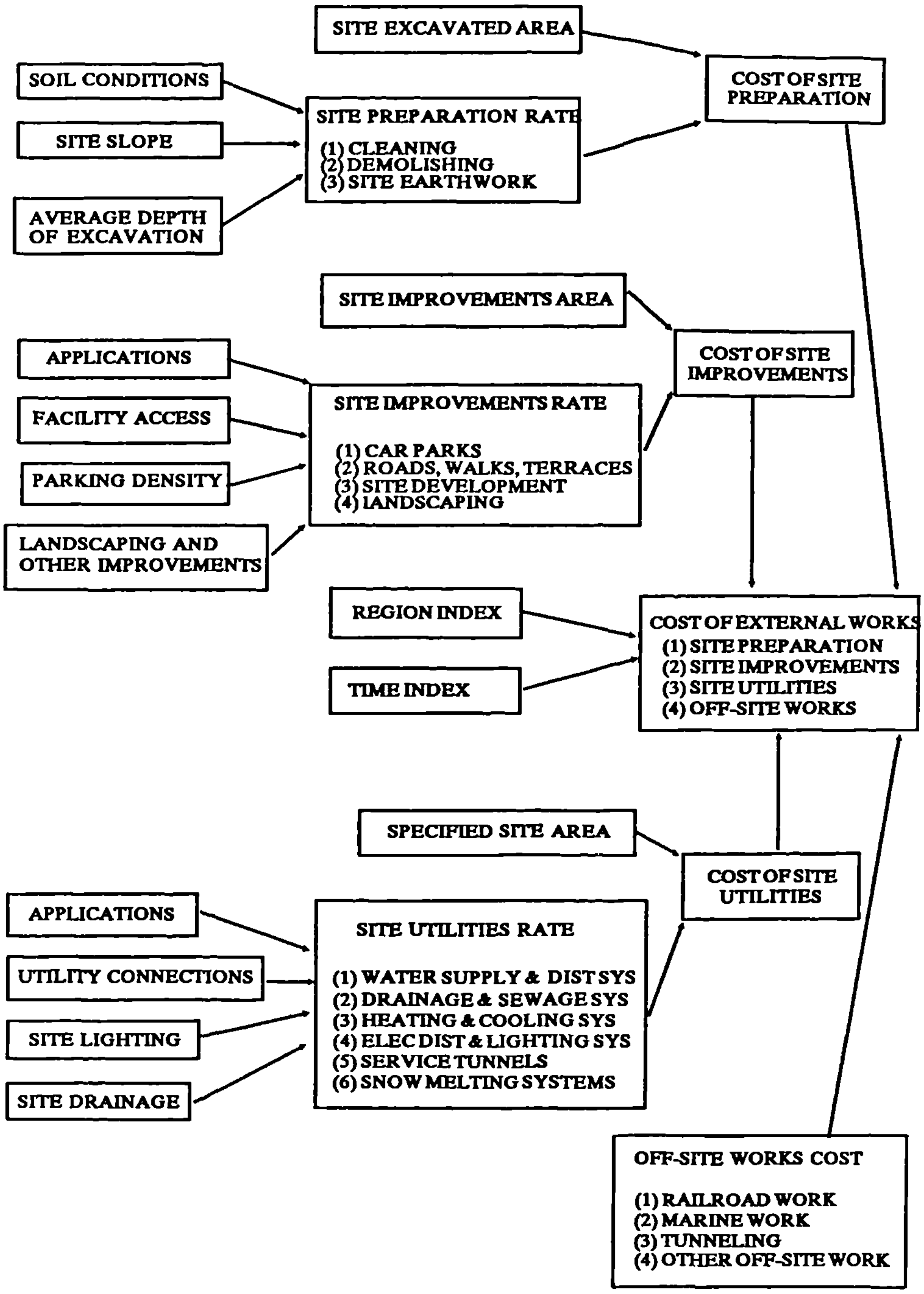


Figure 6-17 The Inference Net for External Works

given situations. The assumptions for this cost figure are: 1) minimum site area of 100,000 sf, add 10% for site less than 50,000 sf, deduct 10% for site over 2000,000 sf; 2) average ground cover and small trees, add 2-10% for dense heavy ground cover; 3) average earth haul distance, add 5-10% if the distance is over 2 miles.

The cost for site improvement includes: car parks, access roads/walks, landscaping and site development. Questions concerning the target cost of site improvement are:

- Can you specify the parking density on the site? (low if < 5% site area, average if <60% and > 5% site area, high if > 60% site area) (answer: average)

- How high are the requirements for landscaping and other improvements? (minimal, average, high) (answer: high)

- What kind of access facility is likely needed on the site? (simple, average, complex) (answer: simple)

- Which of the following descriptions best specifies the security requirements? (minimal, average, high) (answer: average)

The target cost of site improvement is then determined as £1.21/sf improved area. Here site area has been assumed as 100,000 sf, add 10-20% for areas smaller than specified, reduce 10-20% for areas larger than specified. It has also been assumed that no special requirements e.g., fountains have been made.

Site utilities include: water supply and distribution systems, drainage and sewage systems, heating and cooling systems, electrical distribution and lighting system, snow melting systems, service tunnels. Questions to be asked are:

- For what percentage of the site area do you want lighting facilities? (low if < 10% site area, average if > 10% and < 50%, high if > 50% and < 80%, very high if > 80%) (answer: 50%)

♦ To what extent are site drainage utilities needed? (minimal, moderate, extreme) (answer: extreme)

♦ Which of the following expression could best describe the difficulty concerning the connection with municipal drainage utilities? (simple, average, complex) (answer: simple)

Based on the answers to these questions and the required Gross Internal Floor Area of 150,000 sf, the target cost of site utilities can be determined as £2.17/sf site area. The figure contains allowances for utilities suited to the application. If areas are less than specified 100,000 sf, add 10-30%. Special systems, such as irrigation, waste treatment, and process utilities should be added separately.

Since the cost of off-site works is, to a large extent, random and subjective, it is not appropriate for the system to estimate. Instead, it should be provided by the user. By summarising the previous three cost issues and the cost for off-site works, the target cost for external works can be determined. A comparison between this target cost and the estimated elemental cost will be made to see whether there is a cost saving potential around the external works. If the ratio is over 3.0, it is likely to have a big saving potential, and therefore needs in-depth analysis.

(2) Analyse Functions and Determine Worth

After locating elements with high saving potential, the system analyses the functions of components of each selected element, and divides them into basic and secondary functions. Based on the VM expertise, historical cost data as well as latest technical information regarding new materials and methods, the functional worth of each component will be determined. The worth of each element will then be calculated by summing together the functional worth of its components. The functions of the building in this example were defined as: 1) house office activities, 2) process data, 3) improve image. The functions of major elements of typical office buildings have also been defined in the system, which are listed in Table 6-5. Table 6-6 lists all the components and their functions of the roofing system. The components and functions of the HVAC system are listed in Table 6-7.

Table 6-5 Function Analysis of Office Complex

#	Element	Function (verb/noun)		Kind
1.	Foundation	support	loads	use/basic
2.	Substructure	support	loads	use/basic
3.	Superstructure	support	loads	use/basic
4.	Exterior Closure	enclose	space	use/basic
		improve	image	aesthetic/basic
		exclude	elements	use/basic
5.	Roofing	enclose	space	use/basic
		exclude	elements	use/basic
6.	Int. Construction	divide	space	use/basic
		finish	space	aesthetic/basis
7.	Elevators	convey	objects	use/basic
8.	Plumbing	convey	fluids	use/basic
9.	HVAC	condition	space	use/basic
		circulate	air	aesthetic/basic
10.	Fire Protection	extinguish	fire	use/second
11.	Service	transmit	power	use/basic
12.	Lighting	illuminate	objects	use/basic

(3) Generate Alternative Solutions

Table 6-6 Components and Functions of the Roof System

Component	Function	Kind
Deck	Support Roofing	B
	Brace Beams	S
	Transfer Shears	S
Concrete	Provide Fire Protection	S
	Attenuate Sound	S
Edge Form	Contain Concrete	S
Spray on Fireproof	Protect Beam	RS
Concrete Finish	Prepare Surface	S
Structural Steel	Support Deck	B
Roof Covering	Control Elements	B
Rigid Insulation	Control Temperature	B
Building Felts	Control Leakage	B
Gravel	Protect Membrane	S
Asphalt	Bonds Felts	S
Sheet Metal	Provide Seal	S
Roof Walkway	Provide Access	S
Ceiling (Acoustic)	Provide Finish	S
	Absorb Noise	S

Table 6-7 Components and Functions of HVAC System

Component	Function	Kind
Package AC Unit	Cool Equipments	B
Duct Work	Distribute Air	S
Duct Installation	Retain Temperature	S
Diffuses & Grilles	Distribute Air	S
Fire Damper	Protect Structure	S
Pressure Relief Vent	Exhaust Air	S
Toilet Exhaust Fan	Exhaust Air	S
Electrical Supply	Provide Power	B
AC Unit Foundation	Support Unit	B
Fence	Enclose Unit	S
Humidifier	Add Moisture	B

By comparing the functional worth of each selected element with its estimated initial cost, elements with value mismatch (i.e., high ratio of estimated initial cost over functional worth) will be located. A list of alternative means that can achieve the required functions but with lower overall cost will then be suggested by the system.

Recent studies have shown that "researching materials, manufacturing processes, and design requirements to generate design alternatives is one of the most time-consuming efforts in a VM study" (Gibbs, 1989). The time spent on this creativity phase can be reduced significantly when the system is used to generate a number of useful ideas. The alternatives suggested by the system may not be the best solution, but can stimulate and widen the users' creative thinking. With the help provided by the system, the users can also generate alternatives themselves. Table 6-8 is an example of some alternatives generated for the HVAC system.

Table 6-8 Ideas Generated for The HVAC System

1. Roof-top VAV.
2. Adjustable speed.
3. Direct drive vane axle fan systems.
4. Air intakes/exhaust louvres through wall.
5. In the space fan coil units with separate ventilation system.
6. V.A.V. induction for perimeter heating.
7. Individual fan rooms for each floor.
8. V.A.V. re-heat for perimeter heating.
9. Closed loop water source heat pumps.
10. Combine AHU's with one roof-top air handler.
11. Through the wall AC pumps.
12. Through the wall heat pumps.
13. Ventilating glazing with under the floor returns.
14. Heat duct-work after V.A.V. boxes.
15. Spot cooling VA louvres.
16. Heat extract fixtures.
17. Radiant ceiling panels.
18. Locate plant to separate building.
19. Operate sash.
20. Task cooling with fan/coil units.
21. Gravity vent system for toilet rooms.
22. Use solid state starters.
23. Eliminate ceiling.
24. Use water storage of fire protection system for sink.
25. Floor supply plenum.

Alternatives for the parking facilities suggested by the system can as follows:

1) Locate the car park in an area with gentle slope -- Past experience shows that average slopes of up to 5% are the least expensive to develop; once the slope is over 5%, development costs jump rapidly in proportion to each 1% increase in slope;

2) Use an internal car park or hire a nearby car park -- If the site density is very high, and it is difficult to find a place with gentle slope, then an internal car park might be the best solution; If a nearby car park is available within two or three minutes by walking, hiring a car park might also be a good idea;

3) Locate the car park in a least vegetated area -- Based on past expertise, parking is best located in the least vegetated area of a site, so that extensive and expensive clearing and grubbing can be avoided;

4) Integrate the car park with drainage control -- The car park, if properly sited, can be used as an integral part of the drainage control system. This could be done by using the median areas between parking bays as water catching areas, metering run-off by the size of the drain inlets;

5) Use parking bays -- This can effectively reduce the area and per-space cost.

(4) Evaluate Alternative Solutions

Alternatives will be evaluated qualitatively and quantitatively. Qualitative evaluation can be obtained by ranking alternatives in terms of advantages and disadvantages. Table 6-9 is an example of comparing alternatives for the HVAC system listed in Table 6-8. Quantitative evaluation of alternatives can be undertaken by using the weighted evaluation technique and an LCC analysis (as introduced in Section 6.2.3) and obtaining user's judgement through a specially designed user-friendly interface.

Table 6-9 Comparison of Ideas for the HVAC System

Index No	Advantages	Disadvantages
1	less cost and space less architectural more flexible	maintenance
2	better turn DW control	higher cost
3	less cost than others less maintenance lighter weight	more noisy require acoustic
4	save space and cost	worse aesthetic
5	decrease size of AHU system possible energy saving	increase maintenance additional piping noisy
6	energy savings better repair circulation	higher PD higher cost
7	reduce shaft regiments individual floor control flexibility	increase maintenance more space and BHP longer piping more controls
8	eliminate perimeter	central system

(5) Conclude Consultation and Generate Report

A report including Value Management Change Proposals (VMCPs) will be provided at the end of the consultation.

6.4 SUMMARY AND CONCLUSIONS OF THIS CHAPTER

This chapter presents an overview of the system structure. The functionality of the system and the facilities provided by the system reflected the required features described in Chapter 5. The embodied two modules concentrate on the strategic use of the VM techniques in the design process. It is the first system of its kind which can provide intelligent support to the users in their VM studies.

Similar to the value specialists in organising a VM study, the system provides a number of facilities and a guidance to the user about the procedures of the study, to expedite the study process. The CFD generated by the system for the specific type of building under analysis provides a framework within which a number of techniques can be used to set up a clear project definition. It also reminds the designers not to overlook any important issues related to the design. The dynamic project database will keep the user informed by providing the latest updated CFD of the project under analysis. The facility of retrieving historical project information makes cross-fertilisation possible. The introduction to methods of creating a variety of alternative solutions and the use of a checklist for stimulating creativity facilitate the generation of alternatives. By informing the possible roadblocks of the study, system users can be well prepared to prevent them from happening. Possible interactions between building elements are notified by the system, which reflect the interdependency of building functions and the corresponding knock-on effects on building elements. The suggestions of verb/noun combinations and the explanation of glossary assist the users in describing functions and reduce the risk of misunderstanding.

The knowledge refinement framework embraced in the system extends the knowledge base from its original content to include valuable users' expertise. It also sheds some light on how a system can deal with open-ended problems. The integration of CAVA with the ELSIE Budget Module enables the users to convert the elemental costs into functional costs without difficulty. The allocation of extra project cost above a norm building against supporting functions presents a clear picture to the clients showing where his/her money was spent. Complex evaluations of alternative solutions against several criteria can be speeded up by using the models of weighted evaluation and LCC evaluation provided by the system. The user-friendly interfaces designed in the system stimulate users' interests in using the system and increase the acceptance of the system. With the aid of these facilities, clients' objectives and needs can be identified, requirements can be clarified, the project itself can be clearly defined.

The information generated by the CA module provides the basis for the VA studies on the same project. They can be passed into the VA module if required. The VA Module has clearly demonstrated the feasibility of representing the expertise in producing a reasonable target cost, a yardstick with which alternative solutions can be compared. Graphical analysis of the functional costs represented in the system simplifies the process of allocating building elements with high saving potentials.

CHAPTER 7. THE VERIFICATION AND VALIDATION OF CAVA

In previous chapters, the processes of modelling the expertise of the VM domain and developing a knowledge-based framework to facilitate VM implementation into the design of office buildings were introduced. The overall structure of the proposed system - CAVA was outlined and discussed. This chapter devotes special attentions to the Verification and Validation (V&V) of CAVA. Section 7.1 introduces widely-cited approaches in verifying and validating knowledge-based systems. Section 7.2 discusses the approach adopted in this research towards the V&V of CAVA. Section 7.3 and Section 7.4 illustrate the detailed methods and processes in verifying and validating CAVA which were undertaken during the research.

7.1 SYSTEM VERIFICATION AND VALIDATION (V&V)

Validation and Verification are formal methods employed to test whether computer programs will satisfy users' requirements. Since an expert system represents human knowledge and reasoning, the representation level must be justified through validation and verification. These two terms, however, are often confused with each other. Validation, as Gupta (1991) stated, is a black-box testing, designed to determine if the designed system meets users' needs, i.e., it refers to building the right system; whereas verification is a white-box testing, designed to determine if the system completely and accurately implements users' specifications, i.e., it refers to building the system right. In essence, verification ensures an expert system has been developed correctly and does not contain technical errors, while validation ensures the expert system satisfies its users' needs (Geissman and Schultz, 1988).

In spite of their significance, V&V have been a neglected topic in the AI research (Krishnamurthy et al, 1987). One of the major obstacles to the acceptance of expert systems is the lack of methodologies for validating and verifying expert systems. Unfortunately, the V&V of expert systems are hampered by the lack of stable documentation, inadequate methods to evaluate test results and a vicious circle (where nobody requires V&V of expert systems, nobody does it, and nobody learns how to do it) that hinders the developing of V&V methods (Green and Keyes, 1987).

7.1.1 Difficulties in System V&V

V&V is a difficult task for any computer program. It is the very complexity of traditional systems that has led to the development of the formal methodologies and thus to the potential for V&V (Schultz and Geissman, 1988). As with knowledge acquisition and representation, system V&V is described as a bottle-neck in the development of expert systems. Because of the technical, environmental, design and domain characteristics of expert systems, which distinguish KBSs from other computer-based systems, there are a number of unique problems concerning the V&V of expert systems. They are listed as follows:

1) No widely-acceptable methodology -- There is no widely-accepted, reliable method for evaluating the results of expert systems (Green & Keyes, 1987). Although some elements of V&V methodologies exist in design and development of expert systems, because of the infancy and fragmentation of the expert system industry, the large number of applications, design paradigms, and various development approaches, these elements have not yet been assembled and standardized (Geissman & Schultz, 1988).

2) The very complexity in system V&V -- V&V of expert systems are more complex than the V&V of conventional programs, since an extra effort of identifying and verifying the knowledge to be coded is necessary during the V&V exercise. The V&V process of expert systems involves two essential parts: the one which ascertains whether the knowledge acquired from the human experts is accurate, consistent and complete; and the one which ensures that the knowledge acquired in the acquisition stage is represented in the system consistently, accurately, and completely.

3) Lack of precise requirements specifications -- Green & Keyes (1987) argued that the success of system verification depends on the quality of the requirements specifications which should be at least unambiguous, complete, verifiable, consistent, modifiable, traceable, and usable in operations and maintenance. According to him, expert system requirements specifications are, however, often nonexistent, imprecise, or rapidly changing. This is partly due to the use of the widely-used rapid prototyping methodology in system design and development which generally leads to a lack of precise specifications (Taylor, 1989).

4) Difficulties in finding more knowledgeable experts -- It may be possible to find an expert who will devote some of his/her time to interviewing, debugging the knowledge base, and running through test cases. It is, however, much harder to find more experts who are willing to devote their valuable time to the validation process of the system, because they do not have the personal commitment to the project. Sometimes there could be no human expert who can evaluate the performance of the system, because the expert system may be operated in a domain where no human can do the job reliably or efficiently (Lehner, 1989). This can lead to further difficulties in system V&V. Even more experts are available, the approach of having experts in

the domain of the system to evaluate the results has several drawbacks (Yu et al, 1984), for example, the cost of validating a system by experts is often very high, and the bias of experts towards the use of computers may severely affect the results.

5) Anti-computer or pro-computer bias -- The V&V of computer systems may be biased by the evaluators either in favour of or against the use of computers. When judging the performance of a system, an expert biased against introducing computer-based systems may unfairly assess the system, or vice versa (O'Keefe et al, 1987). A possible solution to this obstacle is a Turing test, i.e., the results produced by human experts and the system for the same problem are provided to the evaluators without disclosing their identities (Marcot, 1987).

6) No correct answers available -- The evaluation of expert systems could be more difficult if there are no correct answers to the problem specified. Occasionally, a number of criteria are used to evaluate the performance of this kind of systems subjectively. Various criteria have been established for this purpose (Marcot, 1987; Hollnagel, 1989). One major problem associated with this subjective method is that different parties (e.g., developer and user) involved in the development of a system may not agree on the relevant importance of each criterion (Gaschnig et al, 1983).

7.1.2 Cited Approaches in System Verification

Verification can be viewed as a part of the larger process of knowledge acquisition; its objective is to discover and correct errors that arise during the process of eliciting and transferring expertise from a human expert to a computer system (Suwa et al, 1989). Most of the existing verification techniques may be classified as either consistency checking or completeness checking (Botten et al, 1989). These two issues however, as Cragun and Steudel (1987) described, "have been largely ignored in the flurry of hands-on learning and development, leading to expert systems with knowledge base errors and no safety factors for correctness".

According to Cragun and Steudel (1987), consistency checking is testing to show the system produces expected answers, which includes the checking for and reporting of built-in discrepancies, ambiguities, and redundancies in the rules of the knowledge base. Completeness, on the other hand, means that a knowledge base is prepared to respond to all possible situations that could arise within its domain. It is therefore a measure of robustness. Completeness checking is a debugging aid which finds logical cases that have not been considered, or in other words, missing rules. As outlined by Morell (1988), a system is inconsistent if it asserts something that is not true of the modelled domain; a system is incomplete if it lacks deductive capability.

Although the earliest reported verification approach can be traced back to 1976 (i.e., Davis, 1976), the majority of verification approaches (e.g., meta-knowledge, decision tables, and analytical hierarchy process) were developed in the late 1980's by a number of researchers (e.g., Suwa et al, 1984; Cragun and Steudel, 1987; Bahill et al, 1987). Table 7-1 summarises frequently cited verification approaches.

7.1.3 Cited Approaches in System Validation

The common concerns associated with validating an expert system include: (1) what to validate, (2) what to validate against, (3) what to validate with, and (4) how to undertake a validation.

Table 7-1 Cited Approaches in System Verification (After Botten et al, 1989)

APPROACH	REFERENCE	PROJECT NAME
Meta-Knowledge	Davis (1976) Nguyen et al (1987) Morell (1988) Stachowitz et al (1986)	TEIRESIAS CHECK EVA
Tables	Nguyen (1987) Nguyen et al (1987) Stachowitz et al (1986) Suwa et al (1982, 1984)	ART CHECK EVA
Decision Tables	Cragun & Steudel (1987) Stachowitz et al (1986)	ESC EVA
Deduction	Suwa et al (1982, 1984)	
Confidence Values	Parsaye (1988)	
Networks, Graphs, Matrices	Freeman(1985) Fenton & Kaposi (1987) Nguyen (1987) Nguyen et al (1987)	BEACON ARC CHECK
Analytical Hierarchy	Bahill et al (1987)	
Early cycle check	Fenton & Kaposi (1987) Parsaye (1988)	
Run-time checks	Davis (1976) Bahill et al (1987) Parsaye (1988)	TEIRESIAS

In terms of what to validate, the reasoning process, the intermediate results, and the final results i.e., conclusions, or all combinations of these three, can all be the candidates to be validated. In terms of what to validate against, as shown in Figure 7-1, there are two commonly-used approaches: against human performance or against known results. According to O'Keefe et al (1987), if possible, expert systems should be validated against expert performance. This is because although known results (when available) can provide a useful background for validation, they may be largely influenced by previous expert decisions. The following questions are often used in validating a system against human performance: "Are the results consistent with the results obtained from a domain expert?", "Is the reasoning process consistent with that used by the domain experts?", and "Are the questions asked and the explanations given by the system typical of that provided by the domain experts?".

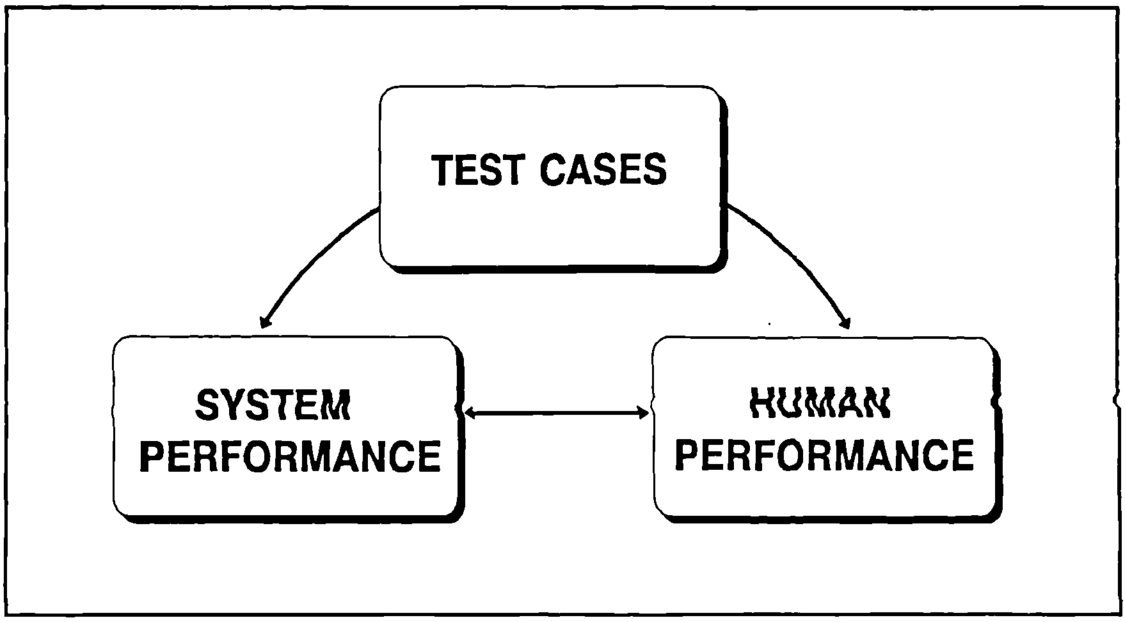


Figure 7-1 Approaches in Expert System Validation

In terms of what to validate with, Marcot (1987) suggested a number of criteria which may be used in testing and evaluating the validity of a knowledge base. They are: accuracy, adaptability, adequacy, appeal or usability, precision, availability, breadth, depth, face validity, technical and operational validity, generality, realism, reliability, resolution, robustness, sensitivity, turing test, usefulness, and wholeness. Discussions on the definitions of all these criteria would be outside the scope of the research. The explanations for the first five criteria are as shown in Table 7-2, explanations for others can be found in Marcot's paper (1987).

Expert systems can be validated qualitatively and quantitatively. Qualitative validation employs subjective comparisons of performance of the designed system, whereas quantitative validation employs statistical techniques to compare expert system

Table 7-2 Evaluation Criteria and Their Explanations

Accuracy	It means how well a system reflects reality. This can be done by comparing inferences made by rules with historic data, and observing the correctness of the outcome.
Adaptability	This means possibilities for future development and applications. This can be done by keeping I/O and control rules general; revising facts and rules when new information is available; and periodically reviewing the desirability of integrating with existing or proposed hardware or software systems. Should the system be self-modifying or context sensitive? Can it be customized for specific user needs?
Adequacy	This means the fraction of pertinent empirical observations that can be simulated. Establish a list of parameters (variables, conditions, and relations) that influence inference outcome, determine which to include in the rule sets.
Appeal or Usability	This means how well the knowledge base matches our intuition and stimulates thought. Appeal is a potentially key criterion for marketability. Test usability by assessing I/O friendliness relatively early in the development process. Test simulation and practicability on site in beta-development stage.
Precision	The capability of a model to replicate particular system parameters; also the number of significant figures used in numeric variables and computations. Ensure that all pertinent variations of parameters are represented in the rule base and facts. Experts numbers as floating point or real format as necessary; use double precision for calculations, especially those involving matrix or linear algebra calculations.

performance against either test cases or human experts. Where appropriate, qualitative and quantitative validation can be combined. It is considered important (e.g., O'keefe et al, 1987) that during the validation process, the performance of the system should not be simply categorised into right or wrong system. Rather they should be categorised in a range, such as ideal, acceptable, sub-optimal, and unacceptable. O'Keefe et al (1987) and Green et al (1987) have summarized the following methods of qualitative validation:

(1) Face Validation: It is a useful preliminary approach to validation. All concerned participants (such as project team members and potential system users), and the people who are knowledgeable about the application domain, will be invited to use their knowledge and intuition to subjectively compare the system performance against human expert performance. The face-value results obtained from running an expert system under a given set of test cases will be assessed with regard to a prescribed acceptable performance range.

(2) Predictive Validation: It requires using historic test cases with either known results or measures of human expert performance on those cases. A system is driven by inputting past data from the test cases, and its results are compared with corresponding results - either known results or those obtained from human experts.

(3) Field Test: This approach places the designed prototype expert system in the testing field, and seeks to perceive performance errors as they occur. It is only possible in non-critical applications where users can assess the performance of the system without any real danger.

(4) Turing Test: This method validates a system by asking human experts to evaluate the results provided by domain experts and the designed system without knowing the performer's identity. The objective of this test is to eliminate any prejudice pro or against using computers. The difference between this approach and the face validation approach is whether results to be evaluated have identities of their origins.

(5) Sensitivity Analysis: This is undertaken by changing the values of system variables and parameters over some range of interest and observing the effect upon the performance of the system. It could be especially useful where few or no test cases are available. According to O'Keefe et al (1987), "It is also highly appropriate for systems using uncertainty measures and requiring users to provide judgements for premise uncertainty".

(6) Module Validation: Also known as Subsystem Validation, this method requires the system be decomposed into subsystems, enabling the performance of each subsystem to be observed under given input data. In this approach, modules or subsystems are validated one at a time as they are developed.

(7) Visual Interaction: It is a validation method which provides visual animation of system performance and allows human experts to interact and alter parameters as necessary. This can be seen as an environment for interactive face validation, module validation, and sensibility analysis.

(8) Static Validation: As the name itself suggests, this is a method which simply asks the domain experts to examine the rules fabricated in the knowledge base of a system. The weaknesses of this method are: firstly, it can only be used in a small-scale knowledge base, since the number of alternative routes grows exponentially with the number of rules; secondly, because the majority of expert systems developed so far do not use standard English-like readable syntax to construct their rules, the experts may face great difficulties in reading the rules.

(9) Robustness Test: This is designed to test the robustness of a system by using a number of specially-designed hypothetical cases which reflect extreme conditions under which the system may be operated. The test cases should be prepared with care and their dimensions should be within the boundaries of the system.

(10) Requirements-Centred Test: This is a method proposed by Green et al (1987). It focuses on the requirements of the system under development, and it contains five basic tasks: requirements definition, knowledge base and supporting software verification (including requirements tracing and engineering analyses), case test preparation, test execution, and evaluation.

As suggested by O'Keefe et al (1987), quantitative validation methods generally fall into two categories: either a confidence interval is constructed for one or more measures to compare it subjectively with an acceptable performance range; or a formal test of hypotheses is employed to compare measurements with a predefined acceptable performance range. The hypotheses can be either H1: the expert system is valid for the acceptable performance range under the prescribed input domain, or H2: the expert system is invalid for the acceptable performance range under the prescribed input domain. The quantitative validation methods include:

(1) Paired T-Tests: this method is based on measuring the difference between expert system performance and human expert performance or known results, i.e., $D_i = X_i - Y_i$, where X_i are system results, and Y_i are either known results or results produced by human experts. If n test cases are used, there will be n observed differences

$D_1 \ldots D_n$. For the difference D_i, the following confidence interval can be produced:

$$\bar{d} \pm t_{n-1,\alpha/2} S_d / \sqrt{n}$$

where d is the mean difference, S_d is the standard deviation, and $t_{n-1,\alpha/2}$ is the value from the t distribution with n degrees of freedom. If zero lies in the confidence interval, then the hypothesis H1 is proved to be true; otherwise, hypothesis H2 will be true. This method is appropriate only when a system produces a single final result.

(2) Hotelling's One-Sample T^2 Test: Applying the paired t-test simultaneously to a number of final results is inappropriate, since the final results could be correlated (O'Keefe et al, 1987). To validate a multi-results system, the Hotelling's one-sample T^2 test should be used. This method observes the differences between the results generated by the system and the results generated by human experts, and determines the differences between corresponding k paired responses. Repeating this for different input values, k vectors of differences can be constructed. The one-sample T^2 test is then used to determine if the means of the difference vectors are significantly different from zero simultaneously or jointly.

(3) Simultaneous Confidence Intervals: To validate multi-response expert systems, simultaneous confidence intervals or joint confidence regions can be constructed for differences of paired responses. The confidence intervals or regions are usually compared with a prescribed acceptable performance range.

7.2 A PRAGMATIC STRATEGY TOWARDS V&V OF CAVA

In addition to the generic difficulties relating to the V&V of expert systems, there are several practical constraints which are unique to the system developed during the research. They are as follows:

(1) Since the main objective of the research is to explore whether and how VM knowledge and expertise could be elicited and implemented into a system, rather than to develop a commercial system, research efforts have been mainly devoted to the understanding of practical applications of VM, knowledge elicitation, and modelling of the domain expertise. The proportion of time allocated to system validation was therefore limited.

(2) As described in Chapter 6, unlike conventional expert systems, the results of the proposed system depend, to a large extent, on the interactions and cooperation of the system and the user(s). This is because the participants of VM studies are usually persons from several different disciplines; experts of the VM domain do not usually possess specific knowledge about the details of all the disciplines involved in the design of a building project. This unique characteristic has imposed difficulties on the validation of the system.

(3) Because of the difficulties of involving more experts to evaluate a system as described previously, and the confidentiality issues pertaining to the expertise included in the research, it is not possible to invite more experts from outside ICI Plc to participate in the validation process of the system.

(4) All historical cases provided by ICI Plc have been used in the formation of the proposed system (they include: a typical office building, a national computer centre, a research laboratory, two chemical plants, and a spillage control project). Therefore no extra historical test cases could be used to validate the system. Historical cases

available from other sources such as text books are not appropriate because of the personalised expertise implemented in the system, which can be quite different from other person's experience, as can their conclusions.

(5) As introduced in Chapter 3, the proposed system developed during the research is the only one of its kind in the VM domain. Although the author does not rule out the possibility that some similar systems may have been developed or still under development, little research work has been publicised throughout the literature of expert system applications. This lack of similar research has reduced the possibility of learning from others about their successful or failing experience, which obviously increases the difficulties of carrying out V&V on the system.

(6) During the processes of knowledge elicitation and representation, several gaps pertaining to the expertise within the VM domain have been found. As illustrated in Chapter 4, there is no appropriate method of allocating project cost against required functions. Unlike the conventional knowledge elicitation where the knowledge or expertise is possessed by the experts and acquired by the knowledge engineers, this research had an additional task of developing a formal method to remedy the gaps within the knowledge and expertise.

Because of these practical constraints of the research, the V&V methods introduced in Section 7.1.2 and Section 7.1.3 could not all be used for the proposed system. A compromise had to be made between the formality and extent required for V&V and the constraints imposed on the research. Since the system is not for commercial purposes (the V&V of a commercial system can be very costly), the formality and extent of the V&V should not be the same as commercial systems.

Approaches undertaken during the V&V of CAVA are summarised in Table 7-3. The detailed processes involved will be discussed in Section 7-3 and Section 7-4. Methods which were introduced in previous sections but not used in this research include: predicative validation, Turing test, visual interaction and static validation. The predictive validation was excluded because of constraints in finding test cases from the domain experts involved in the project. Turing test was not used because of the difficulties in finding more experts from outside ICI. Visual interaction was abandoned because of the limitations of the graphic facilities in Leonardo, which prohibit the visual animation of system performance. Static validation was not used because of the weakness of the method itself: it is designed to test small systems; experts can face great difficulties in reading the knowledge base.

Although there were a few software packages e.g., CHECK (Nguyen et al, 1987) and ESC (Cragun & Steudel, 1987) which could automatically undertake the verification task, it was decided not to use them, since most of them were at the research stage. They might prevent further understanding of the VM domain which, as a by-product, could be obtained through the manual verification process.

The V&V of CAVA were incorporated into the system development methodology throughout the development cycle of the proposed system. System performance was tested progressively as the knowledge base was gradually built through prototype formation, development and refinement. As Marcot (1987) argued, testing of KBSs should be integrated into the development-application cycle, and it is good programming practice to test a computer program in various ways throughout its development. This is especially true for system verification. As suggested by several researchers such as Botten et al (1989), the consistency and completeness of a knowledge base will be much improved if the verification process is incorporated routinely into the development of the system.

Table 7-3 SUMMARY OF APPROACHES IN V&V OF CAVA

I. THE VERIFICATION OF CAVA

1. Consistency Checking
   (1) Redundant Rules,
   (2) Conflicting Rules,
   (3) Subsumed Rules,
   (4) Unnecessary "if" Conditions,
   (5) Circular Chains, and
   (6) Safety Analysis and Sensitivity Analysis

2. Completeness Checking
   (1) Un-referenced Attribute Values,
   (2) Illegal Attribute Values,
   (3) Unrelated Conclusions,
   (4) Dead-End Goals and Dead-End "if" Conditions, and
   (5) Missing Rules (Using Decision Tables).

II. THE VALIDATION OF CAVA

1. Validation was integrated in the development process.
   (1) Frequent informal validation, e.g. meetings
   (2) Validation as knowledge base developed
   (3) Against criteria e.g. usability
2. Testing against expected performance features
   (1) Facilitate CA studies by using CFD structures
   (2) Provide functional cost information
   (3) Assist project definition
   (4) Enrich store of knowledge/expertise
   (5) Provide base cost guidelines
   (6) Provide tools for using supporting techniques
3. Face Validation By An Independent Value Specialist
4. Sensitivity Analysis of CAVA
5. Robustness Test, Field Test and Module Validation

7.3 APPROACHES TOWARDS THE VERIFICATION OF CAVA

7.3.1 Checking for Consistency

Consistency, according to O'Leary (1987), refers to the relationship between the information in the knowledge base and the ability of the inference engine to process the knowledge base in a consistent manner. In this sense, it can be categorised into static consistency and dynamic consistency. As distinguished by Morell (1988), a system is statically consistent if its initial knowledge base state is consistent with the modelled world; a system is dynamically consistent if the intermediate state of its knowledge base is consistent with the modelled world.

Static consistency in the knowledge base of the proposed system has been checked by a continual process of finding, removing or solving the following problems: (1) Redundant Rules, (2) Conflicting Rules, (3) Subsumed Rules, (4) Unnecessary "if" Conditions, and (5) Circular Chains.

(1) Checking for Redundant Rules: According to Nguyen et al (1987), a rule is redundant if it succeeds in the same situation and has the same conclusions as another rule. For example, the following two rules are redundant: R1 - if X is high, then cost will be high; R2 - if Y is high, then the cost will be high. Since X an Y represent variables that will be instantiated to a function required by the clients, one of the two rules is therefore redundant. As reported by Suwa et al (1982, 1984), although redundancy in a knowledge base does not necessarily cause logical problems, it might affect the efficiency of the system.

(2) Checking for Conflicting Rules: Two rules are conflicting if they succeed in the same situation (conditions) but with conflicting conclusions. For example, the following two rules are conflicting: R1 - if the image required for a building is high, then the cost of the building is high; R2 - if image required for a building, then the cost of the building is low.

(3) Checking for Subsumed Rules: One rule is subsumed by another if the two rules have the same conclusions, but one contains additional constraints on the situations in which it will succeed. For instance, consider the two rules that follow: R1 - if the image required for a building is high, and the performance level required is high, then the cost of the building is high; R2 - if image required for a building, then the cost of the building is high. In this case, rule 1 is subsumed by rule 2, because in rule 2 only a single condition is needed in order to reach the conclusion, whereas in rule 1, two conditions need to be matched in order to generate the same conclusion.

(4) Checking for Unnecessary "if" Conditions: Two rules contain unnecessary "if" conditions when they have the same conclusions, and the "if" condition in one rule is in conflict with an "if" condition in the other rule, and all other "if" conditions in the two rules are equivalent. For example, if both of the following two rules are true then they contain unnecessary "if" conditions: R1 - if the image required for a building is high, and the performance level required is high, then the cost of the building is high; whereas R2 - if image required for a building is high, and the performance level required is not high, then the cost of the building is high. The second condition in both rules is therefore unnecessary.

(5) Checking for Circular Chains: A set of rules are considered circular if the chaining of these rules in the set forms a cycle. For example, four rules (A, B, C, and D) form a rule set: the conclusions of A form the conditions of B, the conclusions of B form the conditions of C, the conclusions of C form the conditions of D, finally the conclusions of D form the conditions of A. These rules constitute a circular chain, i.e., A=>B=>C=>D=>A. A circular chain in a system can cause serious problems, because it potentially leads a system into a dead loop.

The proceeding checks were undertaken mainly by examining the knowledge base. They were facilitated through the use of Leonardo's knowledge base exporting facility, which enabled the developer to export rules and various objects in the knowledge base into a normal ASCII file. This ASCII file can be loaded into a word processing package or directly sent to a printer for a hard copy of the exported knowledge base. Since the exported knowledge base could be as large as the original knowledge base (the existing knowledge base of CAVA is about 750K Bytes in size), it is a painful job to simply examine the rules and frames printed on papers. The author found it is very helpful to use a good word processor such as WordPerfect, which has a good and fast spelling and searching facilities.

Static consistency deals with what the knowledge base *directly* asserts, whereas dynamic consistency deals with what the knowledge base *potentially* asserts. The dynamic consistency of the proposed system has been checked by running the system many times, observing the behaviour of the system, recording errors, and making corresponding modifications if necessary. Two methods were used in checking the dynamic consistency of the proposed system: safety analysis and sensitivity analysis. As suggested by Morell (1988), safety analysis verifies that a system does not violate prescribed safety conditions; whereas sensitivity analysis determines the system's response to slight modifications in the input or the knowledge base.

7.3.2 Checking for Completeness

The development of a knowledge-based system is an iterative process in which knowledge is acquired from human experts, then encoded, tested, added, changed, and refined by knowledge engineers to form a knowledge base and inference mechanism. This process often leaves gaps in the knowledge base which might be overlooked by both the knowledge engineers and the experts (Nguyen et al, 1987). As Morell (1988) suggested, incompleteness can arise from several sources, such as inadequate expressiveness of the model, inadequate knowledge base, and an inadequate inference mechanism. As the number of rules grows large, it may become impossible to check every possible route in the system.

The expressiveness of a system is the degree to which arbitrary units of knowledge from the application domain can be expressed via the facilities provided by the system (Morell, 1988). Since models are representations of reality (Brandon, 1988), inadequate expressiveness of the model would be inadequate in solving the problems in the real world. This expressive adequacy has been made possible by selecting the most appropriate representation mechanism via the selection of appropriate system development tools as described in Chapter 5, and the careful design of the human-computer interfaces of the proposed system.

The completeness check in the knowledge base of CAVA has been undertaken by frequently-examining the knowledge base and looking for (1) Un-referenced Attribute Values, (2) Illegal Attribute Values, (3) Unrelated Conclusions, (4) Dead-End Goals and Dead-End Conditions, (5) Missing Rules.

(1) Checking for Un-referenced Attribute Values: Un-referenced attribute values occur when some values in the set of possible values of an object's attribute are not covered by any rule's "if" conditions. A partially covered attribute can prohibit the system from attaining a conclusion or can cause it to make a wrong conclusion when an uncovered attribute value is encountered at run time. Leonardo 3.24 has a facility for pointing out attributes which are not used by any rule in the knowledge base.

(2) Checking for Illegal Attribute Values: An illegal attribute value occurs when a rule refers to an attribute value that is not in the set of legal values. This type of errors is often caused by spelling mistakes or misuses of characters such "-" and "_". Although seems minor, it may take much of the programmer's time in finding them.

(3) Checking for Unrelated Conclusions: Unreachable conclusions are the ones in a goal-driving production system, which neither match a goal, nor match an "if" condition of another rule. The rules which contain unreachable conclusions may therefore never be fired. For example, if a rule states that: "if the level_of_functions_required is high, then the cost_of_the_building is likely to be high", and only two options "basic" and "medium" are available in the frame level_of_functions_required, this rule will never be fired.

(4) Checking for Dead-End Goals and Dead-End Conditions: To achieve a goal in a goal-driven system, either the attributes of the goal must be askable (i.e., user provides needed information), or the goal must be matched by a conclusion of a rule in the rule sets applying to the goal. If neither of these requirements is satisfied, then the goal cannot be reached, i.e., it is a dead-end goal. Similarly, the conditions of a rule must either be able to obtain a value from the user directly, or be matched by the conclusions of a rule in the rule sets. Otherwise they will be called "dead-end conditions" which may never be used by any rule in the system.

(5) **Checking for Missing Rules**: The checking for missing rules is facilitated by the utilisation of simplified decision tables, a method of organising and documenting logic in a way that facilitates system inspection and analysis (Montalbano, 1974; Metzner & Barnes, 1977). Since the number of rules increases exponentially with the number of conditions for each factor, the checking for missing rules soon becomes a tedious and error-prone task. For example, in order to determine the target cost of a roofing system, four factors need to be considered: total roof area, roof openings, roof construction, and the required U-factor. If each factor has three options to vary, the total number of rules required to represent this knowledge will be 3*3*3*3=81!

As shown in Table 7-4, a modified decision table is used to expedite the process of formulating rules and checking completeness. The four cost-affecting factors are listed horizontally and vertically, each of them is represented by a letter i.e., A,B,C,D respectively, and the conditions for each factor are represented in numbers i.e., 1,2,3... (To simplify the illustration process, only two conditions are considered for factor C and D, the total combinations are 3*3*2*2=36). Every combination of the factors and conditions forms the "if" part of a rule in the knowledge base, e.g., "a1b1c1d1" means all factors have taken the first conditions as their value. The advantage of using this table is that all possible combinations of the factors and conditions are clearly displayed, all missing rules can be clearly identified.

All knowledge-based system development tools have their own defects, Leonardo has no exception. The integrated development and verification processes proved to be one of the most time-consuming tasks during the research. This was to a large extent due to the natural difficulties of these two integrated processes, and partially due to the weakness (or bugs) in the internal structure of Leonardo. For example, during the

Table 7-4 A Decision Table for Checking Missing Rules

		C1		C2	
		D1	D2	D1	D2
A1	B1	a1b1c1d1	a1b1c1d2	a1b1c2d1	a1b1c2d2
	B2	a1b2c1d1	a1b2c1d2	a1b2c2d1	a1b2c2d2
	B3	a1b3c1d1	a1b3c1d2	a1b3c2d1	a1b3c2d2
A2	B1	a2b1c1d1	a2b1c1d2	a2b1c2d1	a2b1c2d2
	B2	a2b2c1d1	a2b2c1d2	a2b2c2d1	a2b2c2d2
	B3	a2b3c1d1	a2b3c1d2	a2b3c2d1	a2b3c2d2
A3	B1	a3b1c1d1	a3b1c1d2	a3b1c2d1	a3b1c2d2
	B2	a3b2c1d1	a3b2c1d2	a3b2c2d1	a3b2c2d2
	B3	a3b3c1d1	a3b3c1d2	a3b3c2d1	a3b3c2d2

above processes, if an object (e.g. a procedural object) or a ruleset (containing a number of rules closely related to each other) has been checked several times without checking the complete knowledge base, it is very likely to corrupt the knowledge base as a whole, which could lead to a waste of time in hours or even days.

Another problem occurred during the research was "undefined" objects. This problem is probably specially associated with Leonardo, and is not mentioned in any other sources. In Leonardo, objects are categorised into the following types: text, real, list, procedure, screen, and class. If Leonardo can not determine the type of an object, the object will be treated as an undefined object. Theoretically, undefined objects should not cause any problem to the performance of a knowledge base. Practically, however, they could interfere the normal execution of a system. This could be an irritating problem, since every part of the knowledge base seems workable, but the results may not be what were originally expected. The author's experience is to define every object in the knowledge base either through normal rules or through dummy rules which are used purely for defining the types of objects.

7.4 APPROACHES TOWARDS THE VALIDATION OF CAVA

7.4.1 Validation as a Process of System Implementation

The validation of the proposed system was a continuous process during its design and development. As stated in Chapter 5, the implementation of the proposed system followed the phased development methodology. Validation was part of the initial stage of creating the prototype; performance of the system was tested progressively as the knowledge base was gradually developed.

During the design and development of the proposed system, the author has arranged regular meetings with the company involved in the research. Interim reports were periodically sent to the company and the latest developments of the proposed system were frequently demonstrated to the experts for comments and future directions. Modifications and adjustments to the systems were subsequently made according to the experts' opinions. The system presented to the company was considered by the experts as a satisfactory and very promising system.

For example, at an early stage of the development process, the system only allow the users to develop a CFD on a vertical basis, i.e. functions at the same level will be dealt with one by one, with no regard to the sub-functions each of them may have. Having examined the system, the experts pointed out this unusual way of constructing a CFD. The modified version of the system has therefore added another option of horizontal analysis, i.e. the sub-functions of a function will be dealt with earlier than those functions which are in the same level as the concerned function.

Since every expert system is unique in its intent and application, when testing a system, it is important to determine the specific domain within which the system should operate. The prototype should show a fair degree of usefulness to demonstrate the desirability of continuing work on a fully developed system. It was the initial demonstration of usefulness of the proposed system which attracted the attention of the experts in ICI. It was also the usefulness demonstrated from the proposed system, which kept the experts interested in and actively participated in the design, development, and validation of the system.

As stated earlier, two essential components of a system should be validated, i.e., the knowledge itself elicited from human experts and its representation in the proposed computer system. Although it was difficult to test the system by experts from outside ICI Plc (because of the confidentiality issues involved in the research, which are regulated by ICI), the knowledge and the expertise acquired from the domain experts and the methods developed during the research have been validated by several domain experts within the Institute of Value Management in the UK.

Previous discussions in Section 7.1.2 reveal that, knowledge based systems are often validated against a number of criteria. As Marcot (1987) argued, validation involves the more deceptively difficult task of insuring that the meaning and content of the rules meet some carefully defined criteria of adequacy. For example, to improve the usability of the system, it is necessary to check the spelling of the wordings appeared on the monitor. (This is because spelling errors are inevitable in a knowledge system, no matter how careful the programmers were during the programming process.)

Since the names of objects and the slots of frames in Leonardo are not standard English words, it is very difficult to check the spelling of the text in the knowledge base. The procedural language in Leonardo is similar to Fortran, the commands and instructions which form the programme are not English, neither are the variables defined. One useful method was used during the validation of the system. The author has retrieved a public domain software which can redirect the screen output from a printer to a normal ASCII file, which can easily be loaded into a word processing package. The spelling can then be easily checked. Any mis-spelling can be recorded and the original source codes can be traced and corrected with ease.

7.4.2 Testing Against Expected Performance Features

According to Durkin (1990), although small and simple systems can be validated through exhaustive testing, for any non-trivial system, this is often impractical, and a different approach must be taken. A number of researchers (e.g., Green and Keyes, 1987; Geissman and Schultz, 1988) have emphasised the importance of validating an expert system against its specifications and requirements. Since CAVA was designed to explore the feasibility of using a KBS to facilitate VM implementation, rather than for commercial purposes, there was no relevant requirements available. Because of the very similarity between system requirements and expected performance features, the validation was undertaken by comparing the performance features of the system (as previously described in Chapter 6 and the detailed illustration in the attached Appendix 5) with the performance characteristics expected by the users (as described earlier in Chapter 5). The following are the results revealed from the comparison:

Comparison of Expected and Actual Performance Features

Expected Performance Features	Actual Performance Features
1) The system should represent the knowledge and expertise of value consultants in organising CA studies by using the CFD structure as an intelligent checklist to clarify client's requirements and remind project engineers not to overlook every important issue concerning the design of office buildings.	- The CFD structure used by human experts has been successfully represented which can be modified by the user(s) through a user-friendly interface. - The procedural knowledge of organising CA studies was represented in the system which imitates the process organised by human value specialists. - Questions commonly prompted by human experts have also been represented in the system.
2) The system should be able to provide functional cost information and to suggest alternative ways to achieve required functions; The proposed system should be integrated with the ELSIE Budget Module to generate a quick cost estimate. Some assumptions should be made in order to avoid asking too many trivial questions.	- The system was successfully integrated with the ELSIE Budget Module, a quick cost estimate is therefore available (assumptions were made to avoid asking too many trivial questions). - Functional costs are generated by means of a number of virtual projects through the use of project database, based on the method developed during the research.
(3) The system should be able to identify clients' objectives, and clarify their requirements which are usually an intuitive expression. The system should help users in expanding their objectives into an overall CFD through a user-friendly interface. It should also allow users easily modify the contents of the hierarchical diagram provided by the system, and express their own opinions for achieving some of the functions.	- By asking a series of fundamental questions, the system helps users in identifying clients' objectives and clarifying their requirements, rather than simply accepts what they want. - It helps the user in expanding the objectives into an overall CFD through the following facilities: display current CFD, retrieve previous CA archives, suggest verb/noun combinations, explain glossary, provide checklist, inform methods of generating large amounts of creative ideas, and use a user-friendly interface. - It allows users to easily modify the contents of the hierarchical diagram, and express their options for achieving some functions. Facilities such as retrieving historical information were also available at this stage.

(4) The use of the system should enrich the store of knowledge and expertise in the VM domain. The system should consider the possibility of taking the user as an integral part of the system and letting users extend and customise the knowledge base.	- The framework of the system takes users as an integral part of the system and allows them to extend and customise the knowledge base. - Users of the system may add new knowledge and expertise to the system during system execution.
(5) The system should be able to provide guidelines for base costs (or target costs). A base cost is the minimum cost for providing the basic functional requirements.	- The system provides guidelines for base (target) costs, based on the methodology introduced by Dell'Isola (1982). Although the figures may vary with parameters in different projects, but the differences possibly hold true.
(6) The system should facilitate the applications of supporting techniques used in VM studies such as a creativity stimulating checklist, weighted evaluation and Life Cycle Cost (LCC) analysis.	- Various forms and calculation formulae were represented in the system which enable the system to facilitate the following supporting techniques commonly used in VM studies: brainstorming techniques (e.g., creativity stimulating checklist, methods of creating a variety of ideas), weighted evaluation (evaluation grid) technique, and Life Cycle Cost analysis.

7.4.3 A Face Validation by an Independent Value Specialist

As stated in Section 7.1.3, face validation is a very useful approach to validate a knowledge-based system. The advantages of having human experts who were not involved in the knowledge acquisition process to participate in the validation have been illustrated by a number of researchers (e.g., Brandon et al, 1988; Tuthil, 1990). Despite the difficulties of inviting external experts to undertake a face validation, an independent value specialist was invited to give an independent judgement on the performance of the system. A questionnaire was designed by the author for testing the performance of the system. The specialist was generally impressed by the system, and gave a very encouraging response. Table 7-5 shows all the questions and the comments given by the expert against each question.

The specialist pointed out two other important application areas where the proposed approaches in CAVA could be very useful and beneficial. They are hospitals and schools. This because hospitals and school buildings are to a large extent function-oriented; they have a pattern of repetition. The suggestions for future development of the proposed system include: facility for saving interim results, allowing users going back to previous questions, accepting answers that are not in the provided list of choices, changing a few objects from text objects to list objects so more than one options can be selected. These suggestions should be implemented in the future development of the proposed system (some of the existing defects are due to the limitations of the shell used).

7.4.4 The Sensitivity Analysis of CAVA

Sensitivity analysis was undertaken by gradually changing the value of a cost-affecting factor (while keeping the rest of the factors at their original values), and observing whether and how the changes affect the results produced by the system. This is to see whether the system has some abnormal behaviour. For example, when the requirements for quality increase, the costs for functions such as provide image should increase as well. It is informative and interesting to see how the cost of a specific functions responds to the changes in quality requirements.

Table 7-6 shows the costs of virtual projects when quality requirements change from 5.05 to 8.05 (These figures are given in accordance to the ELSIE budget module where quality is translated as a figure between 0 and 10) (Each virtual project is a project within

Table 7-5 Questionnaire and Comments Given By an Independent Expert

1. How satisfied are you generally with the performance of the system?

( ) Very satisfied (✓) Satisfied ( ) Reasonably satisfied ( ) Dissatisfied ( ) Very dissatisfied

2. How helpful do you find the Help facilities/Graphics Presentations given by the system?

(✓) Very helpful ( ) Helpful ( ) Reasonably helpful ( ) Unhelpful ( ) Very unhelpful

3. In what way(s) do you think the system can be potentially useful?

(✓) Individual Analysis (✓) Preliminary Analysis (✓) Study Assistant (✓) Training Device

4. What do you think of the benefits of using the system?

	SIG	MAJ	MED	SMA	TRI
Time Savings		✓			
Cost Savings	✓				
Efficiency Improvement		✓			
Increased Accessibility to Expertise			✓		
Training of Relevant Staff		✓			
Consistency in VM Studies		✓			
Provision of Standards Reports		✓			
Knowledge Refinement		✓			
SIG: Significant, MAJ: Major, MED: Medium, SMA: Small, TRI: Trivial					

5. To what extent the users of the system could make better decisions through the facilities provided in the proposed system?

(✓) Very helpful, ( ) Fairly Helpful, ( ) Helpful, ( ) Less Helpful, ( ) Not Helpful

6. To what extent do you think the inference paradigms (e.g. rules, frames, inheritance, procedures) used in the system are appropriate to the proposed problem?

( ) Highly appropriate, (✓) Appropriate, ( ) Generally appropriate, but need some improvement, ( ) Less appropriate ( ) Not appropriate.

7. To what extent do you think the representation of the knowledge and expertise in organising a CA by using the CFD is appropriate?

( ) Highly appropriate, (✓) Appropriate, ( ) Generally appropriate, but need some improvement, ( ) Less appropriate ( ) Not appropriate.

8. To what extent do you think the method of allocating the extra cost of a project (above its norm) to the supporting functions is appropriate?

(✓) Highly appropriate, ( ) Appropriate, ( ) Generally appropriate, but need some improvement, ( ) Less appropriate ( ) Not appropriate.

Table 7-5 Questionnaire and Comments Given By an Expert (Continued...)

9. Which of the following descriptions can best describe the facilities in solving the open-ended problem, i.e. new options from the users are accepted by the system?

( ) Outstanding ( ) Very useful, (✓) Useful, ( ) Reasonable, ( ) Trivial

10. Which of the following can best describe the user-interfaces (e.g., screen layout, ease of use, reasoning transparency) in the system?

(✓) Highly appropriate, ( ) Appropriate, ( ) Generally appropriate, but need some improvement, ( ) Less appropriate ( ) Not appropriate.

11. Which of the following can best describe the usefulness of the system?

( ) Very useful, (✓) Potentially Useful, ( ) Useful, ( ) Less useful, ( ) Not useful

12. How well do you think the system reflect the reality in facilitating CA/VA studies?

( ) Very Well, ( ) Well, (✓) Reasonable, ( ) Not very well, ( ) Poor

13. To what extent do you think the integration of CAVA with the ELSIE Budget Module is useful for providing functional cost information?

( ) Significant, (✓) Very useful, ( ) Useful, ( ) Reasonably, ( ) Not useful

14. How reliable do you think the proposed system is, in terms of the results generated by the system and the inference processes?

( ) Very Reliable, (✓) fairly Reliable ( ) Reliable, ( ) Not Very Reliable, ( ) Not Reliable

15. To what extent do you think the following facilities provided by the CA Module in facilitating the CA/VA studies are appropriate?

(1) Retrieval of historical project information
( ) Significant, (✓) Major, ( ) Medium, ( ) Small, ( ) Trivial

(2) Methods in generating large amounts of alternatives
( ) Significant, ( ) Major, (✓) Medium, ( ) Small, ( ) Trivial

(3) Information about possible roadblocks during brainstorming
( ) Significant, ( ) Major, (✓) Medium, ( ) Small, ( ) Trivial

(4) Provision of information about interactions of building elements
( ) Significant, (✓) Major, ( ) Medium, ( ) Small, ( ) Trivial

(5) Suggestion of verb/noun combinations
( ) Significant, ( ) Major, (✓) Medium, ( ) Small, ( ) Trivial

(6) Explanation of important glossaries
( ) Significant, (✓) Major, ( ) Medium, ( ) Small, ( ) Trivial

16. To what extent do you think the CA Module could facilitate the users in clarifying clients' requirements, by following the CA procedures and using the CFD structure?

( ) Significant, (✓) Major, ( ) Medium, ( ) Small, ( ) Trivial which only one cost-affecting factor in the original project is changed back to its norm, the rest of the factors are unchanged). Table 7-7 shows the cost differences between the initial design and the virtual projects. Table 7-8 shows the corresponding costs of supporting functions. Figure 7-2 illustrates that, when the requirement for quality change from 5.05 to 8.05, the costs of supporting functions change correspondingly within an expected range.

Table 7-6 The Costs of Virtual Projects When Quality Requirements Change

AA	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
5.05	10719	10719	10453	9747	10719	10719	10719	10719	10712	8668	10719
6.05	10991	10991	10726	9939	10991	10991	10991	10991	10985	8912	10991
7.05	11339	11339	11073	10207	11339	11339	11339	11339	11332	9156	11339
8.05	11613	11613	11347	10401	11613	11613	11613	11613	11606	9476	11613

Table 7-6 The Costs of Virtual Projects When Quality Requirements Change (Continued...)

C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21
10719	10677	9531	10719	10585	10601	10585	10706	10717	9162	10632
10991	10952	9788	10991	10865	10840	10852	10982	10985	9416	10900
11339	11302	10119	11339	11220	11154	11194	11334	11328	9745	11242
11613	11578	10377	11613	11502	11395	11463	11612	11597	10000	11512

Table 7-7 The Cost Differences Between Initial Design and Virtual Projects

AA	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
5.05	0	266	972	0	0	0	0	7	2051	0
6.05	0	265	1052	0	0	0	0	6	2079	0
7.05	0	266	1132	0	0	0	0	7	2183	0
8.05	0	266	1212	0	0	0	0	7	2137	0

Table 7-7 The Cost Differences Between Initial Design (Continued...)

D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21
0	42	1188	0	134	118	134	13	2	1557	87
0	39	1203	0	126	151	139	9	6	1575	91
0	37	1220	0	119	185	145	5	11	1594	97
0	35	1236	0	111	218	150	1	16	1613	101

Table 7-8 Sensitivity Analysis of Functional Costs of Supporting Functions

AA	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8	FC9	FC10
5.05	495	271	947	1559	116	1207	23	0	368	551
6.05	519	280	986	1641	118	1265	24	0	406	568
7.05	545	289	1061	1755	121	1325	26	0	446	586
8.05	576	301	1077	1828	124	1397	28	0	490	608

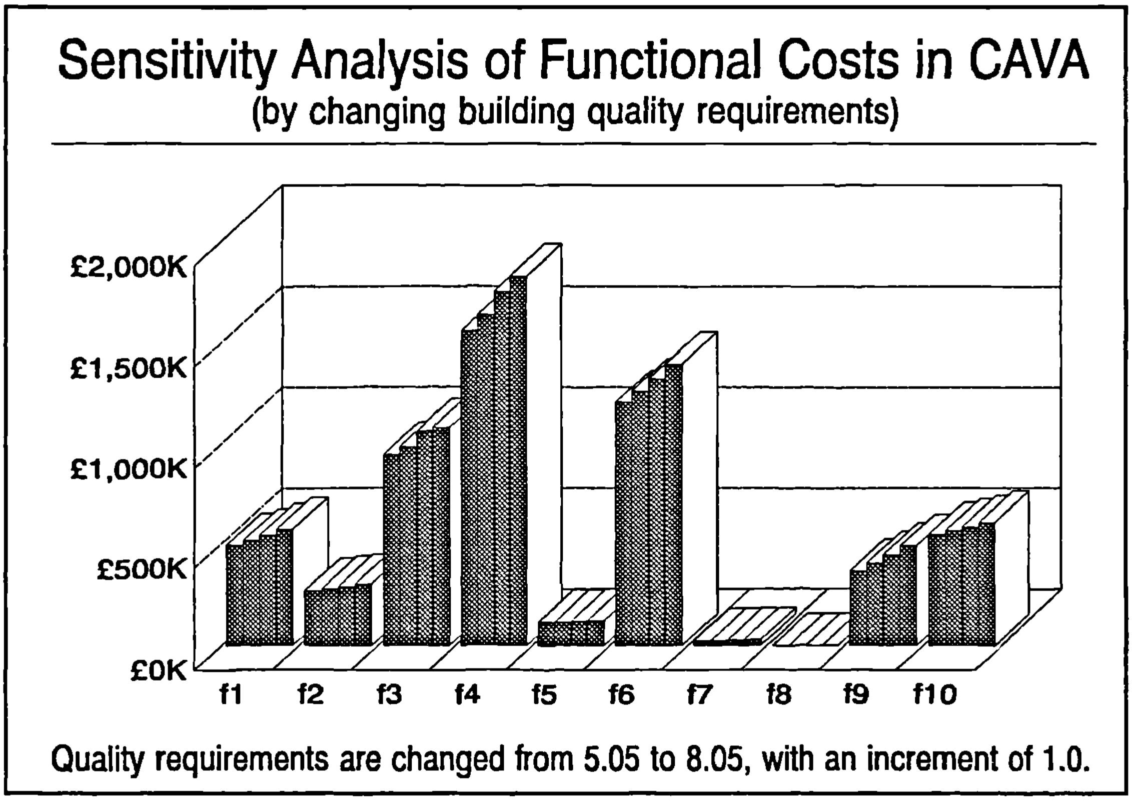


Figure 7-2 Sensitivity Analysis of Functional Costs in CAVA

7.4.5 Robustness Test, Field Test and Module Validation

The robustness test was undertaken by changing values of some variables to reflect the extreme conditions under which the system may be operated. These conditions include: (1) very simple and very complex buildings (in terms of functions required), (2) very small and very large projects (in terms of number of staff to be housed). To expedite the process of undertaking this test, the "playback" facility provided by Leonardo was used for this purpose. A playback file can be easily edited by using a text editor to reflect extreme conditions. A number of such files formed a suite of test cases for testing robustness of the system.

Since field validation has the advantage of testing the performance of a system in the real situation under which it was designed, a copy of CAVA and supporting tools were given to the organisation which participated in the research. To simplify the installation process, all relevant files (about 3.5M Bytes in size altogether) were compressed into a self-extracting file called cava.exe. Users of the system can simply copy the file into a sub-directory and type "cava", this compressed file will be automatically expanded. Because of the recession, however, the number of projects under design and development were very limited over the last two years. The projects initiated there were mainly research laboratories, chemical plants, rather than office buildings. The system has therefore not been used for testing purposes.

Since the proposed system is divided into two separate modules - the CA module and the VA module, module validation is possible. Methods used in validating each module are the same as the methods stated above. The author found that the division of the system into separate modules is very useful for both the implementation and the validation processes, since smaller modules are easy to manage within Leonardo where the system was embedded.

7.5 SUMMARY AND CONCLUSIONS OF THIS CHAPTER

This chapter has illustrated the nature and various widely-cited approaches in verifying and validating expert systems. Despite the constraints and difficulties in testing the proposed system, a practical approach has been adopted, within which a number of feasible methods have been used in verifying and validating the system. The verification was undertaken through consistency checking and completeness checking. The validation of the system was undertaken through regular meetings with the domain experts who have provided the knowledge in the system; comments from the experts were subsequently implemented into the system. A face validation was undertaken by inviting an independent specialist in the VM domain to judge the performance of the system, whose comments are very positive and encouraging. A sensitivity analysis was also conducted to observe the behaviour of the system; the results indicated that the system behaves properly. Other methods such as module validation, robustness test, and field test were also used in validating the proposed system. Because the practical constraints, the system has not been formally tested by a group of independent experts in the VM domain, such a formal validation would be useful for the further development of the system.

CHAPTER 8. CONCLUSIONS AND FUTURE DIRECTIONS

This final chapter of the thesis presents a summary of the approaches adopted in the research, comments concerning the proposed system, and the research findings in general. The usefulness and potential benefits exhibited by the system are discussed. Suggestions for future developments and alternative approaches in facilitating the implementation of VM in the design process are recommended.

8.1 THE BENEFITS FROM DEVELOPING AND USING CAVA

As argued by O'Leary (1987), one important factor used in determining the benefits of a system is how the system ultimately will be used. The system described in this thesis is not a commercial system, rather, it is a demonstration system designed to investigate the feasibility of developing a system to facilitate the implementation of VM in the design process. The usefulness and benefits exhibited by the proposed system (from developing and using the proposed expert system) are as follows:

1) Improvement in efficiency -- If the well-known 40-hour VM job plan is followed, a VM team would usually concentrate on a particular project for five days. Whereas with the assistance of the proposed system, the overall time spent on a study can be significantly reduced. Participants of the study can find more time to concentrate on more creative sections of the studies. If the system is used for an individual analysis, it takes about two hours and one hour respectively to run the CA module and the VA module, depending on the complexity of the project and the users' familiarity with the system. Even when the system is used for a preliminary analysis, because of the

awareness of the VM concepts and principles prior to a formal analysis, users can more actively participate in the study and concentrate on the already focused difficult tasks. It can save much time and work for the Value Specialists.

2) Increased accessibility of expertise -- Because of the limited number of qualified value specialists, it can be difficult to find them to analyse the design of a project. This often leads to a state where the initial design has to be considered as the best design which, in fact, sometimes could have large saving potentials. The proposed system will make the scarce expertise more widely available and easily accessible when it is required. This will reduce the risk of producing an abortive design (one which does not satisfy client's requirements) or expensive design (one which has large saving potentials), because no specialist is available to undertake a VM study on the project.

3) Provision of standard reports of VM studies -- The VM final report and the Value Management Change Proposals (VMCPs) provided by the system will be clearly organised in a standard format. The report which is prepared based on this standard format is valuable historical VM data in succeeding VM studies, since various formats used by different experts for similar problems may cause political, support, reliability and other problems, such as conflicts and inefficiencies.

4) Reduction of the cost for VM studies -- The cost for a VM study varies from project to project. According to Dell'Isola (1982), it is usually 0.5 % of the project cost. This amount can be a large expense when the project cost is relatively high. Because of the increased efficiency brought about by using the system, the time spent on a project can be reduced, as can the cost. Alternatively, the time spent on a study

could be virtually unchanged, but a larger proportion of time will be available for creative tasks. The results can be justified by the enhanced value of the project. The cost of running an expert system will be much smaller than the cost of the VM team.

5) Refinement of knowledge -- Throughout the processes of designing and developing the system, especially the knowledge acquisition process, the knowledge or expertise used by the Value Specialists can be refined. Gaps in the expertise can be highlighted during the development of an expert system (Brandon, 1988). The use of the system can also enrich the knowledge in the VM domain. Every time when the system is used, users' specialised expertise in their specific domains is a valuable input added to the system, which can be retrieved and presented in later applications.

6) Training of relevant staff -- Since VM is not widely used in the UK, most design staff usually know little about VM. By using the proposed expert system with fully developed help and explanation facilities, the system user can learn the concepts and principles of VM as well as some expertise of the human experts, so that they can more easily and actively participate in the VM programmes.

7) Consistency in VM studies -- Since subjective judgement plays a very important role in evaluating design alternatives, consistency is critical to the success of the process. The proposed system can provide more consistent results than that of an ordinary VM team for the following reasons: the knowledge and expertise within the knowledge base were elicited from a number of experienced specialists, the system can store more historical cost data in its database than human memory, and finally the system is not influenced by human emotions during an analysis.

8) Storage of valuable VM expertise -- The system can provide the facility to store the valuable VM expertise in the knowledge base which may otherwise be lost through staff movement or retirement. The knowledge can also be gradually extended as the users may put their expertise into the system when they use it.

8.2 CONCLUSIONS OF THE RESEARCH

As described in Chapter 1, Value Management as a structured methodology was established more than fifty years ago, and it has been used in the construction industry for more than three decades. The usefulness and effectiveness of this methodology have been demonstrated in various successful applications throughout the world. The increasing awareness of the tremendous potential and benefits of applying VM to construction projects has made some clients eager to apply this technique to their projects. As indicated by the recent survey conducted by the European Community (1991), in the next five years, the market of VM in the Community will have a 13% annual growth.

Despite the widely-accepted achievements obtained through the use of VM, there are still a number of obstacles in the UK which inhibit its further applications. The recently matured information technology, especially knowledge-based systems, has shed some light on the solutions to this problem. The research was therefore aiming at exploring the feasibility of building a knowledge-based system to facilitate VM implementation in the design stages of a building project.

This research began with an analysis of the current process of building design, various functional approaches towards design, and the concepts and principles of the VM methodology. The necessity and feasibility of implementing VM into the design process were subsequently identified and discussed, based on which a model of such implementation was also suggested.

As stated in Chapter 4, in attempting to explore the feasibility of applying a knowledge-based system to facilitate the implementation of VM into the design process, the action research approach was adopted, and a large organisation was selected to participate in the research. Several experts in that organisation were interviewed during the research, and their knowledge and expertise were elicited and analysed in detail, which formed the essential components of the knowledge base. In order to fill the gap of the existing expertise in function-cost analysis, a method of allocating the cost of an office building project was developed during the research, which was proved by several experts inside and outside the organisation. It also demonstrated the feasibility of providing the essential information of cost-per-required-function to the clients, and therefore supported the first hypothesis.

The second hypothesis was supported through the following processes. Firstly, as discussed in Chapter 5, the VM domain was carefully analysed against the criteria for selecting a domain suitable for successful KBS applications; each principle of the domain was examined to see how they could be properly implemented in a knowledge-based system, which can be seen as a preliminary proof of its suitability; Secondly, as described in Chapter 6, a workable system - CAVA, containing the essential expertise of facilitating a VM study was developed and frequently demonstrated to the experts for comments. It was regarded by the domain experts in the organisation as a successful and very promising system. The design and development of the proposed system benefited from the phased development methodology introduced by Brandon et al (1988).

Like all other sophisticated computer programs, there is a need for enhancements and future developments. The usefulness of the proposed system was discussed in relation to its performance features expected by the potential users, as discussed in Chapter 7. These features were considered essential in facilitating the implementation of VM into the design process. Because of the current and potential benefits of using CAVA, such as the increased accessibility to the scarce expertise and the improvement in efficiency, a large proportion of the users' time devoted to a VM study can be saved, which can be reallocated to the more creative tasks. In this sense, the system exhibited the potential of facilitating VM implementation in the design of office buildings; therefore the third hypothesis is supported. It seemed also true that through the aid of the proposed system, most of the obstacles can be to a certain extent removed.

The primary contribution of the research seems to be the thorough investigation of the feasibility of utilising KBSs to facilitate the implementation of VM in the design process. Until recently, VM studies were mainly a manual process with little computer assistance. There were a few conventional computing programs developed in the USA, France and Japan. The functions of those systems are however quite simple, and they can only support simple calculations and presentations. There is little literature which introduces how computer systems could help project designers in their design practices. When the research was started in 1988, the author was surprised by the lack of research work in the area of VM all over the world. Newly-established techniques such as Information Technology have not attracted enough attention from researchers in Value Management.

VM is a useful tool in coordinating relevant design disciplines and achieving clients' required functions with the lowest overall cost in the design and construction of a building project. The proposed system has successfully represented the knowledge and expertise in organising a CA study (e.g., constructing and modifying conceptual functional diagrams) possessed by the value specialists in ICI. The research has demonstrated that the use of KBSs in facilitating VM implementation into building design can significantly improve its efficiency and accessibility. Most of the obstacles which inhibit VM implementations could therefore be overcome. Having presented the above discussion, it seems possible to conclude that the building of a knowledge-based system (with VM domain knowledge) to support the decision-making processes in the early design stages of an office building, i.e., to support project engineers in clarifying project definitions, is feasible and worthwhile.

As Ferry and Brandon (1980) stated, there are possibly four attributes which are related to the expression of better cost information. They are: (1) provide cost information more quickly; (2) Provide more information so that a more informed decision can be made. (3) Provide more reliable cost information which will introduce more assurance into the decision-making process; and (4) Provide information at an earlier stage in the design process. The research presented in this thesis has made a step forward towards providing such kind of valuable information.

Despite the successful demonstration of implementing VM into the design process of office buildings through the aid of a knowledge-based system, the following issues are thought to be the limitations of the research:

(1) In VM theory, when a project is analysed during a VM study, the target costs of each item should be determined which will be compared with the estimated design costs or real design costs of the same items. Because the expertise in generating such target costs is not available in the selected organisation, a method - cost adjustment guidelines - introduced by Dell'Isola (1982) was used in the VAM, within which the target costs are determined based on VM specialists' experience.

(2) It is thought that the success of a VM study to a large extent depends on the creative thinking of team members from different disciplines. The commonly used method in generating large amounts of ideas is "brainstorming", which is defined as a problem-solving conference wherein each participant's thinking is stimulated by others in the group. It seems not possible for a computer to undertake such creative work, with regard to the current state of the art of computer technology. Instead of generating ideas by the system, the system uses VM specialists' knowledge and expertise in organising users' creative thinking and assists them in creating more alternatives by themselves.

(3) Because of the limited time of the research, the system can only give a list of suggested alternatives for certain functions which are based on the expertise of VM specialists and design engineers from different disciplines. It is not possible to give a complete list which covers all the possible alternatives to perform functions. As will be discussed in Section 8.2, in future development of the system, detailed expertise from different disciplines of the design engineers should be elicited.

(4) During the research, the author realised that, interpersonal communication is one of the key skills possessed by VA specialists. For example, a value specialist should

be sensitive to the needs of the VM team members, and should not allow them to become frustrated by going into fine details that could not be costed or would have no significant effect on the cost of the next higher level functions (Owen, 1974). As suggested by Owen, since there is a tremendous temptation either to let the team waive the rules of constructing function diagrams or alternatively to insist on the diagram being perfect, the coordinator must strive to achieve a balance between a large functional content on the diagram and the team's desire to shorten their thought process by identifying equipment in some areas. It proved difficult to represent such interpersonal skills in a computer system.

VM specialists do not usually possess specialised knowledge about each project for which they consult. It is important that the coordinator should not try to impose his own views, as opposed to questioning the team's ideas. According to Burgess, an expert in VM in ICI, the team will almost inevitably want to show the function in a slightly different pattern from that which the coordinator himself would have chosen. As Brandon (1990) argued, every expert system except the simplest can only be used as a support to the human activities rather than a replacement. The system described in this thesis does not intend to replace the human value specialists, rather, it attempts to provide assistance to the study by undertaking some of the tedious jobs and providing supporting techniques, so that the team members can concentrate on more strategic and creative issues.

8.3 FUTURE DIRECTIONS OF THE RESEARCH

8.3.1 Expansions for the CA Module

In the present system, only the value specialists' knowledge and expertise have been elicited and implemented in the CA Module. Since a CA programme usually involves a number of people from different disciplines, better results can only be obtained through the interactions and cooperation of these participants. It therefore seems necessary for the CA Module to include the knowledge of other relevant disciplines (e.g. architects' and structural engineers' knowledge) to improve its output. Since different knowledge might be represented in different schemes and different inference mechanisms, the most appropriate structure to organise the multi-disciplinary knowledge seems to be a blackboard architecture. A proposed system architecture for future expansion is illustrated in Figure 8-1.

The controller linked with the blackboard acts as an inference engine, it decides which module or technique should be loaded onto the blackboard. Most instructions given by the controller can be updated by the potential users - project managers who also perform the role of a controller, and form an integral part of the system. Since the system is designed to perform a similar role as a VM consultant, a special interface must be designed in the system to facilitate the communication between the system and the user. An interface definition module might be necessary for the system to understand information given by the user.

8.3.2 Expansions for the VA Module

The VA module has demonstrated the feasibility of determining the target costs of building elements. When applying this method to an office building as a whole, a cost estimation model should be included in the VA module to estimate the elemental costs of each element, based on the design works which have been done. The ELSIE

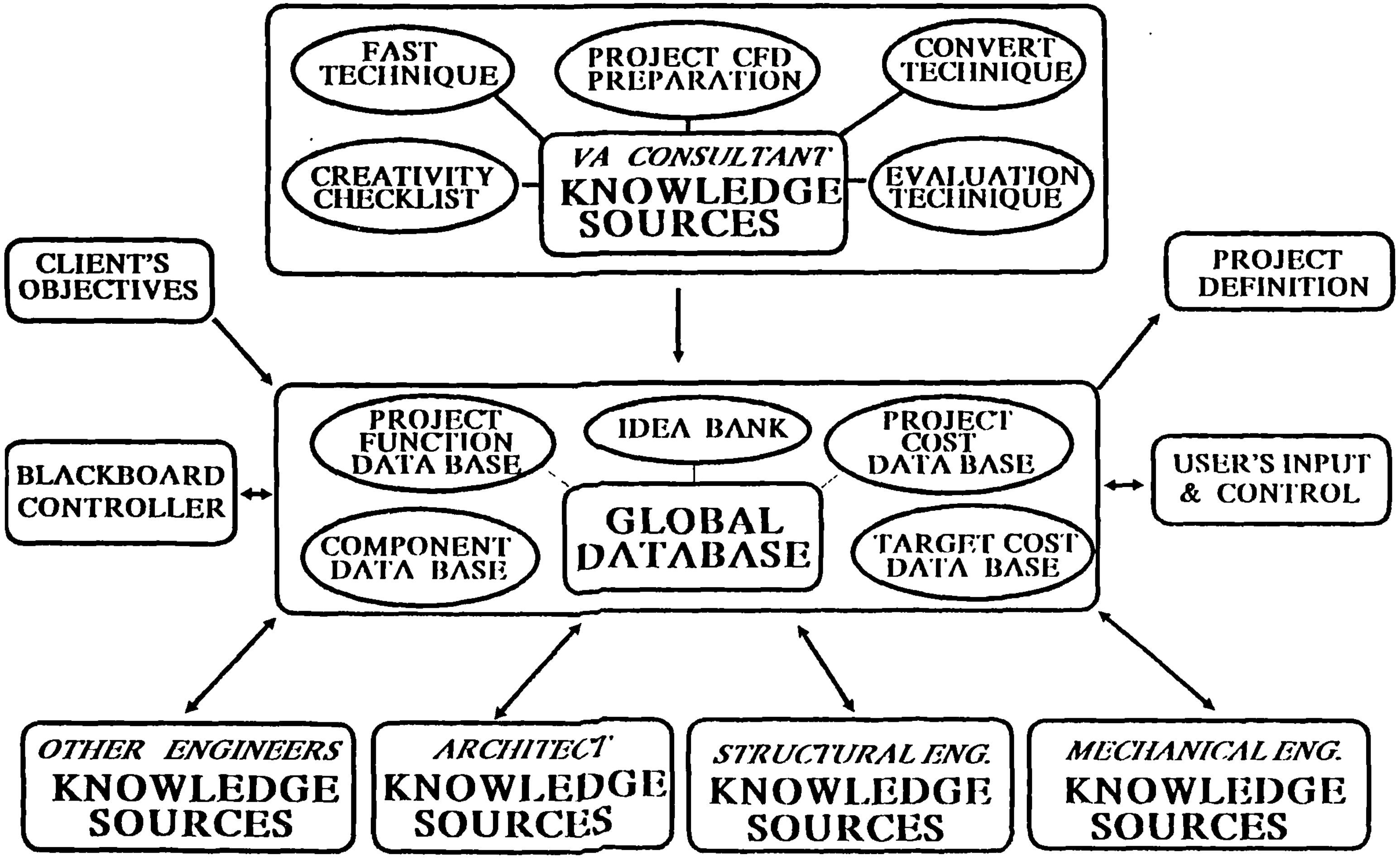


Figure 8-1 A Recommended Blackboard System for Future Development of CAVA

budget module might be the best candidate for providing such information, and a further integration of the VA module and the budget module seems necessary. When the costs of each element are known, the system can use a cost model (or life cycle cost model, if necessary) to compare the estimated costs with the target costs. Those elements that have great cost-saving potential (i.e. high ratios of the estimated cost over the target cost) can therefore be easily located for further analyses.

APPENDIX 1. GLOSSARY

(1) VALUE MANAGEMENT GLOSSARY

Aesthetic Function: 1. A function describing esteem value rather than use value. 2. A function attributable to pleasing user rather than contributing performance. 3. A function that indicates product features which exceed its technical utility or performance requirement. 4. Also referred to as esteem function.

Basic Function: 1. That which is essential to the performance of a user's function. 2. The function describing the primary utilitarian characteristic of a product to fulfil a user's requirement. 3. Also called primary or essential function.

Cost Estimate: 1. A product representing the art and science of predicting cost or price. 2. The summation of unit quantities of labour and material multiplied by unit costs of labour, material, overhead and profit for providing a product under a specified set of conditions.

Critical Function: A combination of the basic and selected required secondary or dependent functions defining the means used to achieve workability of the product.

Critical Path Function: One of the set of basic and dependent functions that meet the "why" and "how" logic on a FAST diagram forming a path of essential functions without which the product would not perform.

Dependent Function: 1. Lower order functions, to the right of each other on a FAST diagram, that are successively dependent on the one to its immediate left for its existence. 2. A function that depends on a higher order function for its existence. 3. A function which exists or is chosen in order to achieve a basic function.

Essential Cost: All cost necessary to provide basic functions.

Essential Function: 1. A function describing a characteristic which is absolutely necessary to a product's ability to perform the user's function. 2. Also called the necessary or required function.

Esteem Function: See aesthetic function.

Esteem Value: 1. The monetary sum a user is willing to pay for functions providing prestige, appearance, and/or other non-quantifiable benefits. 2. The relative value a user places on the aesthetic functions provided by a product. 3. The monetary measure of the functions of a product which contribute to its desirability or saleability but not its required functional performance. 4. The motivated desire to possess for the sake of possession. 5. Also referred to as aesthetic value.

Function: that which the product or service must do to make it work or sell.

Function Analysis: 1. The study of product performance using two words, a verb and a noun. 2. The methodology of value analysis.

Function Analysis System Technique: 1. A diagramming technique to graphically show the logical relationships of the functions of a product; 2. Product functions displayed horizontally in diagram form using the following rules: higher order functions appear to the left answering "why" a function occurs, lower order functions appear to the right answering "how" a function occurs, functions occurring at the same time appear vertically below one another, scope lines indicating the scope of the value study are placed vertically, and basis function or the product is defined as being immediately to the right of the left scope line.

Functional Cost: 1. The proportion of product cost allocated to functions performed by the product. 2. All costs directly associated with the performance of a particular function. 3. costs required for the realization of a function.

Functional Worth: 1. The lowest overall cost that is required to perform a function. 2. The least cost attainable through the use of a functional equivalent. 3. The cost of a function without regard to the consequences of failure. 4. Referred to as the value of a function in some texts (not a preferred usage).

Independent Function: 1. A function that does not depend on another function or on the method selected to perform that function. 2. A function that occurs all the time, i.e. a part or an assembly may have to resist corrosion regardless of what other basic or secondary function that part is performing.

Necessary Function: See essential function.

Poor Value: The condition which occurs when function cost exceeds functional worth by a significant amount.

Primary Function: See basic or essential function.

Quality: Conformance to specifications that results in a product which meets the customer's expectations.

Reliability: Continuing to meet the client's quality expectations for the product's intended life.

Required Function: See essential function.

Required Secondary Function: A secondary function that is essential to support the performance of the basic function. 2. A function that may result from specified design criteria.

SAVE Approved VE Workshop: A workshop approved by the Society of American Value Engineers for meeting the minimum training requirements to count as credit toward becoming a Certified Value Specialist (CVS).

Secondary Function: 1. The manner in which the basic function was implemented. 2. A function indicating quality, dependability, performance, convenience, attractiveness and general satisfaction beyond that needed to satisfy minimum user's needs. 3. Includes supporting unwanted, unnecessary and un-required functions.

Standard Cost: 1. Cost calculated on accepted productivity and material rates used as a norm against which to compare actual performance. 2. Costs accepted as the basis for budgeting or allocation of funds.

Supporting Function: 1. A function required by the user to make a product sell. 2. A function that increases acceptance. 3. A function to assure dependability, assure convenience, satisfy user or attract user. 4. Also called a sell function.

Unnecessary Cost: 1. Costs for functions not desired. 2. Costs for quality or performance above that needed by the user. 3. Any cost which does not contribute to value. 4. That portion of the cost of a product which does not contribute to essential functions, required performance or marketability.

Unnecessary Function: 1. A function not contributing to the utility or desirability of a product. 2. Also referred to as a nonessential function.

Use Value: 1. The monetary measure of the functional properties of a product which reliably accomplishes a user's needs. 2. The life cycle cost (worth to cost relationship) considering user function only.

User's Function: 1. That function performed by a product that causes its purchase by a user. 2. The function performed by an employee for the company. 3. Also referred to as a task function.

Unwanted Function: 1. A negative function caused by the method used to achieve the basic function, e.g. heat generated from lighting which often must be cooled. 2. Also called an undesirable function.

Value: The lowest cost to reliably accomplish a function which will meet quality expectations of the customer. It can be divided further into economic, political, social, aesthetic, ethical, religious, judicial. In VM people are most concerned with economic value which includes: A) cost value: the total cost involved in producing a particular item--the sum of labour, material and overhead. B) exchange value: the properties or qualities of an item which enable us to trade it for something else. C) esteem value: the properties, features, or attractiveness which make its ownership desirable. D) use value: the properties or qualities which accomplish the work or service.

Value Analysis: 1. A method for enhancing product value by improving the relationship of worth to cost through the study of function; 2. A methodology using an organised approach (job plan) with an organised effort (multi-discipline team) to provide required functions at lowest overall cost consistent with achieving required acceptance or performance; 3. The determination of the value of product functions as perceived by the user/customer in the marketplace.

Value Analyst: The person who uses value analysis methodology to study a product and search for value improvement. *Also referred as value engineer.*

Value Engineer: The person who uses value analysis methodology to study a product and search for value improvement. Also referred as value analyst.

Value Engineering: 1. The same as value analysis except with emphasis on application during product development and/or design. 2. The incorporation of functions onto products considered of value by the user. 3. A problem-solving system designed to accomplish essential functions of products and services at lowest cost without sacrifice of quality or delivery requirements.

Value Engineering Change Proposal: A change submitted by a contractor, pursuant to a contract provision, for the purpose of reducing the contract price or life cycle cost of the product under contract.

Value Index: 1. The monetary relationship of function worth to function cost (expressed as VI=FW/FC, where VI is never greater than unity). 2. Sometimes expressed as function cost (VI=FB/FC).

Value Management: The same as value analysis except with emphasis on application as a management technique.

Value Management Programme: A programme which manages costs and manages changes through the deliberate use of the technique. A successful program requires management support, proper planning and organisation, and an understanding of the technique.

Value Mismatch: When functional cost does not fit or match user/customer's function attitude for a given function.

VM Job Plan: A sequential approach for conducting a value study, normally consisting an information step, review or implementation step and an optional follow up or measurement step.

(2) COMPUTER APPLICATION GLOSSARY

Access: The process of seeking, reading, or writing data on a storage unit.

Acronym: A word formed by the initial letters of words or by initial letters plus parts of several words. Acronyms are widely used in computer technology, for instance, FORTRAN is an acronym for FORmula TRANslation, and BASIC is an acronym for Beginner's All-purpose Symbolic Instruction Code.

Application: The system or problem to which a computer is applied. Reference is often made to an application as being either of the computational type, in which arithmetic computations predominate, or of the data processing type, in which data handling operations predominate.

ASCII: Acronym for *American Standard Code for Information Interchange*, *which* was developed by American National Standards Institute (ANSI). It is a standardized 8-bit code (7 binary bits for information and the 8th bit for parity purpose) used by most computers for interfacing.

Batch Processing: A method of operating a computer so that a single programme or set of related programmes must be completed before the next type of programme is begun. There are several batch files in the proposed system package.

Buffer: A temporary storage area from which data is transferred to or from various devices.

Byte: An element of data which is composed of eight data bits plus a parity bit, and represents either on alphabetic or special character, two decimal digits, or eight binary bits. Byte is also used to refer to a sequence of eight binary digits handled as a unit. It is usually encoded in the ASCII format.

Central Processor Unit (CPU): The heart of the computer system, where data is manipulated and calculations are performed. The CPU contains a control unit to interpret and execute the programme and an arithmetic-logic unit to perform computations and logical processes. It also routes information, controls input and output, and temporarily stores data.

Command: A pulse, signal, word, or series of letters that tells a computer to start, stop, or continue an operation in an instruction. Command is often used incorrectly as a synonym for instruction.

Data File: A collection of related data records organised in a specific manner. Data files contain computer records which contain information, as opposed to containing data handling information or a programme.

Delimiter: A character that marks the beginning or end of a unit of data on a storage medium. Commas, semi-colons, periods, and spaces are used as delimiters to separate and organise items of data.

Disk Operating System (DOS): A collection of procedures and techniques that enable the computer to operate using a disk drive system for data entry and storage.

Extension: A one-to-three character set that follows a filename. The extension further defines or clarifies the filename. It is separated from the filename by a period (.).

Field: An area of a record that is allocated for a specific category of data.

File: A collection of related data or programmes that is treated as a unit by the computer.

GIGO: An informal term that indicates sloppy data processing; an acronym for Garbage In Garbage Out. The term is normally used to make the point that if the input data is bad then the output data will also be bad.

Interpreter: A programme that reads, translates and executes a user's programme. A compiler reads and translates the entire user's programmes before executing it.

Interface: An information interchange path that allows parts of a computer, computers, and external equipment (e.g. printers, monitors, or modems), or two or more computers to communicate or interact.

Memory: The high-speed working area in a computer where data can be held, copied, and retrieved.

Menu: A list of choices from which an operator can select a task or operation to be performed by the computer.

Mata-Rule: A meta-rule is distinguished from an ordinary rule in that its role is to direct the reasoning required to solve the problem, rather than to actually perform that reasoning.

Prompt: A character or series of characters that appear on the screen to request an input from the user.

Random Access Memory (RAM): The system's high-speed work area that provides access to memory storage locations by using a system of vertical and horizontal coordinates. A computer can write and read information to and from the RAM.

Symbol: A symbol is something that transfer something else. It is this notion that forms the critical link between AI and formal systems of logic and mathematics.

Syntax: Rules of statement structure in a programming language.

APPENDIX 2. ABBREVIATIONS USED IN THE THESIS

AI	Artificial Intelligence
AVS	Associate Value Specialist
CA	Conceptual Analysis
CAM	Conceptual Analysis Module
CFD	Conceptual Functional Diagram
CVS	Certified Value Specialist
ES	Expert System
FAST	Function Analysis System Technique
IT	Information Technology
IVM	Institute of Value Management
KBS	Knowledge-Based System
LCC	Life Cycle Costing
RIBA	Royal Institute of British Architect
SAVE	Society of American Value Engineers
VA	Value Analysis
VAM	Value Analysis Module
VECP	Value Engineering Change Proposal
VM	Value Management
VMCP	Value Management Change Proposal

APPENDIX 3. LIST OF FILES USED BY CAVA

$$LEOINP	DAT	Input file for interfacing with ELSIE BM
A1	BAT	Batch file for running elsie
ACC-RAMP	LIB	Library for Ramp design
AUTOWASH	LIB	Library for Automatic Wash Machine design
BMDB1	BAT	Batch for interfacing ELSIE Budget Module
BMDB2	BAT	Batch for interfacing ELSIE Budget Module
BMDB3	BAT	Batch for interfacing ELSIE Budget Module
BMDBIN1	DAT	Input data file for bmdb1.bat
BMDBIN2	DAT	Input data file for bmdb2.bat
BMDBIN2	TEM	Temporary input data file for bmdb2.bat
BMDBIN3	DAT	Input data file for bmdb3.bat
BMDBOUT1	DAT	Output data file from bmdb1.bat
BMDBOUT2	DAT	Output data file from bmdb2.bat
BMDBOUT3	DAT	Output data file from bmdb3.bat
BMINPUT	DAT	Input data file for bmlink.bat
BMLINK	BAT	Linking CAA with ELSIE Budget Module
BMOUTPUT	DAT	Output data file from bmlink.bat
CAA1-5	PKB	Knowledge Base - Conceptual Analysis Assistant
CAAPROJ	DB	Project DB used by CAA - With ELSIE DB format
CH-PLANT	LIB	Library for Chemical Plant design
CHEKLIST	TXT	Checklist text file used in CAA
CIVIL	DBF	DB file - worth for Civil, used by VAA
COMPUTER	LIB	Library for the design of a Computer Centre
CONTINGE	DBF	DB file - Worth for contingency
COSTMODI	DBF	DB file - Worth for Cost Modification
CRITERIA	1	Heading 1 of criteria file used in CAA
CRITERIA	2	Heading 2 of criteria file used in CAA
CRITERIA	DB	Criteria used in an analysis by CAA
DB	EXE	File for manipulating CAAPROJ.db
ELECTRIC	DBF	DB file - Worth for Electrical
ELSIE	DB	ASCII file prepared to load into caaproj.db
ELSIE	DB1	File prepared to form elsie.db - 1st record
ELSIE	DB2	File prepared to form elsie.db - 2nd record
ELSIE	DB3	File prepared to form elsie.db - 3rd record
ELSIE	DB4	File prepared to form elsie.db - 4th record

ELSIE-Q	DOC	Questions asked by ELSIE BM
ELSIEASS	DOC	Assumptions made when linking ELSIE with CAA
EMPTY	DB1	Empty file based on which elsie.db1 is formed
EMPTY	DB2	Empty file based on which elsie.db2 is formed
EMPTY	DB3	Empty file based on which elsie.db3 is formed
EMPTY	DB4	Empty file based on which elsie.db4 is formed
ERECTION	DBF	DB file - Worth for Erection
ESCALATI	DBF	DB file - Worth for Escalation
EXPLAIN	TXT	Explain no more subfunctions when meet end
FILELIST	DOC	This file
FUN-COST	ASP	Assumed percentages for allocating cost to functions
GLOSSARY	TXT	Glossary used in CAA
HVAC	DBF	DB file - Worth for HVAC
INDEX	DBF	DB file - Worth for INDEX
INSTRUME	DBF	DB file - Worth for Instrument
LAGGING	DBF	DB file - Worth for Logging
LEO	BAT	Normalize screen - after using CAA text files
LROLLOUT	COM	Leonardo file for rolling PKB out of memory
METHODS	TXT	Methods for creating more creative ideas.
NORM	DB	File to form a project record in caaproj.db
NORM	DOC	Documentation of Norms assumed for CAA
NORM	TEM	Temporary Norm.db file
NORM14	TXT	Text file for Norm No 14
NORM20	TXT	Text file for Norm No 20
NORM30	TXT	Text file for Norm No 30
NORM32	TXT	Text file for Norm No 32
NORM50	TXT	Text file for Norm No 50
NORM52	TXT	Text file for Norm No 52
NORM53	TXT	Text file for Norm No 53
NORM54	TXT	Text file for Norm No 54
NORM55	TXT	Text file for Norm No 55
NORM90	TXT	Text file for Norm No 90
NORM140	TXT	Text file for Norm No 140
NORM141	TXT	Text file for Norm No 141
NORM142	TXT	Text file for Norm No 142
NORM150	TXT	Text file for Norm No 150
NORM151	TXT	Text file for Norm No 151

NORM174	TXT	Text file for Norm No 174
NORM181	TXT	Text file for Norm No 181
NORM191	TXT	Text file for Norm No 191
NORM193	TXT	Text file for Norm No 193
NORM194	TXT	Text file for Norm No 194
NORM200	TXT	Text file for Norm No 200
NORM225	TXT	Text file for Norm No 225
OF-BLOCK	LIB	Library file for standard Office Buildings
OUTPUT	BIN	File containing un-wanted output
PIPING	DBF	DB file - Worth for Piping
PLAN-CM2	LIB	Library file -- Chemical Plant
RANKHELP	TXT	Text which explains how rank criteria
REPLAY1	PLB	Auto Replay of the key strokes - record 1
REPLAY2	PLB	Auto Replay of the key strokes - record 2
REPLAY3	PLB	Auto Replay of the key strokes - record 3
REPLAY4	PLB	Auto Replay of the key strokes - record 4
RES-LABS	LIB	Library file -- Research Laboratory
ROOFING	DBF	DB file - Worth for Roofing
SITEIMPR	DBF	DB file - Worth for Site Improvement
SITEPREP	DBF	DB file - Worth for Site Preparation
SITEUTIL	DBF	DB file - Worth for Site Utilities
SPILLAGE	LIB	Library file -- Spillage Treatment
STRUCTUR	DBF	DB file - Worth for Structures
TEM-PROJ	CFD	Temporary CFD file to form project CFD
TESTCAA1	CRI	Criteria used in project testcaa1
TESTCAA1	REP	Report of test run 1
TESTVAA1	RES	Result of test run 1 - for VAA
TESTVAA2	RES	Result of test run 2 - for VAA
TESTVAA3	RES	Result of test run 3 - for VAA
VAA1-1	PKB	PKB of Value Analysis Assistant
VMFORMS	PRN	Various Forms for VM studies
WORDHELP	TXT	File containing words to define functions

APPENDIX 4. OBJECTS USED IN THE CA MODULE OF CAVA

1	: conceptual_analysis	Text
2	: define_building_project	Text
3	: read_record_pointer	Real
4	: packrecord_number	Real
5	: total_record_number	Real
6	: original_record_number	Real
7	: project_name	Text
8	: name_to_review	Text
9	: declare	Text
10	: level0_functions	Class
11	: functionname:	Slot referent Text
12	: code:	Slot referent Text
13	: includestate:	Slot referent Text
14	: subfunctions:	Slot referent List
15	: cost:	Slot referent Real
16	: initiate_screen	Text
17	: weigh_global_criteria	Text
18	: project_type	Text
19	: project_task	Text
20	: proc_retrieve_archives	Procedure
21	: scr_cfd_introduction	Screen
22	: proc_review_archives	Procedure
23	: project_initiation	Text
24	: preferred_process	Text
25	: functions_inlevel1	Text
26	: functions_inlevel2	Text
27	: functions_inlevel3	Text
28	: functions_inlevel4	Text
29	: cost_estimation	Text
30	: compare_to_norm	Text
31	: prepare_report	Text
32	: save_archive	Text
33	: Satisfy_Client_Req	Text
34	: Identify_Site	Text
35	: Establish_Building	Text
36	: Minimize_Risks	Text
37	: horizontal_Analysis	Text
38	: level1_functions	Class
39	: selected_funname	List
40	: value:	Slot referent Global
41	: subfunctions	List
42	: function_reqs	List
43	: report_name	Text
44	: totnumbers	Real
45	: totfunctions	List
46	: totflexibility	List
47	: Dummymember	Text
48	: Prov_Office_Facils	Text
49	: level2_namelist	Text
50	: level3_namelist	Text
51	: functionname	Text
52	: functioncode	Text
53	: Establish_options	Text
54	: Define_siterequire	Text
55	: Consider_conditions	Text
56	: identify_geography	Text
57	: Specific_issues	Text
58	: Satisfy_operability	Text
59	: Undertake_design	Text
60	: Improve_intenviron	Text

```
 61 : Improve_extenviron          Text
 62 : Provide_furnishings         Text
 63 : Provide_services            Text
 64 : Satisfy_regulations         Text
 65 : Number_of_uncertain         Text
 66 : Ground_contamination        Text
 67 : Unknown_conditions          Text
 68 : Maximize_opportunity        Text
 69 : Identify_quarequire         Text
 70 : Determine_qualevel          Text
 71 : Agree_finishes              Text
 72 : Agree_fittings              Text
 73 : Ground_slope                Text
 74 : Water_problems              Text
 75 : Rock_problems               Text
 76 : Bearing_capacity            Text
 77 : Previous_development        Text
 78 : Access_difficulty           Text
 79 : Staff_availability          Text
 80 : Service_availability        Text
 81 : Number_of_storeys           Real
 82 : Support_mechanism           Text
 83 : Plan_shape                  Text
 84 : Architectural_style         Text
 85 : External_walling            Text
 86 : Window_design               Text
 87 : Building_relations          Text
 88 : Condition_space             Text
 89 : Provide_heating             Text
 90 : Circulate_air               Text
 91 : Control_humidity            Text
 92 : Control_noises              Text
 93 : Illuminate_objects          Text
 94 : Prepare_site                Text
 95 : Provide_landscape           List
 96 : Illuminate_site             Text
 97 : Access_parking              List
 98 : Supply_electricity          Text
 99 : Supply_gas                  Text
100 : Supply_water                Text
101 : Supply_communication        List
102 : Supply_air                  List
103 : Dispose_refuse              List
104 : Convey_people_goods         List
105 : Provide_refreshment         Text
106 : Provide_drainage            Text
107 : Satisfy_build_regs          Text
108 : Satisfy_fire_regs           Text
109 : Satisfy_safety_regs         Text
110 : Satisfy_secure_regs         Text
111 : Brick_Stone_Mix             Text
112 : Natural_Stone               Text
113 : Prestigious_Stone           Text
114 : Sheeting_Metal              Text
115 : Brick_Cladding              Text
116 : PVC_Coated_Metal            Text
117 : Exposed_Aggregate_PC        Text
118 : GRP_GRC_Walling             Text
119 : Glazed_curtain_wall         Text
120 : start                       Text
121 : screen_type                 Text
122 : proc_startup                Procedure
123 : p_check_proname             Procedure
```

124	: global_criteria	Class
125	: criname:	Slot referent Text
126	: explain:	Slot referent Text
127	: weight:	Slot referent Real
128	: global_weight_list	List
129	: Initial_cost	Text
130	: Life_cycle_cost	Text
131	: Construction_time	Text
132	: Buildability	Text
133	: Constr_difficulty	Text
134	: Esthetics	Text
135	: Functionality	Text
136	: Environment	Text
137	: global_criteria_list	List
138	: p_weigh_criteria	Procedure
139	: get_weight_list	Text
140	: p_assign_weight	Procedure
141	: Assign_weight	Text
142	: scr_define_project	Screen
143	: modify_major_functions	Text
144	: proc_mod_functions	Procedure
145	: change_inlevel1	Text
146	: read_function_flag1	Text
147	: addition_inlevel1	Text
148	: deduction_inlevel1	Text
149	: scr_conclusion1	Screen
150	: modify_funlevel1	Text
151	: change_inlevel2	Text
152	: proc_concate_subfuns	Procedure
153	: level1_subfunctions	List
154	: level2_functions	Class
155	: read_function_flag2	Text
156	: addition_inlevel2	Text
157	: deduction_inlevel2	Text
158	: name:	Slot referent Text
159	: function_prep_inlevel2	Text
160	: clarify_funslevel2	Text
161	: scr_conclusion2	Screen
162	: proc_select_functions	Procedure
163	: selected_level2_funs	List
164	: funs_tobe_mod_inlevel2	Text
165	: change_inlevel3	Text
166	: level2_subfunctions	List
167	: level3_functions	Class
168	: read_function_flag3	Text
169	: addition_inlevel3	Text
170	: deduction_inlevel3	Text
171	: scr_conclusion3	Screen
172	: selected_level3_funs	List
173	: funs_tobe_mod_inlevel3	Text
174	: change_inlevel4	Text
175	: level3_subfunctions	List
176	: level4_functions	Class
177	: read_function_flag4	Text
178	: addition_inlevel4	Text
179	: deduction_inlevel4	Text
180	: link_elsie	Text
181	: s_link_elsie	Screen
182	: p_prep_elsiedb	Procedure
183	: p_call_elsiebm	Procedure
184	: s_introduce_norm	Screen
185	: p_prepare_norm	Procedure
186	: s_showing_norm	Screen

187 : s_funcost_analysis	Screen
188 : p_compare_to_norm	Procedure
189 : p_analyse_funcosts	Procedure
190 : norm14	Text
191 : norm20	Text
192 : norm30	Text
193 : norm32	Text
194 : norm50	Text
195 : norm52	Text
196 : norm53	Text
197 : norm54	Text
198 : norm55	Text
199 : norm140	Text
200 : norm141	Text
201 : norm142	Text
202 : norm150	Text
203 : norm151	Text
204 : norm174	Text
205 : norm181	Text
206 : norm191	Text
207 : norm193	Text
208 : norm194	Text
209 : norm200	Text
210 : norm225	Text
211 : p_open_report	Procedure
212 : p_prep_report	Procedure
213 : packlevel1	Text
214 : packlevel2	Text
215 : packlevel3	Text
216 : packlevel4	Text
217 : p_close_report	Procedure
218 : proc_open_archive	Procedure
219 : p_save_procfd	Procedure
220 : savelevel1	Text
221 : savelevel2	Text
222 : savelevel3	Text
223 : savelevel4	Text
224 : proc_close_archive	Procedure
225 : main_function	Text
226 : s_get_subfuns	Screen
227 : p_get_subfuns	Procedure
228 : expsubfuns_inlevel2	Text
229 : proc_select_fname	Procedure
230 : p_get_totnum	Procedure
231 : scr_get_totnumbers	Screen
232 : proc_mod_funs	Procedure
233 : excluded_functions	List
234 : alt_ext_walling	Class
235 : Basecost:	Slot referent Real
236 : Q_plussage:	Slot referent Real
237 : X_plussage:	Slot referent Real
238 : P_plussage:	Slot referent Real
239 : subfun1	Text
240 : subfun2	Text
241 : subfun3	Text
242 : subfun4	Text
243 : proc_global_help	Procedure
244 : scr_building_relations	Screen
245 : water_type	List
246 : water_distribution	List
247 : escape_priciples	List
248 : provide_ancilaries	List
249 : scr_satisfy_client	Screen

250 :	scr_identify_site	Screen
251 :	scr_provide_facility	Screen
252 :	scr_minimize_risks	Screen
253 :	proc_getnew_functions	Procedure
254 :	flag	Text
255 :	scr_review_archives	Screen
256 :	proc_modify_query	Procedure
257 :	mod_information	Text
258 :	Personnel_reqs	Text
259 :	Quality_reqs	Text
260 :	proc_clarify_functions	Procedure
261 :	Identify_curstaff	Text
262 :	Identify_newstaff	Text
263 :	exit	Text
264 :	subfun5	Text
265 :	subfun6	Text
266 :	subfun7	Text
267 :	subfun8	Text
268 :	subfun9	Text
269 :	subfun10	Text
270 :	subfun11	Text
271 :	subfun12	Text
272 :	subfun13	Text
273 :	subfun14	Text
274 :	subfun15	Text
275 :	subfun16	Text
276 :	subfun17	Text
277 :	subfun18	Text
278 :	num_executives	Real
279 :	num_normalstaff	Real
280 :	num_secretaries	Real
281 :	num_others	Real
282 :	num_design_staff	Real
283 :	scr_identify_curstaff	Screen
284 :	space_shortage	Text
285 :	rearrange_offices	Text
286 :	other_possibilities	Text
287 :	scr_stop_analysis	Screen
288 :	s_whynot_rearrange	Screen
289 :	shortage_status	Text
290 :	hire_office	Text
291 :	notepad	Text
292 :	proc_find_subfunctions	Procedure
293 :	proc_fabricate_tree	Procedure
294 :	proc_locate_costs	Procedure
295 :	proc_explain_nomore	Procedure
296 :	proc_leo_dos	Procedure
297 :	proc_fabricate	Procedure
298 :	proc_help_facilities	Procedure
299 :	proc_display_modify	Procedure
300 :	proc_expan_function	Procedure
301 :	p_convt_number	Procedure
302 :	proc_show_norm	Procedure
303 :	proc_prepare_norm1	Procedure
304 :	p_weigh_spec_criteria	Procedure
305 :	p_rank_alternates	Procedure

APPENDIX 5 A TYPICAL CONSULTATION WITH THE CA MODULE

WELCOME TO

CONCEPTUAL ANALYSIS ASSISTANT

University of Salford
in colloration with
Imperial Chemical Industries
December 1991

Hit any key to continue

Conceptual Analysis Assistant -- Version 4.2

The name of the project must be started with a letter and the number of characters in the project name should be less than 8. There is no need to give any extension to the name.

Could you specify a name for your project?

Tutorial

FKeys: 1 Help 2 Quit 3 Why? 5 Volunteer 6 Back 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

The criteria will be used consistently to evaluate alternatives of every design problem within the project throughout the design process. A special technique -- weighted evaluation (grid evaluation) will be used later to facilitate the evaluation of alternatives against these criteria. Please select the criteria accordingly.

The default value is "Life_cycle_cost, Aesthetics, Functionality". If you want to use the default list, please select "unknown" only.

Which of criteria will be used for this project?

Initial_cost
Life_cycle_cost
Construction_time
Buildability
Construction_difficulty
Aesthetics
Functionality
Environmental_issues

FKeys: 1 Help 2 Quit 3 Why 5 Vol 6 Bac 7 Exp 8 Rev <Ins> Add <Del> Rem

Conceptual Analysis Assistant -- Version 4.2

```
      B     C     D     E
    --------------------
  A |a-2 |a-3 |a-4 |a-3 |
    --------------------
        B |b-2 |b-3 |b-4 |
         ---------------
              C |c-3 |c-2 |
               ----------
                   D |d-1 |
                     -----
```

CRITERIA & REPRESENTING LETTERS

A: Initial_cost
B: Life_cycle_cost
C: Construction_time
D: Buildability
E: Construction_difficulty

Preferring Point:

4--Major Preference
3--Medium Preference
2--Minor Preference
1--Slight Preference
Cri/Cri--No Preference

INSTRUCTION: Compare each pair of criteria, put "-" among the preferred criterion and the preferring point. If there is no preference, put "/" among the two representing letters.

CRITERIA SCORING MATRIX

Conceptual Analysis Assistant -- Version 4.2

	CRITERIA	ORIGINAL SCORE	WEIGHT
A	Initial_cost	12	10
B	Life_cycle_cost	9	8
C	Construction_time	5	4
D	Buildability	1	1
E	Construction_difficulty	0	0

Hit any key to continue

Conceptual Analysis Assistant -- Version 4.2

As a Conceptual Analysis Assistant, the system can support the analysis of following types of buildings: OFFICE BLOCK, COMPUTER CENTRE, CHEMICAL PLANT, RESEARCH LABORATORY. For the time being the system can only support the analysis of an "OFFICE BLOCK".

Use <Cursor Up, ↑> and <Cursor Down, ↓> to select your choice. The one has been selected will be highlighted on the screen, when you move the cursor. Once you have selected one type of buildings for your project, then hit <Return> to confirm.

Which of these terms can best describe your project?

OFFICE BLOCK
COMPUTER CENTRE
CHEMICAL PLANT
RESEARCH LABORATORY

FKeys: 1 Help 2 Quit 3 Why? 5 Volunteer 6 Backup 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

Generally speaking, the system can assist two kinds of task, i.e. (1) Analyse new project, (2) Review previous project.

If the project you are going to analyse has never been analysed by the system before, then you should select "Analyse new project";

If you are going to review a previous project done by the system, then choose "Review previous project". You will be asked to specify the project name stored in my project base.

Would you please tell me what are you going to do?

Analyse new project
Review previous project

FKeys: 1 Help 2 Quit 3 Why? 5 Volunteer 6 Backup 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

SUGGESTED CONCEPTUAL FUNCTION DIAGRAM

The following screens will show you the suggested conceptual function diagram which was based on your answers to those questions I asked.

The objective of Conceptual Analysis is to clarify building project definition at an early design stage by establishing the factors which have (and have not) to be provided.

Hit any key to continue

Conceptual Analysis Assistant -- Version 4.2

Define Building Project	Satisfy Client's Requirements
	Identify Site Selection Issues
	Establish Office Facilities
	Minimize Development Risks

FKeys: 1 Help 2 Quit -><- Mark hypertext keyword <Enter> Select keyword

Conceptual Analysis Assistant -- Version 4.2

Establish Office Facilities	Satisfy Buildability
	Understand Architectural Design
	Create Internal Climate
	Create External Environment
	Provide Furnishings
	Provide Utilities
	Satisfy Building Regulations

FKeys: 1 Help 2 Quit -><- Mark hypertext keyword <Enter> Select keyword

Conceptual Analysis Assistant -- Version 4.2

Satisfy Client's Requirements

Minimize Development Risks	Number of Uncertainties Ground Contaminations Unknown Ground Conditions Maximize Opportunity Minimize Other Risks

FKeys: 1 Help 2 Quit -><- Mark hypertext keyword <Enter> Select keyword

Conceptual Analysis Assistant -- Version 4.2

Conceptual_Functional_Diagram_(Level-1)

Provide_Office_Facilities	1 Satisfy_Client's_Requirements	(1)
	2 Identify_Site_Selection_Issues	(2)
	3 Establish_Office_Facilities	(3)
	4 Minimize_Development_Risks	(4)

Which function do you want to see in details (0 Quit) (0... 4)? 1

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Conceptual Functional Diagram (Level-2)

1 Satisfy_Client's_Requirements
- 1.1 Satisfy_Personnel_Requirements (1)
- 1.2 Satisfy_Functional_Requirements (2)
- 1.3 Satisfy_Quality_Requirements (3)

Which function do you want to see in details (0 Level-1) (0... 4)? 0

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There are two ways to analyse a project and set up its Conceptual Functional Diagram (CFD): (1) "vertical analysis", (2) "horizontal analysis". As you move the cursor up or down, a pop-up screen will appear on the screen to explain what do they mean by the words.

Use <Cursor Up> and <Cursor Down> to select your choice. When you move the cursor, the one which has been selected will be highlighted on the screen. Once you have selected the way of analysis for your project, then hit <Return> to confirm.

Which of the following ways of analysis do you prefer?

vertical analysis
horizontal analysis

Horizontal Analysis
Functions are analysed horizontally. The first function in first level will be analysed first, then its subsidiary functions in second level, then their subs in the third and fourth level.

FKeys: 1 Help 2 Quit 3 Why? 5 Volunteer 6 Backup 7 Expand 8 Review

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Here are the main functions I suggested for your building project:

(1) Satisfy_Client's_Requirements,
(2) Identify_Site_Selection_Issues,
(3) Establish_Office_Facilities,
(4) Minimize_Development_Risks

If you want to make can any change, please select "yes", I will give you the chance to modify above building major functions.

Do you want modify the major functions I suggested ?

yes
no

"yes"

If you think that some of the major issues are irrelevant to your particular project, or you think that you have some major issues which are specific to your project, you therefore want to add them, then you select "yes".

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

MODIFYING FUNCTIONS (Level-1)

Provide_Office_Facilities
- 1 Satisfy_Client's_Requirements
- 2 Identify_Site_Selection_Issues
- 3 Establish_Office_Facilities
- 4 Minimize_Development_Risks

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)... 1

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

```
                 Conceptual Analysis Assistant -- Version 4.2

   Which of the following archives do you want to review?

        1  SPILLAGE.LIB
        2  COMPUTER.LIB
        3  RES-LABS.LIB
        4  CH-PLANT.LIB
        5  PLAN-CM2.LIB
        6  OF-BLOCK.LIB
        7  ACC-RAMP.LIB
        8  AUTOWASH.LIB

       Please put your choice here (0..Quit  0...8)....2
```

```
                 Conceptual Analysis Assistant -- Version 4.2

                    Conceptual Functional Diagram (Level-1)
                    ---------------------------------------

                                  ┌── 1 Prepare_Site               (1)
                                  ├── 2 Other_Specified_Rooms      (2)
                                  ├── 3 Environment_For_Computers  (3)
                                  ├── 4 Continuous_Availability    (4)
 Provide_Computer_Based_Services  ├── 5 Accommodate_Services       (5)
                                  ├── 6 Flexibility                (6)
                                  ├── 7 Prestige                   (7)
                                  ├── 8 Security/Safety            (8)
                                  └── 9 Statutory_Regulations      (9)

   Which function do you want to see in details (0 Quit) (0... 9)?
 Function Keys: <F1> Locate costs on functions
```

```
                Conceptual Analysis Assistant -- Version 4.2

                      Conceptual Functional Diagram (Level-1)
                      ---------------------------------------

                                    ┌─ 1 Prepare_Site               1445995
                                    ├─ 2 Other_Specified_Rooms      1552748
                                    ├─ 3 Environment_For_Computer   2366038
                                    ├─ 4 Continuous_Availability    1272000
Provide_Computer_Based_Services     ├─ 5 Accommodate_Services       1822457
           9240992                  ├─ 6 Flexibility                  81884
                                    ├─ 7 Prestige                    143260
                                    ├─ 8 Security/Safety             566610
                                    └─ 9 Statutory_Regulations        20000

 Use function keys provided, to back to previous screen, put 'B' here:
 Function Keys: <F1> Draw pie chart   <F2> Draw bar graph
```

```
                Conceptual Analysis Assistant -- Version 4.2

          Please Add More Functions For Provide_Office_Facilities!

          (Enter 'no', when finish. You may add up to 12 functions)

     Reference                    Added Functions
         1                   Safeguard Environment

 FKeys: <F1> Help Facilities   <F2> Quit    <↑ & ↓> Modify Input Data
```

Conceptual Analysis Assistant -- Version 4.2

V E R B S / N O U N S   C O M B I N A T I O N S

Here are the possible verbs/nouns combinations, which may give you some suggestions when you expand functions. You can use your own words which are not included in the list.

support weight	reduce sound	attract users
transmit load	reduce losses	identify items
enclose space	collect heat	improve appearance
conduct current	divide space	enhance product
condition space	exclude elements	satisfy owner
protect people	move weight	allocate space

OTHER VERBS:

absorb	enclose	protect	reflect
create	control	collect	apply
hold	separate	transmit	reject

OTHER MEASURABLE NOUNS:

contamination	insulation	radiation	repair
density	liquid	voltage	light

-- More --

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C R E A T I V I T Y   S T I M U L A T I N G   C H E C K L I S T

A check-list with expert suggested trigger words is provided as shown below. This kind of self-questioning method has been proved by Osborn (1963) to be a useful technique to stimulate creative thinking. It can also encourage the user to think more deeply and systematically.

CHECKLIST FOR STIMULATING CREATIVITY

Can it be eliminated?
Can a change in design reduce operation or maintenance costs?
Can construction methods or procedure be simplified?
Can specification requirements be eliminated or modified?
Can a standard part or commercial product be used?
Can we improve the sequence of construction?
Is there a less costly part, product, or method that will satisfy the function required?
Can two or more parts be combined into one?
Do we need the present shape, size, or weight?

-- More --

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R O A D B L O C K S   T O   C A/V A   S T U D I E S

Roadblocks are negative generalisations that intended to stop progress and keep things just as they are. People are naturally hostile and resistant towards changes even remotely threatens their pattern of living (O'Brien, 1976). In order to develop large amounts of creative alternatives for previously identified functions, the potential roadblocks should be broken down and to find ways to prevent them happening. A team member alert to them will be in a much better position to take positive and practical steps to overcome the blocks. There are four types of self-imposed blocks: perceptual, habitual, emotional, or professional. Blocking results from any of these blocks or a combination of them.

The perceptual restriction is created by the failure to use all the senses, e.g. sight, hearing, taste, smell, and touch, to tackle a problem.

Habitual blocks involve the continuance of what has always been done or thought before. They may be generated internally or prescribed by an outside authority.

-- More --

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MODIFIED CONCEPTUAL FUNCTIONAL DIAGRAM

```
                                ┌── 1 Satisfy_Client's_Requirements
                                │
                                ├── 2 Identify_Site_Selection_Issues
                                │
Provide_Office_Facilities       ├── 3 Establish_Office_Facilities
                                │
                                ├── 4 Minimize_Development_Risks
                                │
                                └── 5 Safeguard Environment
```

Do you want to expand these new functions now (Y/n)? n

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Conceptual Functional Diagram (Level-1)

```
                               ┌── 1 Satisfy_Client's_Requirements    (1)
                               ├── 2 Identify_Site_Selection_Issues   (2)
Provide_Office_Facilities      ├── 3 Establish_Office_Facilities      (3)
                               ├── 4 Minimize_Development_Risks       (4)
                               └── 5 Safeguard Environment            (5)
```

Which function do you want to see in details (0 Quit) (0... 5)? 0

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Well done!

You have successfully modified the functions in the first level of the Conceptual Functional Diagram. The following screens will display the functions in the first level and their subfunctions in the second level. You will be provided with chances to modify those functions in the second level by answering "yes" to the question you are asked.

There might be several "yes/no" questions to be asked, please be patient and answer the questions carefully. If you are not sure if the functions listed in the second level are appropriate to your particular project, please **review project archives** provided within the knowledge base, or consult relevant experts in those areas.

FKeys: 1 Help 2 Quit -><- Mark hypertext keyword <Enter> Select keyword

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Well done!

There are a number of archives of previous projects provided to review. Their Conceptual Functional Diagrams are available and for some of them functional costs can be located to relevant functions. The archives are categorised into four groups: (1) Office Blocks (2) Chemical Plants (3) Computer Centres (4) Research labs

Although your project can only belong to one of these categories, you may find some useful and valuable information in other categories. Use appropriate project archives and think carefully before taking the functions into your project.

REVIEW PREVIOUS PROJECT ARCHIVES

FKeys: 1 Help 2 Quit -><- Mark hypertext keyword <Enter> Select keyword

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IDENTIFY CURRENT STAFF SITUATION

It is essential to analyze current staff situation before deciding whether to build a new office building. Although this process should be undertaken in the business analysis, it is still beneficial to think of it at this concept design stage. The following questions should be considered:

1. What's the total number of staff of the organisation, for which the project is to be built? Do we have shortages of staff?

2. What is the shortage in terms of space needed? Is it a permanent shortage or a temporary one? Is it possible to rearrange staff among current offices so that a new project can be saved?

3. Should we build a new office building to house those people? or Should we rent a temporary building to house them?

4. What kinds of functions do those people (for whom the building will be established) perform e.g. consultancy, design etc?

5. Where are they currently located? Will the new building suit them in terms of the distances between the office and their homes?

Hit any key to continue

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Do you have space shortage?

yes
no

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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Could you re-arrange available offices to solve it?

yes
no

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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What kind of shortage do you have?

temporary shortage
long term shortage

FKeys: 1 Help 2 Quit 3 Why? **7 Expand 8 Review**

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Think of hiring a modified office as well as a new office building. If hiring a new office building is not feasible, then a modified office might satisfy your requirements more economically.

Although you have a long term space shortage, it is still likely more economical to hire an office than developing a new one.

Would a hired office be more economical?

yes
no

FKeys: 1 Help 2 Quit 3 Why? **7 Expand 8 Review**

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MODIFYING FUNCTIONS (Level-4)

1.1.2 Identify_Overall_Requirements
- 1.1.2.1 Numbers_Tobe_Housed
- 1.1.2.2 Functions_Involved
- 1.1.2.3 Flexibility_Required

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

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By function, I mean the job they are doing, i.e. the profession. For example, the function can be computer aided design, engineering design or scientists/researchers in a chemical laboratory etc. The functions you input here will affect the size of the new building.

Think the entire number of staff in your organisation, and house them accordingly. It might be better to rearrange current staff and new staff among existing building and the new building, rather than just put new staff in the new building.

What functions will the staff perform in the new building?

Design
Research
Consultancy
Management
System Support

FKeys: 1 Help 2 Quit 3 Why? 7 Exp 8 Rev <Ins> Add <Del> Remove

```
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  What kind of flexibility is likely required?

          Flexi. for staff change
          Flexi. for function change
          Flexi. for extendability

FKeys: 1 Help 2 Quit 3 Why?        7 Exp 8 Rev <Ins> Add <Del> Remove
```

```
                 Conceptual Analysis Assistant -- Version 4.2

    Here the total modular offices required should include:
       M.O. for Directors, for Executives, and for Other Seniors

    While the administration rooms include:
        Equipment Area, Cleaning Rooms, Security Rooms,
        Reception Rooms, Storage Rooms, Service Area

    The Amenity rooms should include:
        Empty Area, Canteen/Kitchens, Sport
                                            Meeting_Rooms
Which of the following functional areas are r Dealing_Spaces
                                            Library_Area
                                            Administration_Rooms
  Production_Spaces is the area in which    Production_Spaces
  some small light construction may take    Amenity_Rooms
  place, e.g., small electronic assembly    Internal_Car_Parks
  areas. It is normal area as far as fi-    Security_Vaults
  nishes, fittings/heating are concerned,   Public_Access_Area
  but has special electrical services.      Modular_Offices
                                            Open_Plan_Offices
                                            Circulation_Spaces

FKeys: 1 Help 2 Quit 3 Why?        7 Exp 8 Rev <Ins> Add <Del> Remove
```

```
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                        MODIFYING FUNCTIONS (Level-3)
                        -----------------------------

                                     ┌1.3.1Clarify_Quality_Requirements
                                     │
                                     ├ 1.3.2 Determine_Quality_Level
1.3 Satisfy_Quality_Requirements     │
                                     ├ 1.3.3 Agree_Finishes
                                     │
                                     └ 1.3.4 Agree_Fittings



        (1) Add More Functions     (3) Recover Deducted functions
        (2) Deduct Some Functions  (4) Stop Modification

                        Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD  <F2> Quit  <F3> Review  Archives
```

```
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 Please specify for whom the quality requirements are?

           ┌──────────────────────┐
           │Quality for Business  │
           │Quality for Customers │
           │Quality for Employees │
           │Quality for Community │
           └──────────────────────┘


FKeys: 1 Help 2 Quit 3 Why?                          7 Expand 8 Review
```

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Think of what kind of quality is really needed to achieve your overall objective. The choice you have made here will directly or in-directly influence the selections of a number of functions, eg the architectural style, external walling, types of windows, int. environment, ext. environment of the building, architectural plan shape, finishing and fittings etc, which, will affect cost of the office building.

Which of the descriptions can best match the building?

Temporary Building
Functional Building
Prestigious Building

Functional Building
We assume that functional building may satisfy your basic office requirements. It however won't supply luxurious decorations inside and outside the building eg it will not use glazed curtain as its ext walling.

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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Could you specify the finishes for the building?

Basic_Finishes
Normal_Finishes
High_Quality_Finishes

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

Since you have defined "Functional_Building" as the quality level of the building, "Partial_Fitting" will be the best choice for your project (You may, of course, select other options provided).

Could you specify the fittings for the building?

Shell_Core_Only
Partial_Fitting
Fully_Fitted_Out

Shell_Core_Only means that there are:

A finished core (to the given quality level) heating/ventilation systems included; except in the core, no internal partitions, no wall finishes, no floor covering/ceiling finishes no fittings & furnishings, no light & power; but raised floor structure if wanted.

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

Generally there are two options for choosing a site for the building, i.e. use an existing site (e.g., Northwich, Wilmslow or Runcorn), or use a new site (eg a new site at Salford). The following factors are thought to be essential in choosing a site:

1. size of the site: reqs of building, car parks, security, landscapes.
2. site conditions: slope, water & rock problems, bearing capacity and previous development.
3. geological factors: access difficulty (road, rail, air & sea), staff availability, service availability.

Which of the following options is preferred by the client?

Existing_site
New_site

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

```
                  Conceptual Analysis Assistant -- Version 4.2

                          MODIFYING FUNCTIONS (Level-3)
                          -----------------------------

                                        ┌── 2.2.1 Requirements_of_Building
                                        │
                                        ├── 2.2.2 Requirements_of_Carparks
2.2 Clarify_Site_Requirements           │
                                        ├── 2.2.3 Requirements_of_Security
                                        │
                                        └── 2.2.4 Requirements_of_Landscape



        (1) Add More Functions      (3) Recover Deducted functions
        (2) Deduct Some Functions   (4) Stop Modification

                        Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD  <F2> Quit  <F3> Review Archives
```

```
                  Conceptual Analysis Assistant -- Version 4.2

                            MODIFYING FUNCTIONS (Level-3)
                            -----------------------------

                                         ┌── 2.3.1 Ground_Slope
                                         │
                                         ├── 2.3.2 Water_Problems
                                         │
2.3 Consider_Site_Conditions             ├── 2.3.3 Rock_Problems
                                         │
                                         ├── 2.3.4 Bearing_Capacity
                                         │
                                         └── 2.3.5 Previous_Development



        (1) Add More Functions      (3) Recover Deducted functions
        (2) Deduct Some Functions   (4) Stop Modification

                        Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD  <F2> Quit  <F3> Review Archives
```

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MODIFYING FUNCTIONS (Level-3)

2.4 Identify_Geographical_Factors
- 2.4.1 Access_Difficulty
- 2.4.2 Personnel_Availability
- 2.4.3 Services_Availability

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

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MODIFYING FUNCTIONS (Level-2)

3 Establish_Office_Facilities
- 3.1 Satisfy_Operability
- 3.2 Undertake_Building_Design
- 3.3 Create_Internal_Environment
- 3.4 Create_External_Environment
- 3.5 Provide_Furnishings
- 3.6 Provide_Services
- 3.7 Satisfy_Regulations

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

Conceptual Analysis Assistant -- Version 4.2

MODIFYING FUNCTIONS (Level-3)

3.2 Undertake_Building_Design
- 3.2.1 Number_of_Storeys
- 3.2.2 Support_Mechanism
- 3.2.3 Office_Plan_Shape
- 3.2.4 Architectural_Style
- 3.2.5 External_Walling
- 3.2.6 Window_Design
- 3.2.7 Relations_With_Other_Buildings

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

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Can you specify the support mechanism the building uses?

Loadbearing_Brick_Walls
Steel_Frame
In_Situ_Concrete_Frame
unknown

FKeys: 1 Help 2 Quit 3 Why? **7 Expand 8 Review**

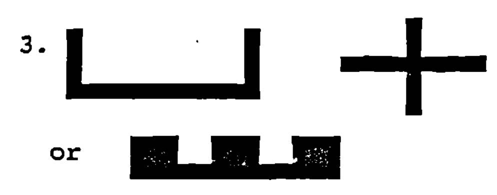
Conceptual Analysis Assistant -- Version 4.2

Please indicate which of the following architectural plan shape could best suit your needs for the quality of Functional Building.

Since it is a functional building, you may choose the shape you like but please bear it in mind that the more complex the plan shape is, the the more costly the building would be.

Which of these can best describe the plan shape preferred?

Single_Bar_Shape
L_Shape/T_Shape/Double_Bars
Channel/Cross_Shape
More_Complex_Than_Above3
Rectangular_Shape
Rectangular+L_Shape
More_Complex_Than_Above6



FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

To achieve the quality level of "Functional Building" you defined, we suggest that the following alternatives may best suit your request, though you may select other options provided within the list: No_Special_Requirements, General_Traditional, or With_High_Level_Of_Detail

Of course, if you select other options e.g. Prestigious Modern, the cost for providing will be considerable higher.

What kind of Architectural Style is going to use?

No_Special_Requirements
General_Traditional
With_High_Level_Of_Detail
Prestigious_Traditional
Prestigious_Modern
Ribbon_Windows
To_Make_A_Statement

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

To achieve the quality level of "Functional Building" and the architechtural style of "General Traditional" you have defined, we suggest "Brick_Cladding, "Brick_Stone_Mix", "Natural_Stone" may best suit your requests (You may, of course, select other options provided within the list).

What kind of material will be used for External Walling?

Brick_Cladding
Brick_Stone_Mix
Natural_Stone
Prestigious_Stone
PVC_Coated_Metal
Exposed_Aggregate_PC
GRP_GRC_Walling
Glazed_Curtain_Wall

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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RELATIONS WITH ADJACENT BUILDINGS

The following factors should be considered in order to harmonise the building with other buildings nearby:

Building Plan Shape
Architectural Style
Inter-Connections
Focus (Focal Point)
Proximity

Hit any key to continue

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MODIFYING FUNCTIONS (Level-3)

3.3 Create_Internal_Environment

- 3.3.1 Condition_Space
- 3.3.2 Provide_Heating
- 3.3.3 Circulate_Air
- 3.3.4 Control_Humidity
- 3.3.5 Control_Noises
- 3.3.6 Illuminate_Objects

(1) Add More Functions (3) Recover Deducted functions
(2) Deduct Some Functions (4) Stop Modification

Please put your selection here (1..4)... 4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

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The constraints for selecting a suitable air-conditioning system are as follows:

1) Climate where the building is located;
2) Scale of Air Conditioning needed;
3) Activities involved in the building;
4) Whether it is necessary to have Sealed Windows;
5) Quality, Prestige and the Fashion required.

Could you specify the AC system to condition the space?

Tempered_air
Reverse_cycle_pump
Local_package_units
Variable_air_volume
Fan_coil
Induction
unknown

Reverse Cycle Heat Pump (RCHP)

Uses refrigeration techniques to transfer heat from a waste source to the air in an area, or vice versa. May be used in reverse cycle for cooling in the summer. For small load cooling applications, this is often the least expensive option.

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

Please think which of the following options can achieve user specified functional requirements.

Here the function is to "Provide Heating". You may think some other ideas which can also achieve the function, but with lower costs.

Which of these can achieve the functional requirements?

Gas_Oil_Unit_Heaters
Electric_Heating
In_Between_Heating
District_Heating
Steam_Heating
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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Can you specify a preferred method to "Circulate Air"?

Mech_Extract/Natural_Inlet
Mech_Inlet_Natural_Extract
Mech_Extract/Inlet_Combined
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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What kind of noises need to be controlled?

```
Airborne_noise
Solid-borne_noise
unknown
```

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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What kind of lighting is required to illuminate objects?

```
Day_Lighting
Art_lighting
unknown
```

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

```
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MODIFYING FUNCTIONS (Level-3)

                                    ┌── 3.4.1 Prepare_Site
                                    │
                                    ├── 3.4.2 Provide_Landscape
3.4 Create_External_Environment     │
                                    ├── 3.4.3 Illuminate_Site
                                    │
                                    └── 3.4.4 Provide_Access_Parking

(1) Add More Functions        (3) Recover Deducted functions
(2) Deduct Some Functions     (4) Stop Modification

        Please put your selection here (1..4)... 4

FKeys: <F1> Display Current CFD  <F2> Quit  <F3> Review Archives
```

```
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What kinds of landscape are needed?

        Hard_Surfaces
        Soft_Area
        Signs_and_Ornaments
        unknown

FKeys: 1 Help 2 Quit 3 Why?          7 Exp 8 Rev <Ins> Add <Del> Remove
```

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For which the access and parking facilities are needed?

Pedestrians (inc. disabled)
Emergency_Services
Private_Cars
Goods_Vehicles
Bicycles
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Exp 8 Rev <Ins> Add <Del> Remove

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Are furnishings required in this project?

yes
no

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

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MODIFYING FUNCTIONS (Level-3)

```
                                   ┌── 3.6.1 Supply_Electricity
                                   ├── 3.6.2 Supply_Gas
                                   ├── 3.6.3 Supply_Water
                                   ├── 3.6.4 Supply_Communication_Facils
3.6 Provide_Services               ├── 3.6.5 Supply_Air
                                   ├── 3.6.6 Dispose_Refuse
                                   ├── 3.6.7 Convey_People_Goods
                                   ├── 3.6.8 Provide_Refreshment
                                   └── 3.6.9 Provide_Drainage
```

(1) Add More Functions　　(3) Recover Deducted functions
(2) Deduct Some Functions　　(4) Stop Modification

Please put your selection here (1..4)...4

FKeys: <F1> Display Current CFD <F2> Quit <F3> Review Archives

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What functions should we perform in order to achieve the function **Supply Electricity** ? Please give your answers as following:

1. Quantity
2. Reliability
3. Voltage
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.

Hit Ctrl+End when the input is completed.

You may overwrite the functions displayed in the field.

FKeys: 1 Help 2 Quit 4 FldHelp

```
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 What functions should we perform in order to achieve the function
 Supply Gas     ?   Please give your answers as following:

 1.   Installation                      Hit Ctrl+End when the input is
 2.   Safety                            completed.
 3.   Source
 4.   Quantity                          You may overwrite the functions
 5.                                     displayed in the field.
 6.
 7.
 8.
 9.
 10.
 11.
 12.
 13.
 14.
 15.
 16.
 17.
 18.

FKeys: 1 Help 2 Quit           4 FldHelp
```

```
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 What kind of water is likely needed in the building?

          Drinking_water
          Cooling_water
          Fire_water
          Hot_water
          unknown

FKeys: 1 Help 2 Quit 3 Why?       7 Exp 8 Rev <Ins> Add <Del> Remove
```

Conceptual Analysis Assistant -- Version 4.2

Which of the methods can supply water best?

Local_system (Hot)
Central_boiler_System (Hot)
Boosting_by_pump
Boosting_by_pneumatic_cylinder
Break_cisterns/indirect_supply
High_rise_system
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Exp 8 Rev <Ins> Add <Del> Remove

Conceptual Analysis Assistant -- Version 4.2

Which of the communications facilities are needed?

Fax_Machine
PA_Systems
Telephones
Information_Retrieval
Fire_&_Security_Alarms
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Exp 8 Rev <Ins> Add <Del> Remove

Conceptual Analysis Assistant -- Version 4.2

Which of the alternatives will be used to dispose refuse?

Waste_Grinders
Refuse_Chutes
Garchey_Systems
Trolley_Service_Lift
Dustbin_Disposal_Bags
unknown

FKeys: 1 Help 2 Quit 3 Why? 7 Exp 8 Rev <Ins> Add <Del> Remove

Conceptual Analysis Assistant -- Version 4.2

What functions should we perform in order to achieve the function **Satisfy_Regulations ?** Please give your answers as following:

1. Satisfy_building_regulations
2. Satisfy_fire_regulations
3. Satisfy_safety_regulations
4. Satisfy_security_regulations
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.

Hit Ctrl+End when the input is completed.

You may overwrite the functions displayed in the field.

FKeys: 1 Help 2 Quit 4 FldHelp

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What functions should we perform in order to achieve the function **Maximize_opportunity ?** Please give your answers as following:

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.

Hit Ctrl+End when the input is completed.

You may overwrite the functions displayed in the field.

FKeys: 1 Help 2 Quit 4 FldHelp

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Would you like me to call ELSIE to estimate the cost?

yes
no

FKeys: 1 Help 2 Quit 3 Why? 7 Expand 8 Review

Conceptual Analysis Assistant -- Version 4.2

LINK ELSIE BUDGET MODULE

Within the next step, you will be able to run ELSIE Budget Module -- a successful commercial ES to estimate building cost at early design stages.

The project information provided and generated within current module will be transferred to ELSIE BM automatically. You may still need to answer some questions asked by the Budget Module, in order to generate a fairly accurate cost estimation. Please follow the instructions & help facilities provided by the Budget Module and get whatever cost information required by the project.

Please remember to switch the database from default "ov3proj.db" to the CA/VA project database i.e. "c:\leo\caaproj.db", as your data were stored in the CA/VA database. Detailed information about how to switch the databases is introduced in the ELSIE Budget Module.

Hit any key to continue

Conceptual Analysis Assistant -- Version 4.2

There are some questions, which have not been asked in this module, to be asked in the ELSIE BM. It may take some times for you to answer them, and for ELSIE BM to respond to your answers. However I can make some assumptions for you if you wish. You may change those assumptions later in the ELSIE Module by using the facilities provided by there.

Would you like me to make some assumptions? (Y/N) y

<F1> display assumptions, <F2> print assumption report

Conceptual Analysis Assistant -- Version 4.2

To link with ELSIE Budget Module, relevant project data have to be stored in database.

Currently there are 24 project records in the database -- caaproj.db.

Where would you like to put your new project data? (1...26) 15

Do you want to replace record No. 15 in the database? (Y/N) y

ELSIE BUDGET MODULE

This is Version 3.1 of

T H E   B U D G E T   M O D U L E

Fixing a Financial Budget
June 1990

Press <Enter> to continue

ELSIE BUDGET MODULE

Are we considering a new building project, or giving further consideration to one stored in the Projects Database?

IF A NEW PROJECT: Enter 0.

IF IN DATABASE: Enter its index number.

TO OPEN A NEW FILE: Enter -1 (Current file is OV3PROJ.DB)

(You may obtain a list of Projects currently in the Database from Help No. 11.)

There may be a pause of 10 seconds or so after you answer this question, since I will be propagating the information throughout the entire Knowledge Base.

(-1 ..1000).. -1

ELSIE BUDGET MODULE

Please enter the name of the file in which the Projects Database resides, ensuring that you enter it correctly. Make sure you get the name right.

(If it is on a floppy disc, the name should be preceded by the name of the disc, such as <a:harrison.db>. If on another directory, it should be preceded by the directory path, such as <\DB\3\harrison.db>.)

The name of the file before the dot, that is 'harrison' above, can have up to 8 letters.

(Enter1 ..30 Characters or ? Option) c:\leo\caaproj.db

```
ELSIE BUDGET MODULE          Project:   15  cava tutorial

THE WHAT-NOW POINT:  What would you like to do now?

Reports:
  1. Cost Breakdown            3. Graphs
  2. Assumptions Report        4. Send reports for printing

Changing and Overriding:
 11. Site and Location        16. External Appearance, Image
 12. Functional Needs         17. Building Structure
 13. Functional Spaces        18. Fitting Out
 14. Major Items              19. Services
 15. Size and Shape           20. Other

Other:
 21. Store project information in database
  0. Stop.                    90. Start a new run

Tender Estimate    =  £11.83 M    ALL FIGURES ARE APPROXIMATE
Rate (excl. DR,CC) =  £912 /m2 of 11455 m2, 123258 sqft, GIFA
                   =  £1406 /m2 of 7432 m2 of  Usable Space.

                         (0 ..100).. 1
```

ELSIE BUDGET MODULE   Project: 15 cava tutorial

ELEMENTAL BREAKDOWN	%	0........50	£/m2	£
1 Substructure	2		18	207479
Basement	0		0	0
2A Frame	11		101	1154452
B Upper floors	6		56	637120
C Roof	1		10	112292
D Stairs	2		18	209372
E External Walling	19		171	1961349
F Windows + Ext Doors	1		14	154732
G Internal walls/doors	4		34	390909
3 Finishes	6		54	622167
4 Fitting and Furnishings	0		3	32735
5F Heating and Ventilation	18		165	1885984
H Electrical	5		47	540856
J Lifts	2		22	246386
M Special Installations	0		2	28327
Other Services and BWIC	5		42	479552
6 External services/works	4		37	427936
7 Prelims	13		119	1358522
Total (less contingencies)	100		912	10450170

B)ackwards, F)orwards or S)top [B,F,S]

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* * * INTRODUCTION TO BUILDING NORM * * *

Here the term "norm" is defined as the alternative of an element which can satisfy the basic functional requirements, with the lowest overall cost.

Norm is dependent on where and when it is used. For instance, different organisations may have different norms for their projects. Personal Computer has become the norm for data processing, as the power of a PC is increasing and the prices of PCs are declining.

In the following screens, we are going to compare the scheme and the cost of the scheme with the norm which is assumed by the system. You can however change the norm according to the practice in your organisation.

Hit any key to continue

Conceptual Analysis Assistant -- Version 4.2

DISPLAYING SPECIFIED NORMS

The norm project has been specified and stored in the project database - caaproj.db in the directory of C:\LEO. A chance is provided now for you to examine the differences among the initial project definition and the norm project. You may also explore the differences later by running the ELSIE Budget Module.

Please remember to switch the project database from the default one to c:\leo\caaproj.db where your project information was stored.

Hit any key to continue

```
              Conceptual Analysis Assistant -- Version 4.2

                      Norms Assumed In The System
   No  14. Height restriction.....0: (no restriction)
   No  20. Car park place.........0: (no car park)
   No  30. Wall appearance........1: Brick
   No  32. Architectural style....1: No style in mind
   No  50. Level of fitting out...1: shell and core only
   No  52. Need large spaces......0: Not at all
   No  53. Column-free space......0: False
   No  54. Airtightness...........0: Not at all
   No  55. AC where?..............1: No AC
   No 140. AA quality.............3: Medium
   No 141. Performance quality....3: Medium
   No 142. Level of flexibility...3: Moderate-high
   No 150. AC type................1: Tempered air
   No 151. Raised floor...........1: In special areas only
   No 174. Plan shape.............1: Rectangular bar shape
   No 181. Structural complexity..3: Average
   No 191. Ext wall details.......5: Medium level of detailing
   No 193. Roof construction......1: Pitched
   No 194. Roof complexity........1: Roof has one or two steps
   No 200. Frame type.............1: Frameless
   No 225. Install complexity.....4: Medium complexity

       Do you want to change these norms? (Y/N) N
```

```
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 Which project do you want to compare with the norm? (The
 index number inside CAAPROJ.DB where the project was stored) 15


Where would you like to store the norm file? (Give a index
No. inside the CAAPROJ.DB where the file will go [1..26])   16
```

```
ELSIE BUDGET MODULE          Project:  15  cava tutorial

THE WHAT-NOW POINT:  What would you like to do now?

Reports:
  1. Cost Breakdown            3. Graphs
  2. Assumptions Report        4. Send reports for printing

Changing and Overriding:
 11. Site and Location        16. External Appearance, Image
 12. Functional Needs         17. Building Structure
 13. Functional Spaces        18. Fitting Out
 14. Major Items              19. Services
 15. Size and Shape           20. Other

Other:
 21. Store project information in database
  0. Stop.                    90. Start a new run

Tender Estimate     =  £5.87 M    ALL FIGURES ARE APPROXIMATE
Rate (excl. DR,CC) =  £482 /m2 of 10759 m2, 115764 sqft, GIFA
                    =  £698 /m2 of 7432 m2 of  Usable Space.

                            (0 ..100).. 1
```

ELSIE BUDGET MODULE   Project: 15 Cava Tutorial Norm Building

ELEMENTAL BREAKDOWN	%	0........50	£/m2	£
1 Substructure	4	......	18	191079
Basement	0	....	0	0
2A Frame	0	....	0	0
B Upper floors	11	....	53	569994
C Roof	2	......	9	93508
D Stairs	3	......	16	167921
E External Walling	6	......	29	315268
F Windows + Ext Doors	9	......	41	446184
G Internal walls/doors	7	......	33	354237
3 Finishes	11	....	55	592840
4 Fitting and Furnishings	1	....	3	27068
5F Heating and Ventilation	8	......	40	434530
H Electrical	9	......	43	459474
J Lifts	5	......	22	241968
M Special Installations	1	....	3	27221
Other Services and BWIC	8	......	38	404284
6 External services/works	4	......	17	184702
7 Prelims	13	....	63	673950
Total (less contingencies)	100		482	5184229

B)ackwards, F)orwards or S)top [B,F,S]

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The following functions are defined for this building:

Basic Functions include:
1. Accommodate Activities
2. Accommodate Personnel

Supporting Functions include:
1. Provide Flexibility
2. Ensure Buildability
3. Improve Efficiency
4. Project Corporate Image
5. Assure Convenience
6. Ensure Reliability
7. Satisfy Regulations
8. Maintain Security
9. Ease Maintenance
10. Conserve Energy

The extra cost of the project above the norm building will be allocated against the supporting functions as mentioned above. It may take a while, please wait....

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The first step I take is to find the differences in costs among the original design and a number of virtual projects. The cost-affecting factors in each virtual project have the same values with the factors in the original design, except in one factor each time. Because there are 21 defined cost-affecting factors in this calculation, there are 21 virtual projects in the compare.db database.

The cost of the initial design is: £10450K
The cost of the norm building is: £ 5184K
The costs of each virtual project are as follows:

Cost 1= £10450K	Cost12= £10406K
Cost 2= £10184K	Cost13= £ 9278K
Cost 3= £ 9078K	Cost14= £10450K
Cost 4= £10450K	Cost15= £10309K
Cost 5= £10450K	Cost16= £10365K
Cost 6= £10450K	Cost17= £10322K
Cost 7= £10450K	Cost18= £10433K
Cost 8= £10444K	Cost19= £10449K
Cost 9= £ 8428K	Cost20= £ 8912K
Cost10= £10169K	Cost21= £10368K
Cost11= £10450K	

Hit any key to continue

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The differences among the cost of the initial design and the costs of virtual projects are therefore as follows:

D 1=	£ 0K	D12=	£ 44K
D 2=	£ 266K	D13=	£ 1172K
D 3=	£ 1372K	D14=	£ 0K
D 4=	£ 0K	D15=	£ 141K
D 5=	£ 0K	D16=	£ 85K
D 6=	£ 0K	D17=	£ 128K
D 7=	£ 0K	D18=	£ 17K
D 8=	£ 6K	D19=	£ 1K
D 9=	£ 2022K	D20=	£ 1538K
D10=	£ 281K	D21=	£ 82K
D11=	£ 0K		

Hit any key to continue

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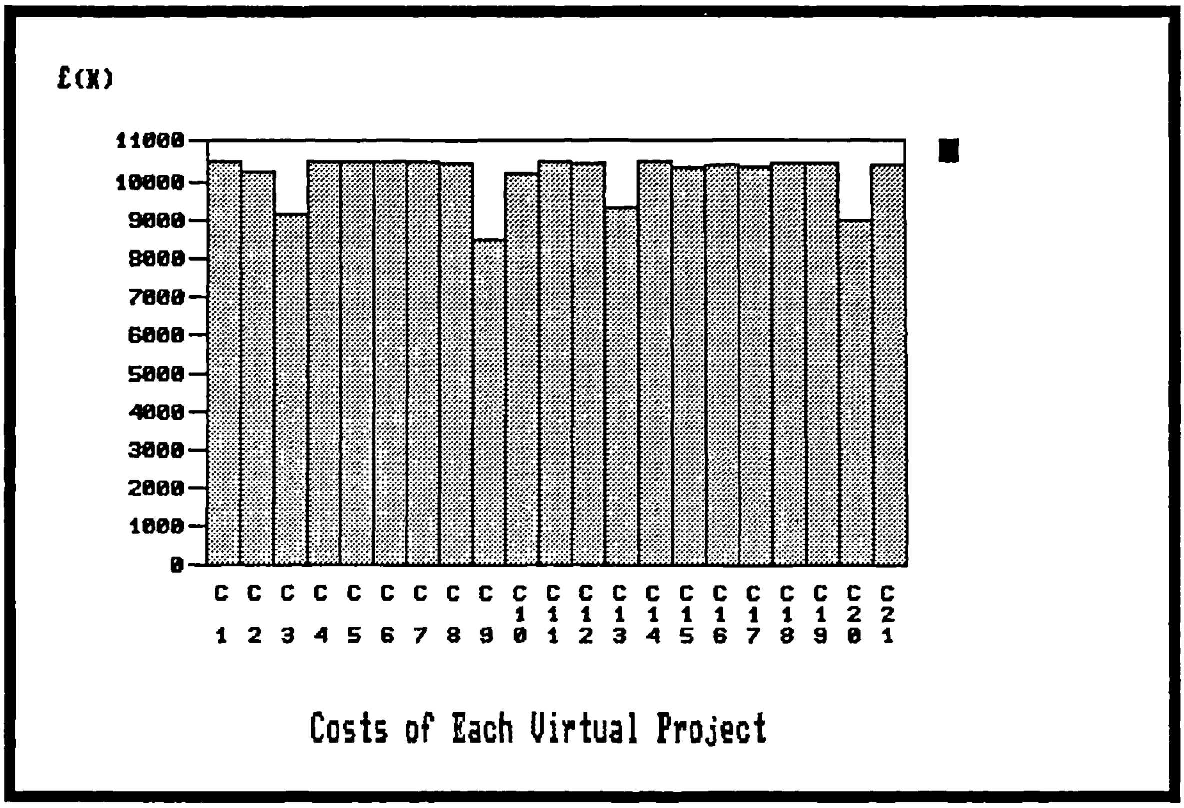
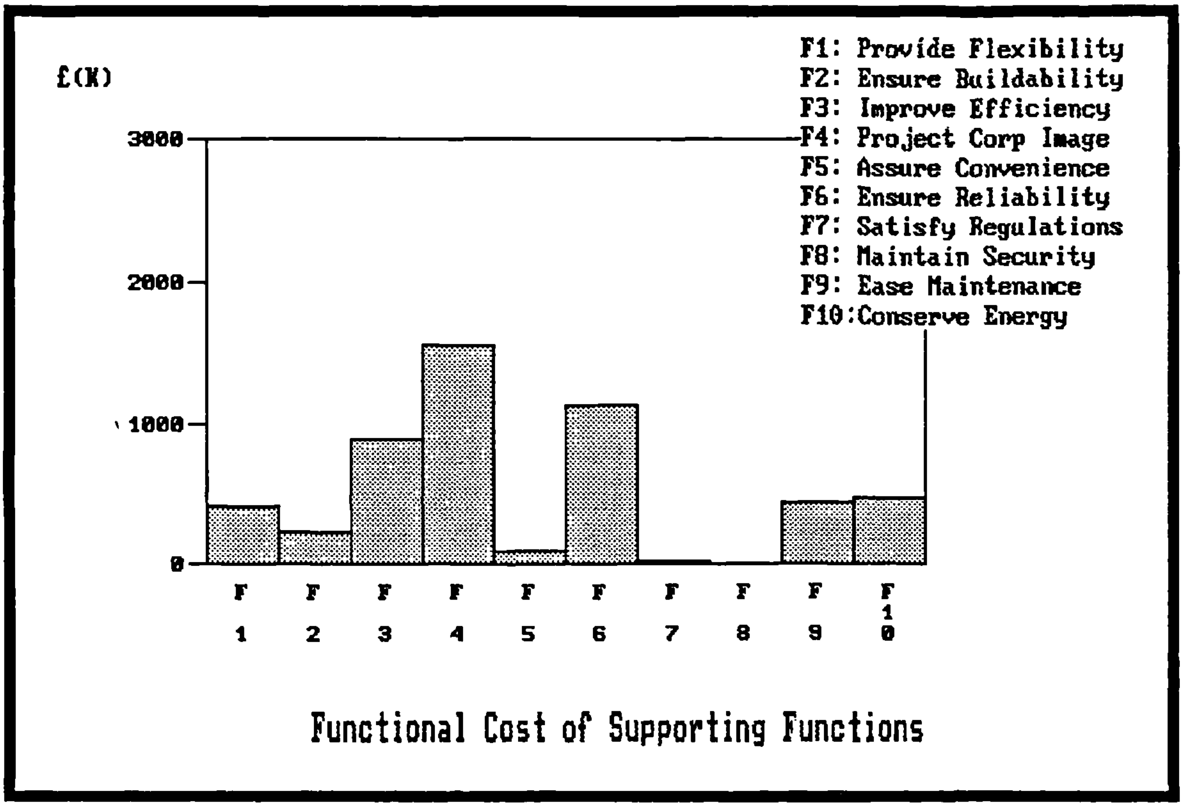
The costs of each supporting function are:

FC 1=	£ 419K
FC 2=	£ 233K
FC 3=	£ 896K
FC 4=	£ 1552K
FC 5=	£ 101K
FC 6=	£ 1132K
FC 7=	£ 19K
FC 8=	£ 0K
FC 9=	£ 440K
FC10=	£ 475K

Total= £ 5266K

Hit any key to continue


£(K)
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20 C21
Costs of Each Virtual Project


£(K)
3000
2000
1000
0
F1: Provide Flexibility
F2: Ensure Buildability
F3: Improve Efficiency
F4: Project Corp Image
F5: Assure Convenience
F6: Ensure Reliability
F7: Satisfy Regulations
F8: Maintain Security
F9: Ease Maintenance
F10: Conserve Energy
F1 F2 F3 F4 F5 F6 F7 F8 F9 F10
Functional Cost of Supporting Functions

```
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  The name of the report must be started with a letter and the number
of characters in the report name should be less than 8.  There is no
need to give any extension to the name, as an extension of 'rep' will
be automatically added to the name you give.



Could you specify a name for the report of the analysis?

          tutorial 1




FKeys: 1 Help 2 Quit 3 Why?                          7 Expand 8 Review
```

```
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    Please input the following information for the VM report:

 Project Title: tutorial 2
 Project Location: Yorkshire
 Study Date (from... to...): 20/10/1992
 Team Leader: ABC                                 Phone: XXXXX
 Number of Team Members: 4
                          Full Name                    Discipline
 Team Member 1: A1                                Architect
 Team Member 2: A2                                Structural Engineer
 Team Member 3: A3                                Service Engineer
 Team Member 4: A4                                Contractor



      Preparing report, please wait....
```

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