A Computer Integrated System for Crane Selection for High-Rise Building Construction

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ABSTRACT

A COMPUTER INTEGRATED SYSTEM FOR CRANE SELECTION FOR HIGH-RISE BUILDING CONSTRUCTION

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Material handling is an important part of the delivery process of construction projects, and cranes are the pivotal tool for achieving this, specially on a building construction site. Selection of type(s), number(s), and location(s) of crane(s) to be used in constructing a high-rise building is a focal issue in planning the construction operations. The selection process is complex and demands detailed planning and good judgment. Selecting a crane, requires prediction as to the consequences of the choice that is to be made. A wrong decision is likely to have significant effects in terms of high cost and possible delays. The ability to predict and make decisions grows out of knowledge and experience gained during many years of work on construction sites. Most of the time this knowledge is not available to the decision maker when needed, making a knowledge-based system containing knowledge on the cranes selection process a valuable tool to be used in this domain.

Conventional algorithmic programs are unable to manipulate heuristic and qualitative knowledge which is necessary to solve construction problems such as the equipment selection. On the other hand Knowledge Based Expert System (KBES) are not robust in numerical data manipulation, while being very effective in declarative knowledge manipulation and handling of logical inferences and reasoning. Therefore, expert systems and conventional programming can be combined to support an effective decision throughout the crane selection process.

This research concentrates on presenting a methodology for crane selection for high-rise building construction projects. The methodology is incorporated into an integrated computer system, called CRANE ADVISOR, capable of advising the users on the selection of appropriate cranes for their building construction projects. Experts knowledge has been captured, classified and coded in the system's knowledge-base. CRANE ADVISOR integrates a knowledge-base with algorithmic programmes, and commercially available tools such as: database management (Dbase III), spreadsheet applications (QuatroPro), and graphic simulation (AutoCAD).

The system incorporates two main modules. The first being a Knowledge-Based module that contains experts knowledge, heuristics and rules of thumb related to cranes selection. The second is a Case-Based Reasoning module containing information on various cases representing already constructed buildings with pre selected crane(s). In addition to the knowledge-base, the system integrates procedural algorithms for performing routine calculations and graphic validation to support the crane selection process, in three other modules: geometry calculations, graphical validation, and cost estimation. All the modules share a global database containing information on a number of already constructed buildings, information on problems related to cranes used in their construction, and data on a large number of commercially available cranes, that includes their types, their specifications and cost.

The system benefits from the Object Oriented Programming characteristics of the abstraction, inheritance, modularity, and encapsulation of data. LEVEL 5 as an Object-Oriented Expert System shell, has been used to develop the CRANE ADVISOR. It allows for the stored data and knowledge to be accessed by all parties involved in the crane selection process. It is also capable of facilitating user friendly interface. An example case is presented in order to demonstrate the effectiveness of the methodology.

The Crane Advisor contributes to the current automation efforts in construction industry and its modular architecture allows for further enhancements and expansions.

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CHAPTER I

INTRODUCTION

1.1 GENERAL

Crane selection is a complicated task and depends greatly on skilled judgment, taking into account all likely involved variables. Useful information is available to assist in modelling the process and exists in the form of work study data, manufacturers machines performance specifications, guidelines on methods of calculating production output, and equipment requirements. Contractors generally attempt to minimize cost and maximize profit within the constraints of contract requirements including specifications. This requires prior knowledge of the cost of the resources used in constructing the project including cranes. This means that, such resources would by implication have already been decided on. Therefore, cranes must be carefully selected and their related costs taken into consideration when optimizing the cost of operations that involve their usage. This makes the crane selection a complex process and difficult for the inexperienced personnel to accomplish. To reduce the complexity of the problem, artificial intelligence (AI) techniques including Expert Systems (ES) and case-based reasoning have been applied in a computerized integrated environment, where cases and heuristics in addition to algorithmic techniques are used to formulate a methodology for crane selection. In the proposed methodology tasks are to be carefully evaluated then appropriate cranes selections are to be made using rules of thumb i.e., knowledge acquired from the domain experts and stored in an expert system. In addition to the knowledge-base, the system integrates a procedural algorithms for performing routine calculations needed for the selection process.

1.2 RESEARCH OBJECTIVES

Most of the materials used in the buildings construction sites are handled several times and in different directions. Cranes are mainly the principal equipment used in their hoisting.

The main objective of this research is to study the current practices of the crane selection used on high-rise building projects, aiming at modelling the process in a computerized integrated environment. The research objectives can be listed as follows:

- Obtaining a precise understanding of the Decision-Making process for crane selection.
- Investigating the factors affecting cranes and their selection in High-Rise building projects.
- Establishing a knowledge acquisition methodology for crane selection.
- Developing an integrated computer system, capable of advising on the selection of the most appropriate crane(s) for constructing high-rise buildings.

1.3 METHODOLOGY

In order to achieve the above mentioned objectives the following steps were followed:

1.3.1 Literature Review

An intensive review of literature in the area of crane selection, was carried out and presented in chapter (2)

1.3.2 Site visits (construction sites and equipment rental companies)

Site visits were conducted to meet with practitioners and discus matters related to the current practices used in crane selection.

1.3.3 Knowledge Acquisition

Experts in the domain of crane selection were identified, their knowledge was acquired and stored in the knowledge-base of the expert system to be used in the decision making process, as described in chapter (4).

1.3.4 Development of a prototype system

Information and knowledge collected from the experts were classified, coded, and represented in a computer prototype model. This model was presented to the experts for criticism, feed back and to test its effectiveness. Chapter (5) describes the development process of the system.

1.4 THESIS ORGANIZATION

Chapter 2 includes a summary of the literature review. Current practices and the nature of crane selection process is discussed. A description of the computer-aided building design and new trends in computing, with more emphasis on Knowledge-Based expert system, Case-Based reasoning and Object-oriented programming are also included. Spreadsheet and Graphic software together with some of their applications to the equipment selection in the construction industry are presented. Management database systems and some of their applications in construction are also described.

Chapter 3 discusses the crane types and factors affecting their selection. A description of cranes types commonly used in construction (mobile cranes, tower cranes, and derrick), is presented.

Chapter 4 describes the knowledge acquisition and representation processes.

Chapter 5 Covers Computer Integrated Systems, their design methodologies and their main features.

Chapter 6 discusses the proposed Computer Integrated System. Description of the design methodology including the development of its components: the Knowledge-Based module, Case-Based Reasoning module, the Calculation module, the Graphic Adaptation module, the Cost Estimation Module, the systems Data-bases, and the global data-base is presented.

Chapter 7 presents the application of the system to a case study.

Chapter 8 includes the research conclusions and recommendations for future work in the area of crane selection.

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

Selecting cranes for building construction and locating them on site depend greatly on skilled judgment that accounts for all likely involved variables. Much information is available to assist in this process in the form of: work study data, manufacturers' machines performance specifications, guidelines on methods of calculating production output, labour resources and equipment requirements, etc.. Unfortunately this information is incomplete and generally requires the user to make bold decisions on job conditions and categories of cranes for a particular situation leading to unavoidable mistakes and perhaps to a wrong decision.

The selection process is complex and demands detailed planning and good judgment. Selecting a crane, requires prediction as to the consequences of the choice that is to be made. A wrong selection is likely to have serious consequences in terms of high cost and possible delays.

This chapter describes the methods and current practices used in the area of crane selection for construction projects. In addition, a review of the applications of Knowledge-Based Expert systems, Object-Oriented Programming, Case-Based reasoning methodology, Computer Aided Design (CAD) systems, Spreadsheet, and Data-Base management systems in the construction industry in general and to the crane selection in particular are also described.

2.2. KNOWLEDGE-BASED EXPERT SYSTEMS (KBES)

Expert systems as a branch of the Artificial Intelligence field deal with emulation of the human thinking process in computers. Expert Systems are computer programs that use knowledge and information collected from experts in a specified domain, combined with procedures in solving problems that are difficult for inexperienced personnel to solve. Knowledge-Based Expert Systems use symbolic logic and heuristics in order to find solutions efficiently in a narrow problem area (Waterman, 1986).

The use of expert systems was very limited two decades ago, because of the difficulties in their development since complex programming languages and mainframe computers were required (Baker, 1988). Developing an expert system has become less complicated by the introduction of expert systems shells that run on personal computers.

Expert system shells concentrate mainly on the programming need for building Knowledge-Based Expert Systems and provide a set of tools to allow multiple paradigms in the same program (Ramamoorthy et al., 1987)

2.2.1 KBES Main Characteristics

Decision making requires a sequence of actions needed to be taken to perform the process from an initial status to a goal status (Hegazy 1993). **Facts** and **Heuristics** are the main characteristic of such a decision making process. **Facts** constitute a body of information that is widely shared, publicly available and generally agreed upon by experts in a specific domain. **Heuristics** are mostly private rules of good judgment, that characterize expert-level decision making in the field. These characteristics can be combined in a KBES making it to function like human experts (Valliere and Lee, 1988).

2.2.2 KBES Structure

The course of actions in a KBES environment involve several components: a User, a Knowledge-Base, and an Inference Mechanism.

The user is the main component in any structured KBES. The user is best described by Waterman (1986), as a human who uses the KBES ones it is developed, and rely on the system for advice. The user is the person who is asked to input the required data and description of the problem he/she is facing, in order to enable the system to generate a solution. The final decision is validated by the same user. In this respect a user friendly system, supported by graphic representation capabilities is required in order to provide convenient communication between the system and the user.

The knowledge is specific to the domain of the problem to be solved and can be classified into 'deep' (basic principles) and 'surface' (heuristics) knowledge with respect to how well it is established (Maher 1985, Parsaye and Chignell 1988).

The Inference mechanism (engine) contains the inference strategies, tricks and controls that an expert would use to manipulate the facts and rules (knowledge) while solving a problem.

2.2.3 KBES and the Equipment Selection

Knowledge based systems and their various applications in construction have been extensively described in the literature, (Mohan 1990, Moselhi et al. 1990, Alkass 1988, Levitt 1987). They have been used for equipment selection (Alkass et. al. 1993, Amirkhanian et al. 1992, Moselhi and Ghazal 1992, Alkass and Aronion 1990, Alkass et al. 1989, Christian et al. 1987, Bernel, and Colin 1986, and James 1989).

Very few attempts in developing computer modules for crane selection and their use have been reported in the literature. **PRECISE** (Karl & Gary 1993) is a computerized analysis method to minimize the number of moves required by a mobile crane to erect steel structures. The system selects the optimum path for the crane and detemines the steel erection sequence. The system uses Artificial Intelligent (AI) techniques to solve the problem. It is limited to a single story steel structure, and the use of mobile crane on site.

CRANES (Cooper. C., 1987) is a rule based expert system for the selection of tower cranes for the construction of multi-story buildings, it requires the user to input the building dimensions, the load distributions, and the cranes location. The system is limited to the selection of tower cranes only, and requires the location to be selected in advance.

The module **CRANES** (Gray, C. and Little, J. 1985) was developed to assist the users in the selection of appropriate cranes and their locations on construction sites. It has two components, the graphics routine which considers the implications of the building's shape, and the load distribution and possible crane location. The system is based on mathematical calculations rather than knowledge, it requires a change of the number and the size of the selected crane(s) during the course of the project construction, such practice is not practical and usually unacceptable to the contractors.

LOCRANE (Wrszawski 1990) has been developed as a test case for the application of the expert system methodology to construction planning tasks, it was limited to the selection of cranes for a given building.

Earlier models such as **COCO** developed by the PSA, "Department of the Environment, London" (DoE, 1972), as described by Gray and Little 1985. The model requires the identification of the load and crane position assuming limited types of cranes. Similar approach, but, considering the building as a regular shape to optimize the crane's locations was also introduced (Furusaka and Gray, 1984).

2.3 OBJECT-ORIENTED PROGRAMMING (OOP)

The major challenge in computer programming is to develop quality software in the shortest amount of time. Conventional software generally are delivered late, their costs usually run over budget, and they are often not bug-free and are difficult to modify.

On the other hand Computer Assisted Software Engineering (CASE) allows to automate certain modular design and structured programming activities, the role of structured and modular programming is limited, because it is difficult to anticipate the whole system's design before it is effectively implemented.

Large systems need to store permanent information to be shared by the systems different modules through a database management systems (DBMS). Different database structures are available, such as: Hierarchical and networked DBMS which represent data and its inter-relation using predefined structures and are, therefore, difficult to modify. In this context relational DBMS which allow to model data using simple structures (tables) without having to predefined the data inter-relations. However, these databases have reported bad performances when dealing with complex data structures where different types of information, such as text, graphics, images,...etc. need to be stored.

In view of these facts, a new approach in developing computerized systems that are flexible, reliable, easy to maintain, and able to rapidly adapt to changes is needed.

Object-Oriented Programming technology (OOP) as a new approach to programming, which can eliminate the separation between data and procedures, appears to be suitable for developing effective computer systems.

2.3.1 Object-Oriented Programming main approach

The prevailing concepts and features that characterize OOP languages and distinguish them from traditional programming are 'Encapsulation' and 'Inheritance' (Cox 1990, Duff and Howard 1990). This kind of relation is performed between Classes and Objects.

Object usually represents a physical entity, e.g. building, facade, equipment etc. it is called the encapsulation of data and procedures. The object holds the data representing the object in whatever format is convenient for it and contains a collection of permitted manipulations that may be applied to this data.

Class is a concept of the abstraction of an object or objects, it is the description of properties (variables and methods) common to objects of the same type. Every object is an **Instance** of a predefined class, and all the objects of a given class are identical in their structure and in their potential behaviour, they differ from the other objects of the same class by the value of their variables. The variables and the methods of an object are described in the class, while the values are contained in its instance.

Encapsulation is the foundation of the whole approach and it implies that the information contained in an object is hidden from the other objects in the system. In general it is used to describe an object's protection of its private data from outside or **interface** access. It constitutes the list of all the **service** (methods) which other objects can access.

Messages are the signals that an object send to another object to request the execution of one of the methods included in the receiving object. In general messages mediate all possible interactions between objects. Three main components are involved in each message: the message recipient's name or **receiver**, the **method** to be applied, and all the **parameters** required for that method.

Inheritance is the ability of an object to automatically derive its data and functionality from another object. Classes can be defined with respect to others using the **inheritance** mechanism. When a class inherits from another class, it can use the variables and methods defined in the class it inherited from. With this respect, classes are organized into a hierarchy of superclass. A subclass inherits all the methods, data structures and class variables that were possessed by its superclass.

2.3.2 Object-Oriented Programming Applications in Construction Industry

Object-Oriented Programming provides a highly flexible and modular programming environment for analysis and design of computer systems capable of solving complex engineering problems. Object-Oriented Programming (OOP) paradigm and characteristics of abstraction, inheritance, modularity, and encapsulation of data as described by (Booch, 1991) have received considerable attention among professional and academic groups. OOP has been successfully used by researchers; Forde and Stiemer (1989) showed how OOP can be used to improve the design and implementation of interactive engineering software systems. Yu and Adeli (1991) presented a CAD model using the OOP in manipulating intermediate data created during a consultation with the CAD system. Moselhi, O., and El-Rayes (1993) utilized the OOP technique to design the different components of repetitive projects, and presents the relationship between different types of activities as an objects. This has been done in an OOP module, which provides the capability of maintaining the crew work continuity constraint for repetitive activities, that help avoiding non-productive man-hours and reducing construction time and cost. Paset, L. (1995) has successfully used OOP techniques in the development of the heuristic method for construction project scheduling, by integrating the resource allocation model with modelling uncertainties technique for construction scheduling, employing Fuzzy set theories for modelling the uncertainties associated with the durations of project activities and the resource availability.

2.3.3 Case-based reasoning

Case-based reasoning approach was found to be suitable for solving complex problems controlled by large number of parameters In this approach data on existing cases, (i.e. a building as a case that has already been constructed and the crane selection problem has been solved) is gathered and stored in a database, along with description of the decision making process and procedures used in their construction. Associated problems raised from wrong decisions made during the planning process are also stored in the database. This data can be used to avoid potential problems that might occur during the decision making process for new projects.

The use of Case-Base Reasoning approach in construction has been mainly limited to solve design problems, CADRE (Bailey and Smith 1994) is an approach which focuses on dimensional and topological adaptation of geometric models of existing buildings to find solution for new design problems. CYCLOPS (Navinchandra 1988) is a landscape planning and design system which uses analogical reasoning to identify cases with previous problems and their solution.

CADSYN (Zhang and Maher 1993) is a case-based building design system that considers architectural space planning, structural design, and services design.

No attempt however, to use case-based reasoning for equipment selection has been reported in the literature despite the fact that the equipment selection process is complex, and is affected by a large number of technical and economical factors, making such a process complex.

2.4 DATABASE

A computer integrated system which combines the Case-based reasoning (CBR), with a Knowledge-Base, and algorithms, would need many hundreds of cases to reason from, making the design of a database to accommodate the related data a difficult task. Such a database can be best structured using OOP.

Part of this research concentrates on designing this database to be capable of storing, indexing and retrieving information on cases to perform communication between all the system's components. Facts relating to the crane selection process in high-rise building such as: shape of the building site constraints, terrain condition, design drawing specifications, cranes types, cranes sizes, material handling specifications, material storage, etc. can be stored in such a global database that can be updated with new information as it becomes available.

2.5 SPREADSHEET APPLICATIONS

Large number of cost components such as owning and operating costs are associated with the use of cranes on a construction site. Their calculations require mathematical procedures using computerized spreadsheet to assist in ameliorating the selection procedures and estimating equipment costs (Harris and Macffer 1983; Roberts, 1987; Chan, C., 1989; Alkass, 1994). Spreadsheet have effectively been linked to expert systems (Alkass et al 1992; Alkass 1990). For the purpose of this research a spreadsheet application (QuatroPro) with its capability of handling algorithm calculation to solve financial problems was used in developing a computer cost module called Equipment Cost Estimation and Analyzer (ECSA). The module is capable of performing equipment cost calculations.

2.6 COMPUTER-AIDED DESIGN (CAD)

Computer-aided design (CAD) is capable of formulating domain knowledge and design. It can be linked to a database such as DBase III, spreadsheet applications such as QuatroPro. It can also be used to graphically present the selected crane, and its location and simulate its movements on construction project.

2.7 SUMMARY

Expert systems and Object-Oriented Programming with their ability to combine factual knowledge with judgment to handle incomplete data, and to communicate easily with users have been widely used to solve problems related to construction industry. They have received considerable attention among professionals and academic groups, they appear to be an appropriate decision supporting tools for equipment selection process. Researcher have utilized commercially available software including, Database management (DBASE III), Spreadsheet applications (QuatroPro), and graphic simulations (AutoCAD), in developing variety of computer systems to be used as decision support tools in different fields of the construction industry.

CHAPTER III

CRANE TYPES AND FACTORS AFFECTING THEIR SELECTION

3.1. CRANE TYPES

Many types of cranes are commercially available, each type has different capacities and specifications. Three types of cranes are mainly used in the construction industry : Derricks, Mobile, and Tower cranes. each with its own configurations based on its mounting, jibs and masts as shown in Fig. (3.1).

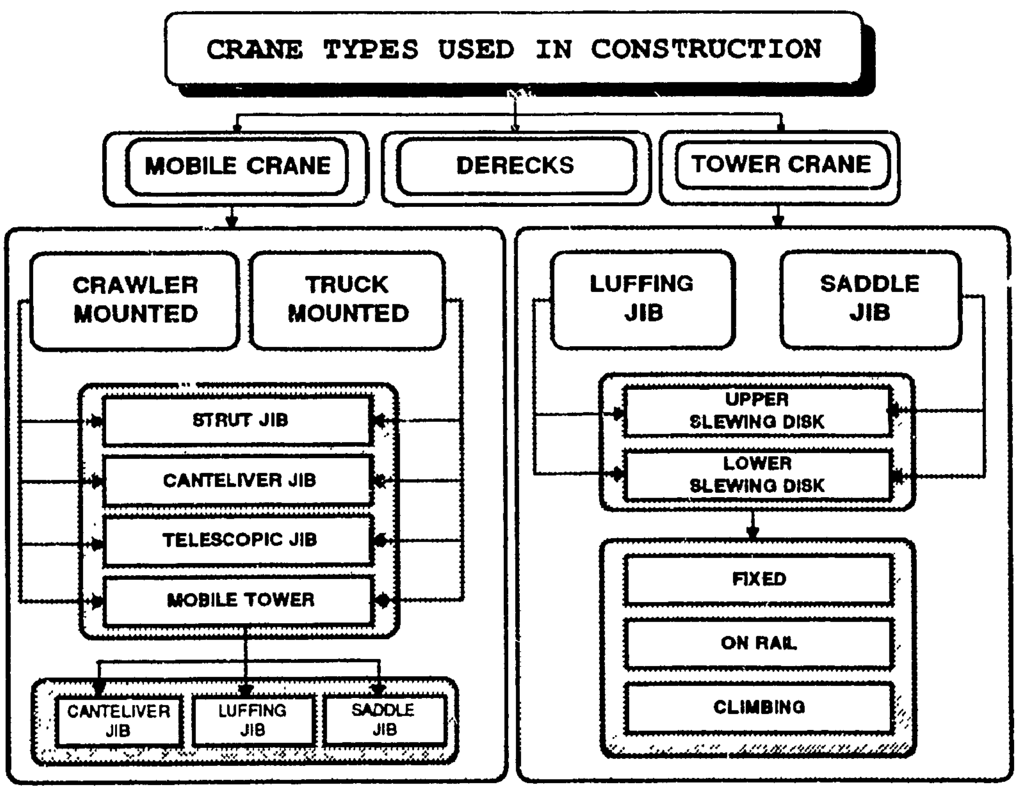


Fig. 3.1 Crane types used in the construction industry and their configurations

Derricks, as shown in [Fig. (1) Appendix A] is normally used in marine construction, on ships, and within the harbour. Smaller sizes and types of derricks are commonly used in dismantling tower cranes at the end of their function, afterwards, the derrick is dismantled manually. However, derricks are outside the scope of this research which mainly concentrates on mobile and tower cranes for high-rise building projects.

3.1.1. Mobile Cranes

They are cranes with the ability to travel reasonable distances without the need for a haul unit, and this depends on the size, type of the crane and roads regulations.

Mobile crane are classified into three types by their mounting:

a. *Truck Mounted*

Small cranes with limited capacities but are used widely in construction to load/unload material. [Fig.(2) Appendix A]

b. *Crawler Mounted*

Needs a truck for its transportation from site to site, and is used on sites with soft soil conditions [Fig.(3) Appendix A]

c. *Tire Mounted*

Could travel without the need of a truck, they are equipped with outriggers to give them stability and rigidity while operating [Fig.(4) Appendix A].

Both crawler and tire types, come with different types, sizes, and use different jibs.

Mobile cranes are classified into different types by their jibs:

d. *Strut jib:*

The connection of the boom is at the lower part of the superstructure [Fig.(5) Appendix A].

e. *Cantilever Jib:*

The connection of the boom is at the top of the superstructure of the crane [Fig.(6) Appendix A]. This will provide greater clearance under the hock, facilitating the handling of bulk loads [Fig.(7) Appendix A].

f. *Telescopic Jib*

It is similar to the cantilever type but the jib length is controlled by the use of hydraulic power [Fig.(8) Appendix A].

All these types of cranes are classified based on the relationship between the load, boom length and the radius [Fig. (9) Appendix A]. The crane's jib, the load size and shape, and the boom angle with the location of the crane, and its distance to the building, and building size/shape affect significantly the ability of the crane to load/unload the material to be handled [Fig.(10 and 11) Appendix A]. This leads to the introduction of the flying jib, which increases the crane's reach, but also reduces its loading capacity [Fig.(12) Appendix A].

To avoid this reduction in cranes' capacity, the high pivoted jib [Fig.(13) Appendix A], was introduced as the first step towards the introduction of the mobile tower crane [Fig.(14) Appendix A].

3.1.2. Tower Cranes

Tower cranes consist mainly of three elements [Fig.(15) Appendix A], the **mast** which provides the crane with height, the **jib** for reach, and the **slewing Disk** for directions [Fig.(16) Appendix A].

i. Mast Configurations

Cranes are classified based on their mast configurations into three types

a. *Fixed tower crane:*

This crane is fixed to the ground. Whenever the Building Height exceed the crane's mast free-stand limit, the mast should be tied to the building.

b. *Climbing Tower Crane:*

This type of crane is erected in a location within the building floor layout. The crane usually is raised every three floors. At completion the crane will be dismantled on the roof. The advantage of using this type of crane is in locating it within the building centre which reduces the jib size and the loads radius as shown in [Fig.(17) Appendix A].

c. *Tower Cranes on Rails:*

The base of the crane is equipped with special rails to allow for horizontal movement of the crane. This type of crane may eliminate the need for additional cranes on a long block [Fig.(18) Appendix A].

ii. Jib Configurations

a. Saddle Jib Tower Cranes

The jib is in a horizontal position perpendicular to the mast, the hook travels within the jib to change the reach of the crane [Fig.(15, 16, and 17) Appendix A].

b. Luffing Jib Tower Cranes

The jib is capable of rotating in the vertical direction. This rotation provides the crane with flexibility to manoeuvre in restricted areas where the site is surrounded by high buildings or other cranes on the same site [Fig.(18) Appendix A].

iii. Slewing Disk Configurations

a. Lower Slewing Disk

The mast and the jib rotate on the turntable located at the lower part of the crane.

b. Upper Slewing Disk

The turntable is located in the mast/jib connection allowing the jib rotation while the mast is fixed.

Each crane has a specific load chart to determine its capacity based on the relationship between the boom length and the radius. A sample of this chart is shown in [Fig.(19) Appendix A].

3.2 FACTORS AFFECTING CRANE(S) SELECTION

There are many ways to select a crane for a high-rise building construction. Each method depends on the types of material to be handled as well as the type of the construction project. Each project is unique so is its crane selection process. A careful study of the factors affecting the crane selection can reduce the risk of selecting a wrong crane.

These factors can be classified into three major groups, technical, contractual, and economical factors, as shown in fig. (3.2) (Moselhi and Ghazal 1992, Al-Hussein, et, al 1995-A).

FACTORS AFFECTING CRANE SELECTION

Technical Factors

- Site constraints
- Site layout and operational criteria
- Site topography
- Shape of the building
- Access to the site
- Weight and size of material
- Terrain condition
- Cranes capabilitis

Contractual Factors

- Method of operation
- Construction schedule
- Building structure and method of construction

Economical Factors

- Size and number of cranes
- Running cost
- Purchase Vs rent
- Cranes availability
- Dismantling method

Fig. 3.2 Factors Affecting the Crane Selection

3.2.1 TECHNICAL FACTORS:

Selecting a crane to operate on a given construction site has to be technically feasible. The following factors need to be investigated during the selection process:

i. Limitation and site constraints:

Site constraints and limitations are the most critical factors affecting the crane selection, they included the following:

a. Constraints:

Site constraints such as, adjacent buildings either constructed or under construction, or by power supply cables, can restrict the tower crane to weather-vane freely. It may also restrict the manoeuvrability of a mobile crane.

b. Geological exploration:

The closeness of a construction site to a river, valley, buried pipes, mains, etc [Fig.(20) Appendix A] affects the selection of rail mounted tower crane, external static tower crane, and mobile crane. Additional care has to be taken and extra preparation has to be made, during the selection process.

Attention must be paid to the soil stability and its bearing capacity, whenever the unit is a rail mounted, ground support is required or it should be mounted on a temporary base. Ground stability must not be exceeded under the most severe static and dynamic crane loading conditions.

If the tower crane is to be set up in an area having high water tables or an area that might be subject to a flood the crane may require deep foundations or special ground consolidation (Dickie 1989).

c. Topography conditions:

Shoring locations, excavations, slopes, trenches, backfilled or uncompacted material (30 psi at least), (Dickie 1989), when present on site affect the selection of a rail mounted tower crane, an external static tower crane, and a mobile crane. Extra care has to be taken, and additional preparation has to be made.

d. Terrain condition:

Rough or firmed terrain, affects the selection of type of mobile crane. Whenever the pick and carry is required the terrain has to be formed.

e. Site layout and operational criteria:

Manoeuvring space on site, storage space, and the availability of space for the erection and dismantling of the crane, affect the kind of crane to be used i.e either a tower or a mobile cranes, and their locations.

f. Legal access to site:

Availability of side roads and the possibility of using these roads during the construction period are important factors that affect the crane selection. Special attention should be paid to those sites where a bridge has to be crossed, some old bridges are not designed to carry heavy loads, such as the crane's weight and its attachments. Similarly some overhead bridges are too low, and a large crane can not safely pass under them.

ii. Shape of the Facility:

Horizontal and vertical dimensions of a building, affect the type and the size of the crane to be used in its construction. Facades regularity and type of external elements also, affect the selection of crane's jib and its size, mast type and its size, crane size, number of cranes and their locations as is explained below:

a. *Building dimensions*

For the purpose of this research buildings have been classified into three groups based on their heights (low-rise building up to 40 m high, mid-height from 40 m - 90 m high, and high-rise building over 90 m height). Each group has a compaination of six based on their length and width (short less than 40 m, medium length from 40 to 90 m, long building over 90 m long). This kind of classification, generates 18 different combinations as described in chapter (6).

b. *Building shape and facade*

Building are different in their facades, their types, and shapes and their affect on the crane selection are presented in chapter (6).

iii. Possible location of a crane:

For each crane location the project manager should study the load distribution, possibility of directly handling material from the stack in a single operation within the capacity of the crane. Following is a list of recommendations to be followed when locating a crane (Dickie 1989):

a. Have a sufficient clearance between the load and the boom and adequate head room between the load and whatever rigging is required to make the lift.

b. The crane should be capable of making all its lifts in its standard configuration. Its main boom should be of sufficient length and capacity to carry out all required tasks. The jib, the extra counterweight and the special reeving should be held in reserve for unanticipated problems.

c. The crane should be close to the material storage, so to avoid eccentric loads.

d. The crane's capacity is normally being reduced with the increase of the radius as shown in the load chart in [Fig.(19) Appendix A]. Therefore, it is a good practice to locate the crane close to the heaviest loads.

e. The operator should be able to see the hook all the times.

f. The crane's proposed location should also be based on its proximity to other cranes, particulary when their working areas might overlap. Collisions is always possible when two cranes are working in the same area within their reach. The cranes should be located in such a way that the operators have clear view of the other cranes operating in the possible collision area.

g. The crane should not be located in such a way to work over areas to which the public have access.

h. Power or telephone lines, located within the radius of rotation of the crane must be relocated so that they are at least 10 feet away from the extreme outer point of the radius, or otherwise they must be insulated.

3.2.2. CONTRACTUAL FACTORS

i. Method of construction and type of projects:

a. Steel construction

Special attention should be paid to a building with steel frames, some of the steel beams might be very heavy, therefore, a large crane is preferred and its location should be close to the heavy lifts. Internal climbing tower crane is difficult to be supported on the floor slabs, therefore shoring is needed for all floors to bare the total load of the crane, and attention should be paid to the additional cost due to the large number of shoring.

b. *Composite structure steel and/or concrete or precast and cast on situ concrete.*

Consideration must be given to the structural stability and bearing capacity whenever the crane is supported on or by any structure. The foundation, shoring, and the structure must be designed taking into consideration the cranes load.

ii. Method of Operation:

Frequency of lifts, speed, maximum utilization of crane, types of lifts, dimensions, weights and location of lifts, affect the type and location of the crane. If loads are shutter forms, steel bars, concrete bucket and similar, then the operations require less care with higher speed. But if the crane is used for erection of precast elements, glass curtain walls or installation of machinery, then the operations require more care with fine speed and a big crane to avoid vertical vibrations under hook.

iii. Construction programme

In a case where one crane could be sufficient from capacity point of view and out reach to carry out the work, but the construction programme dictates the use of more than one crane, then extra crane should be selected.

iv. Available crane(s) and equipment:

Contractor may use one crane with larger capacity than the selected one as it is available.

v. Possibility of using standard cranes:

The standard crane is the crane, which can be used by the same contractor in different projects.

3.2.3. ECONOMIC FEASIBILITY FACTORS

One of the major problems facing the contractor is the selection of the proper construction equipment. The contractor should not pay for the equipment, it must pay for itself by earning for the contractor more money than it costs (Peurifoy, 1985). However the contractor can not own all types or sizes of equipment needed for the project.

The selected crane can be either already owned by the contractor, to be purchased, or rented. To chose between the feasible alternatives, a careful evaluation of the running and operating cost, must be done.

i. Cost of the crane

Detailing the owning and operating costs of a crane is difficult due to the variety of involved variables such as the severity of site conditions number of working hours, life of the crane, and maintenance program.

- *Owning cost* includes investment cost, insurance cost, taxes, storage cost, depreciation cost, and the cost of replacement of parts
- *Operating Cost* consist of direct Operating Cost: wages, spare parts, repair and service
- *Maintenance Overhead (indirect)* includes maintenance and supervision, maintenance and utilities, and operating extendable cost: Fuel, Oil, Grease, Lubrication, Tire, Hoses, Cables, Site Opportunity Cost, Erecting, Dismantling, Mobilization, Demobilization

II. Mobilization and demobilization costs

These costs includes transportation of the crane to and from the site.

III. Erecting and Dismantling method

The erection of the tower crane must be carefully planned to take into consideration many factors. The crane must be positioned in an area adequately suited to lay out its components and to allow for the use of a mobile crane to erect the tower crane [Fig.(21) Appendix A]. Dismantling of the crane should also be carefully planned, taking into consideration the new restrictions that might be posed by the completed building.

CHAPTER IV

KNOWLEDGE ACQUISITION

4.1 GENERAL

The effectiveness of any knowledge based system depends on the amount and quality of knowledge stored in its knowledge base. This knowledge is acquired from experts and stored in the Knowledge-base by the knowledge engineer during the knowledge acquisition stage of the system's development. Experts from the domain of crane selection were identified, their knowledge was solicited during interview sessions. Experts can be described as persons who, because of experience, are able to perform specific tasks the rest of us cannot do, they are knowledgable and use "tricks" to solve problems in hand, they are good at recognizing similar problems to those they have previously faced (Waterman 1986).

During this work, experts in the area of the crane selection were classified into groups based on their areas of specialization: general contractors, rental companies, project managers, government authorities, training institutions and instructors, expert with academic and practical background, design professionals, crane operators, and crane manufacturers. This grouping simplified the process of accumulation and codification of the knowledge. Two methods of knowledge acquisition procedures were used: structured interviews, and phototyping.

4.2 STRUCTURED INTERVIEWS

Experts were asked to describe the crane selection process with the emphasis on the factors affecting their selection. It was found that, decisions made at various stages had to be tested in the light of discrepancies bound to arise between the experts. All decisions require prediction as to the consequences of the choice that is to be made. The decision could some times be restricted by the company's interests, making different experts to have different point of view in the process.

4.3 PROTOTYPING

This involved the development of a knowledge-based prototype at an early stage of the knowledge acquisition process. Information and knowledge collected from experts were classified, coded, and represented in a prototype module. This module was presented to the experts for criticism, feed back and to test its effectiveness. The demonstration of the prototype proved to be valuable since it helped in revealing new knowledge. The procedure was repeated until the system was finally approved by the experts. The knowledge acquisition procedure is illustrated in fig (4.1).

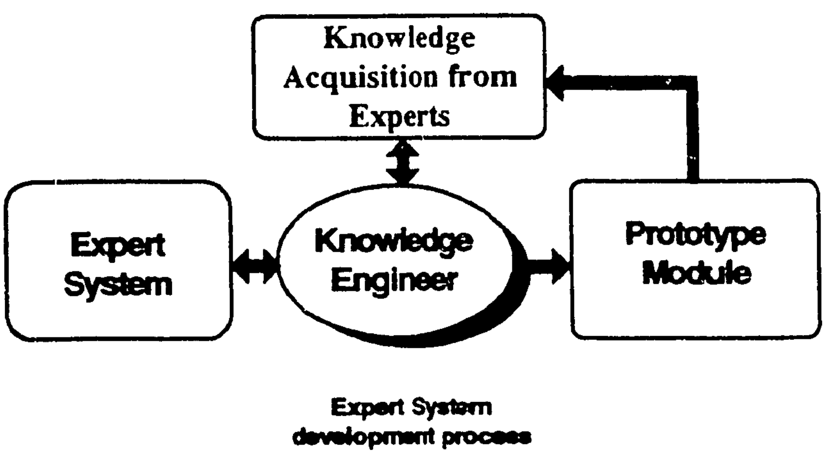


Fig. 4.1 Prototyping Procedure

4.4 KNOWLEDGE ACQUISITION FINDING

Experts decisions are sometimes affected by their company's interests and their area of specialization. Selecting a crane for a building project is viewed differently by each party in the project. For example, the structural engineer is interesting in selecting a light enough crane so the structure can bear its total load with minimum change in the design. The architect, on the other hand, may view the crane as a regular equipment which should not have any impact on the architectural facade, while the general contractor may perceive it as the most profitable and productive equipment on site. The rental company often perceives the crane as the most preferable piece of equipment on a construction site, while the project manager views it as a piece of equipment that ensures, efficiency, higher productivity, and safety. Subcontractors focus on the cranes's efficiency and capacity, government officials stress safety, while crane operators interest is in the crane's capability to carry all lifts and it is located in a clear position.

A sample representing these groups was selected and interviewed during the knowledge acquisition stage. The following is a list of the different experts whose were interviewed:

a- *In-House Experts. (Experienced engineer currently doing graduate studies at Concordia University).*

b- *Colleagues from other Universities.*

c- *Experts with academic and practical background.*

d- *General Contractors.*

e- *Rental Companies.*

f- *Design professionals.*

g- *Project Managers.*

h- *Instructors from a Training Institute.*

i- *Government authorities.*

j- *Crane Operator.*

4.5 CURRENT PRACTICE FOR CRANE SELECTION

a. Crane selection within general contractors companies

General contractors aim at both the profit and reputation when bidding for a job. To achieve reasonable profit, contractors try to minimize the cost of using equipment especially cranes on site. Normally they prefer to use the smallest size crane capable of completing the task. However, contractors rely on their In-House Professionals to advise on the type of crane to be used. Based on this, general contractors are divided into four groups: (a) General Contractors with In-House professionals and who own a number of cranes; (b) General Contractors with In-House professionals who rely on rental companies for the supply of cranes; (c) General Contractors who owns a number of cranes but, depend on outside professional firms for the decision on the crane selection; and (d) General Contractors who use outside professional firms for advice on crane selection and on rental companies for cranes supply.

In the first group, i.e. General Contractors with In-House professionals, although own a fleet of cranes; In addition to heuristics and rules of thumb experts use solutions to similar cases, involving crane selection they faced in previous projects. Therefore analogical reasoning to identify most common cases is required in order to establish a methodology for crane selection process for high-rise building construction. Fig (4.2) illustrates the crane selection process followed by this group. It is noted that the crane selection is affected by the building's requirements that are included in the contract documents and drawings. The process starts with a report from a person called the Crane Manager, regarding a meeting held between experts in different areas (i.e. design professionals, architects, finance department representative, ...). The crane manager's report may contain a recommendation for selecting a particular crane together with the factors considered during the selection process. Based on this report, and additional information on the construction requirements which include: (shape of the building, type of the structure, i.e. concrete or steel, construction program, site constraints, and the method of financing), and alternatives of similar cases from the company's previous work, the experts in their meeting would select the size and type of a crane (i.e. tower or mobile crane).

For a mobile crane the decision in most cases, is made between the crane manager, project manager, site supervisor, and crane operator to determine the type of mobile crane, its attachments and location(s). In a complicated case the decision may require the involvement of the planer and design professionals in the preparation of the design drawings for the selected crane.

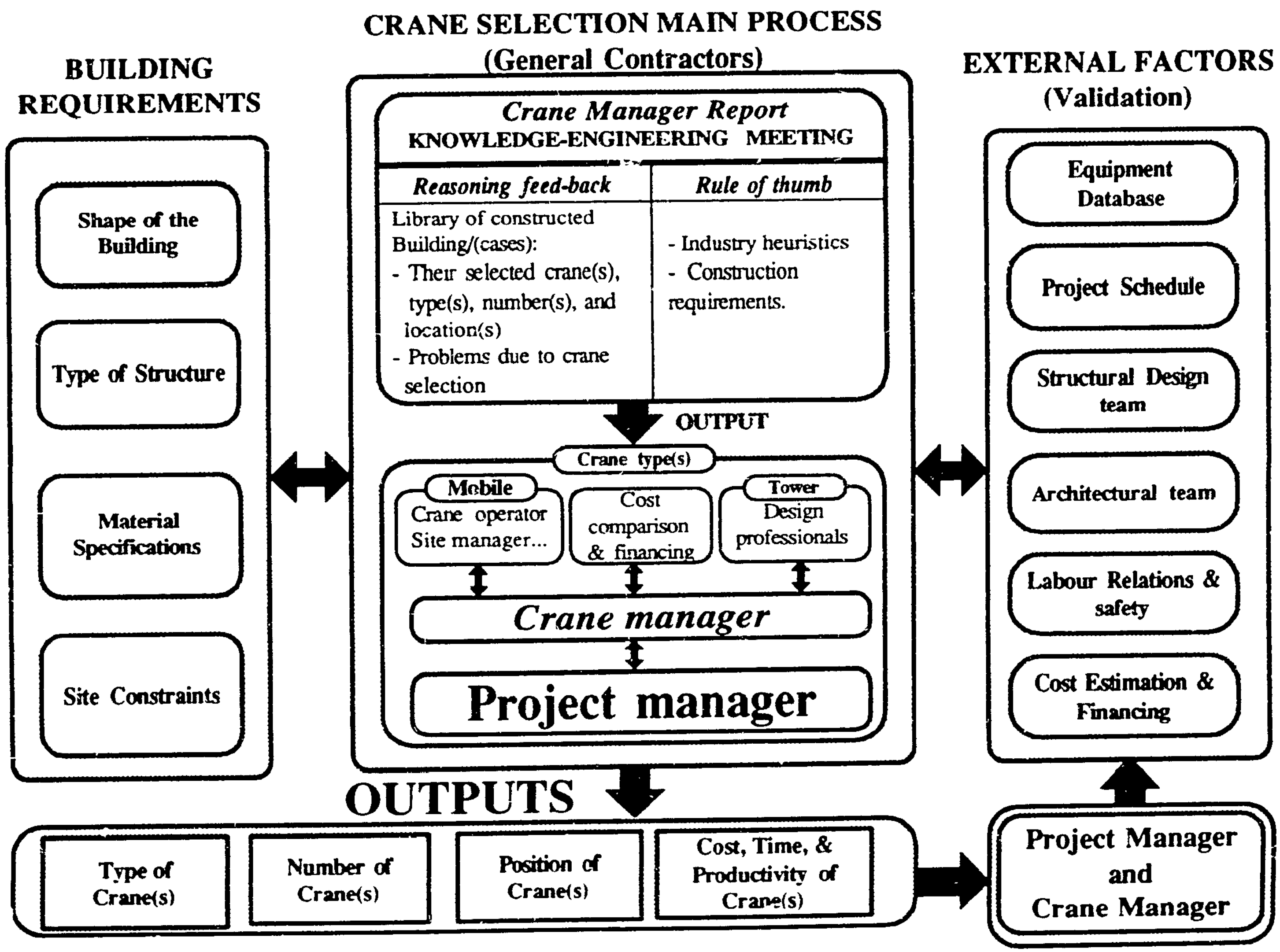


Fig. 4.2 Crane Selection Process Followed by General Contractor Organizations

Selecting a tower crane is decided on between the crane manager, project manager, site supervisor, design professionals, and planers. Fig. (4.3) shows the process followed by the in-house design professionals within the general contractors organizations. In order to prepare design drawings for the selected tower crane that include crane position, crane working range, load chart diagram, erection, and dismantling methods, additional data on the structural and architectural designs is investigated. The focus in this process is on the selection of the mast type of the tower crane (i.e. static tower crane, climbing tower crane, or rail mounted tower crane), this is followed by the investigation of the jib type and size (i.e. saddle jib, or luffing jib). Decision is made for the location of the tower crane, the combination of the mast and jib is investigated, and the use of different mast sizes is decided on if necessary as shown in fig (4.4). These drawings include the location(s) of the tower crane(s), crane(s) working range, and crane(s) load diagram. Additional information regarding the foundation and supporting base of the crane and the necessary reinforcement, could be included in the same drawing or in a separate one.

Selecting either a mobile or a tower crane or perhaps a combination of both, depends on the advice of the financial department on cost issues and financing methods.

As is shown in fig. (4.2), the final output consists of the number, type(s), positions of cranes, and operational costs. This output is further validated by studying the effect of the contractual and the economical factors such as: the availability of the selected crane, wether the selected crane can meet the construction program in terms of capacity and production rates, the effect of the selected crane on the structural and architectural design, and finally the cost of the selected crane. In the case when changes to the construction requirements due to the crane selection is required, the owner and/or his representative is notified, and the process is repeated for the new design.

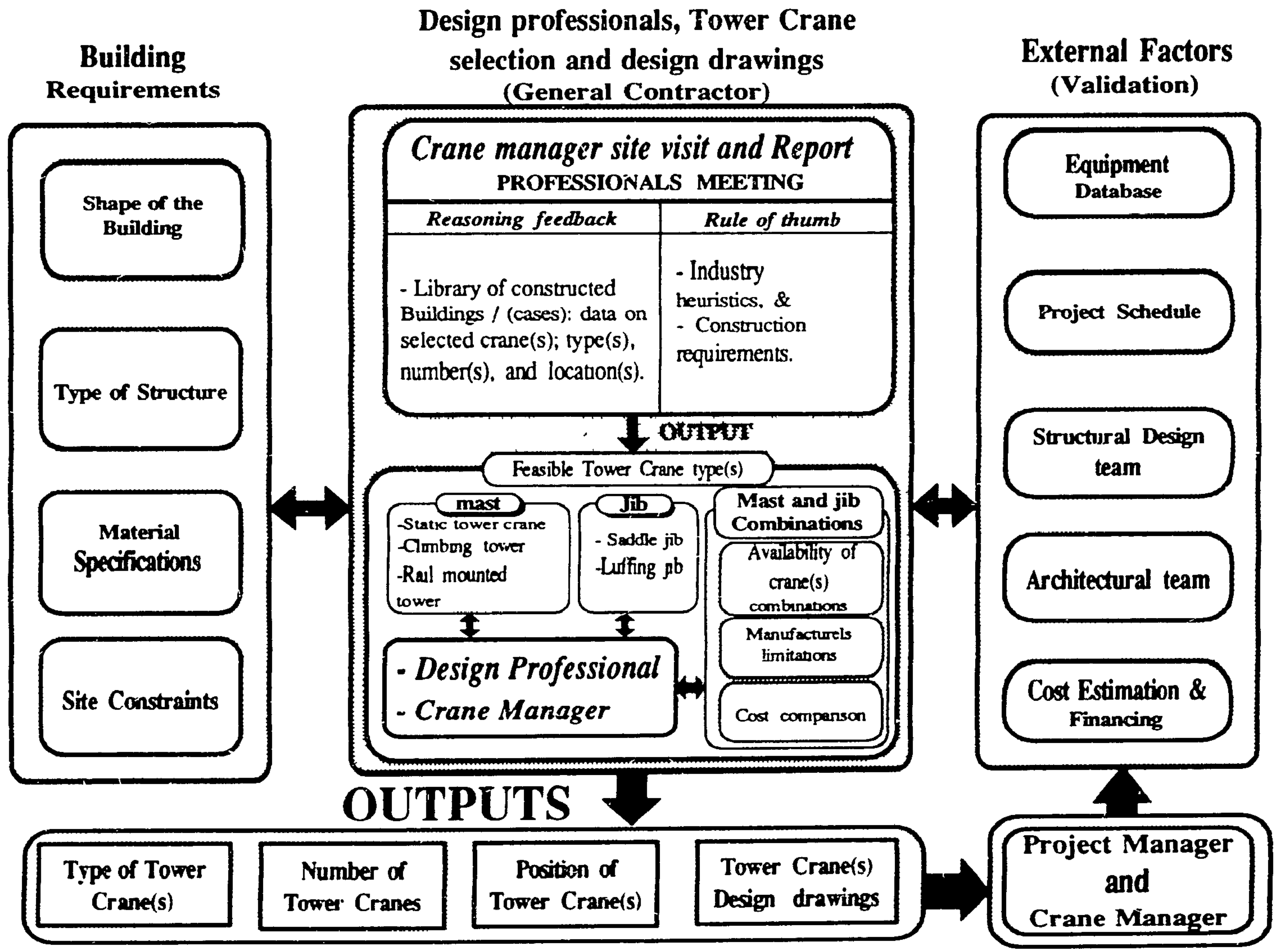


Fig. 4.3 Tower Crane Selection and Design Drawing in (G. C.) companies

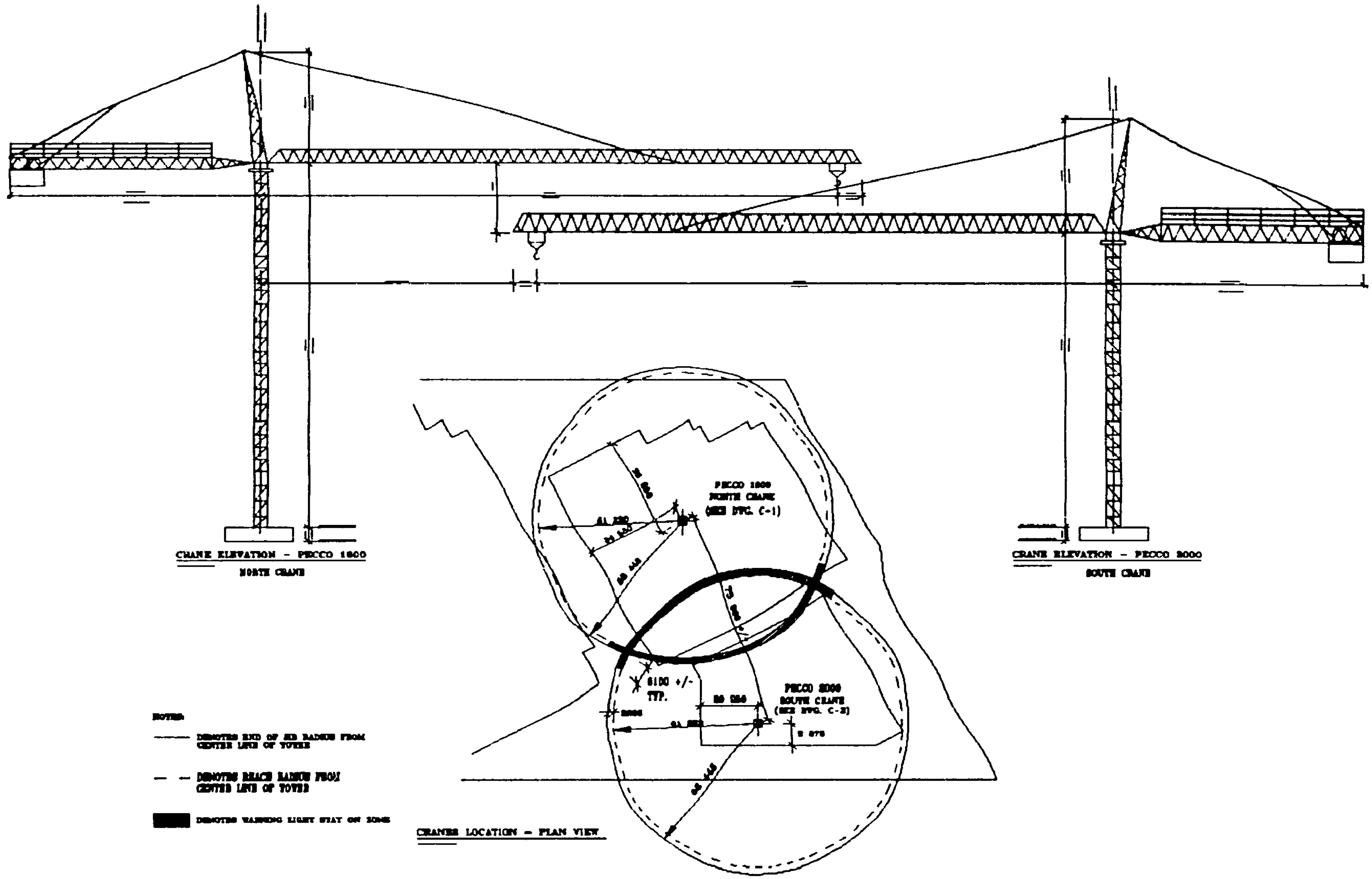


Fig. 4.4 Crane design by general contractors companies Professionals

b. Crane selection within the rental companies

In cases where general contractors do not own cranes, they relay on the rental companies' advice on which crane to select. Fig. (4.5) illustrates the procedure followed by equipment rental companies for selecting cranes. A person called crane manager plays a key role in the decision making process. He/she receives a request from a construction company for a crane. The crane manager request information on the construction requirements that include: shape of the building, type of the structure, i.e. concrete or steel structure, site constraints, and construction program. This is done through a correspondence via a fax or a telephone, the crane manager may solely decide on the type of the crane or with a consultation with other experts within the rental company. These experts could be design professionals, financial representative, planners, etc. Either way the type of the crane i.e. tower or mobile crane is selected.

For a mobile crane the decision in most cases, is made between the crane manager, site supervisor, and the crane operator, in some complicated cases the decision may require the involvement of planers and design professionals. The crane's locations on the site is dictated by the construction program and the shape of the building.

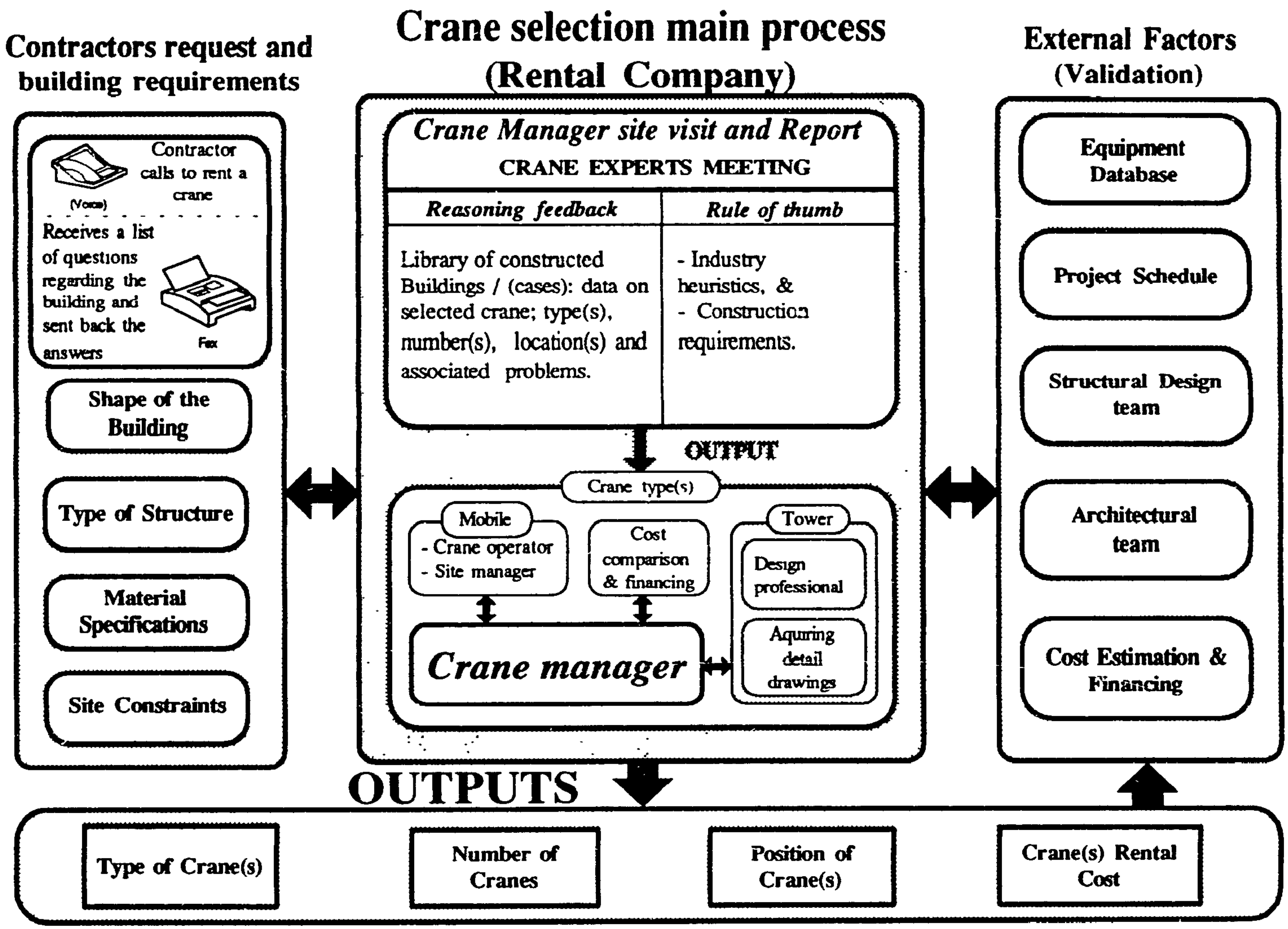


Fig. 4.5 Crane Selection Process Followed by Rental Companies

The decision on the tower crane is made between the crane manager, owner and/or his representative, site supervisor, and in-house experts. Fig. (4.6) shows the process followed by the in-house design professionals in rental companies organizations. In order to produce design drawings for the selected tower crane that include the crane position, crane's working range, load chart diagram, erection method, and dismantling method, additional data on the structural and architectural design is requested and studied. The focus in this process is on the selection of the mast type for the tower crane (i.e. static tower crane, climbing tower crane, or real mounted tower crane), this is followed by selecting the jib type and its size (i.e. saddle jib, or luffing jib). To determine the crane's location the combination of mast and jib is investigated, and the use of different mast sizes if necessary is decided on as shown in fig (4.4). These drawings includes the location(s) of the tower crane(s), crane(s) working range, and crane(s) load diagram. Additional information regarding the footing and support of the crane and the reinforcement necessary, could be included in the same drawing or in a suppurate drawing(s).

This output is further validated with the effect of contractual and economical factors such as: The availability of the selected crane, wether it can meet the construction program in terms of capacity and production rates, the effect of the selected crane on the structural and architectural design is investigated. Finally the cost of using the selected crane is estimated.

In the case of any change in the construction requirements due to the crane selection, the owner and/or his representative are notified, and the process is repeated for the new design.

Decision on either a mobile, a tower, or a combination of them, depends on the financial department assessment of the cost issues and financing methods.

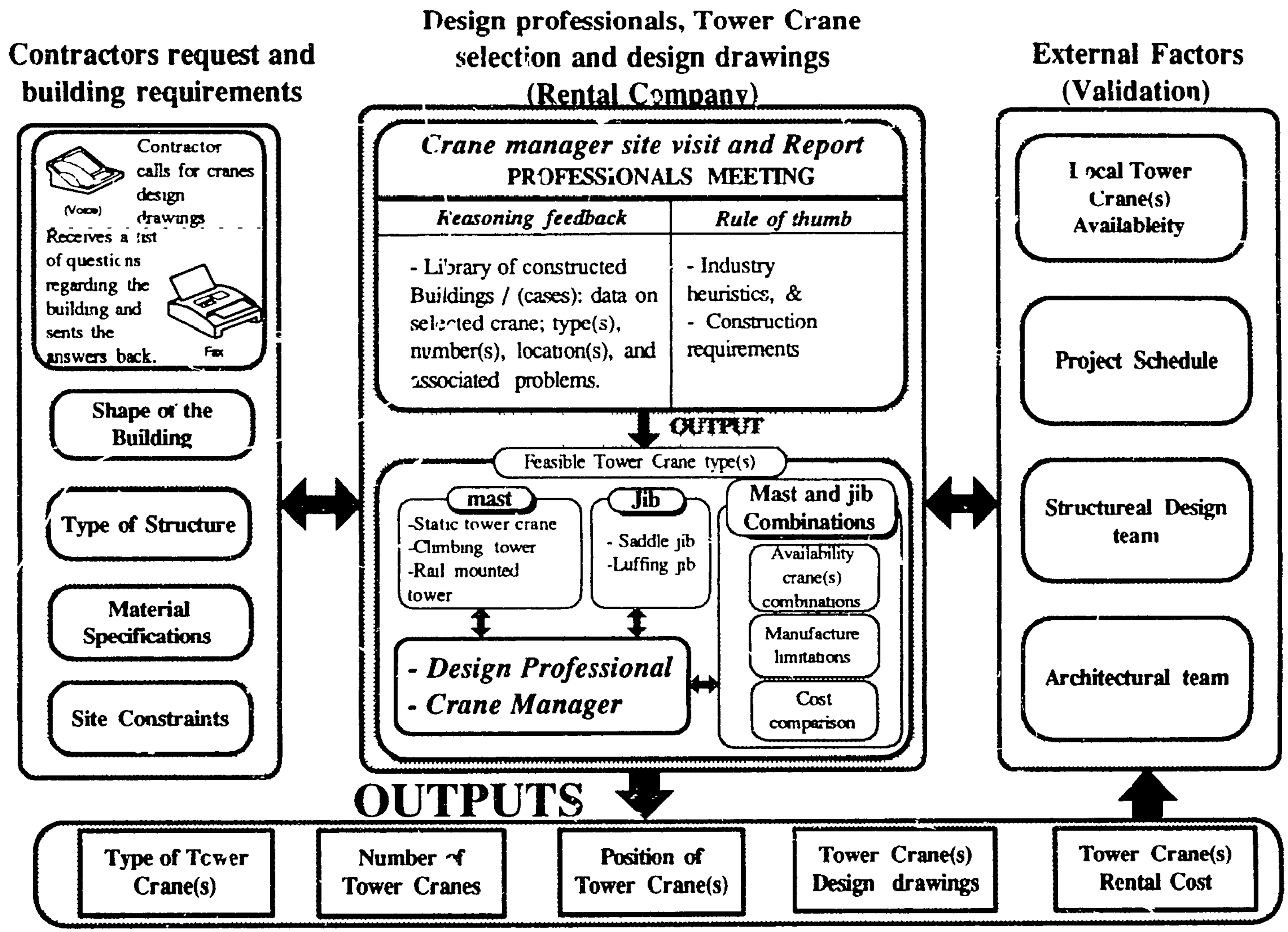


Fig. 4.6 Tower Crane Selection & Design Drawings in Rental Companies

As shown in fig. (4.5), the final output consist of the number, type(s), positions of cranes, and rental costs. This output is further validated with the effect of the external factors such as the availability of the selected crane, wether or not the selected crane can meet the construction program in terms of capacity and production rate, the effect of the selected crane on the structural and architectural design is investigated, and finally the rental cost is estimated.

In the case of any change in the construction requirement due to the crane selection, the owner and/or his representatives are notified, and the process is repeated for a new design.

c. Tower crane selection within the independent design professional companies

In some cases general contractors do not own cranes, and do not have their own design professionals, therefore, they relay on the services offered by independent design professional companies to perform the tower crane selection and to produce its design drawings. Fig. (4.7) illustrates the crane selection process followed by the independent design professional organizations.

The process as shown in fig. (4.7) usually starts by requesting the information on the building requirements including: shape of the building, type of the structure, i.e. concrete or steel, construction program. In addition, professionals visit the site and prepare reports for the experts meeting, during which a crane going to be selected. Following the selection of the crane, design drawings including crane's position, crane's working range, load chart diagram, erection, and dismantling methods, are prepared in a similar way to those previously mentioned.

The final output would be design drawings for the selected tower crane that include the crane's position, the crane's working range, the load chart diagram, erection, and dismantling methods.

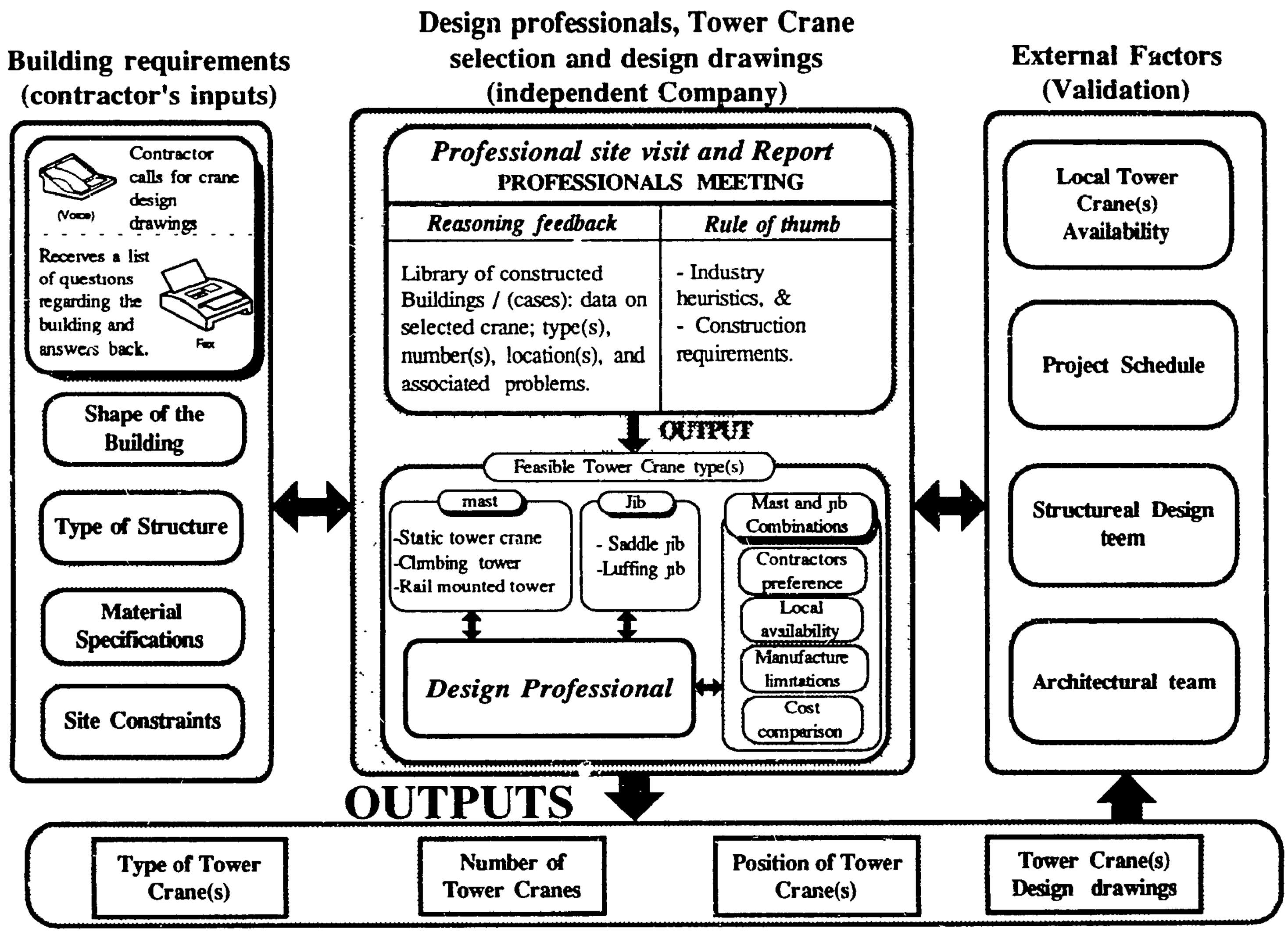


Fig 4.7 Tower crane selection & design drawings in independent companies

4.5 SUMMARY

The construction industry relay heavily on the experts knowledge in dealing with complex problems such as cranes selection. The complexity of the crane selection process for high-rise building projects is due to the large number of factors that affect their operation. The decision process demands detailed planning, good judgment, and prediction. The ability to predict and make decisions grows out of knowledge and experience gained on construction sites. Most of the time this knowledge is not available to the decision maker when needed, making a knowledge-base system containing knowledge on cranes selection process a valuable tool to be used in this area. With this respect this chapter discussed the crane selection strategies used by different organizations, aiming at providing a disciplined method of transferring this knowledge and expertise to young construction engineers.

CHAPTER V

COMPUTER INTEGRATED ENVIRONMENT

5.1 GENERAL

The application of KBES, and OOP approaches, and CBR techniques in construction industry was reviewed in the proceeding chapter. Along the years, $KBES_S$ have become widely used in the construction industry (Moselhi et al. 1990, Alkass 1989, Levitt 1987, Alkass et. al. 1993, Amirkhanian et al. 1992, Moselhi and Gazal 1992, Alkass and Aronion 1990, Alkass et al. 1989, Christian et al. 1987, Bernel 1986 and Colin and James 1985). OOP and CBR techniques have also been applied to the industry in a form of computer systems, (Forde and Stiemer 1989, Yu and Adeli 1991, Navinchandre 1988, Zhang and Maher 1993). These systems proved that a computer program can emulate the human inferencing process and can be used effectively in various areas of construction including equipment selection. Expert systems are not efficient in performing numerically intensive procedures they are particularly well suited for automating heuristic or non-deterministic solution approaches (Jounes and Saouma, 1988).

Traditional algorithmic approaches are used primarily for carrying out calculations and doing analysis and can perform extensive data manipulation, but, the heuristic nature of a conservative industry such as the construction makes the implementation of the algorithmic software alone inadequate.

The combination of algorithmic programs with KBES in a computer integrated environment where experiential knowledge and engineering judgement can be represented using the expert system methodology, and numerically intensive procedures, data storage, and retrieval using available algorithmic methodologies, can present possible solutions for many problems related to construction industry including equipment selection. Such solutions would most effectively take advantage of available software tools and further build on current industry practices.

5.2 INTEGRATED KBES-ALGORITHMIC APPROACH

Expert system technologies and conventional programming can be combined to support decisions to solve construction related problems especially complicated ones such as, the equipment selection. This can be achieved by developing an equipment selection assistant system, which combines a knowledge-base, database management, and simulations. Fig. (5.1) illustrates the structure of a computer integrated system designed to assist the user in selecting equipment for a construction project.

At the beginning of the process, information related to the project and its characteristics are provided by the user who also specifies his/her objectives and preferences with respect to the final selection. During the process the system provides the user with different alternatives, graphically simulate their locations and finally advise on best solution with least cost. The user can interact with the system while being guided to a final conclusion.

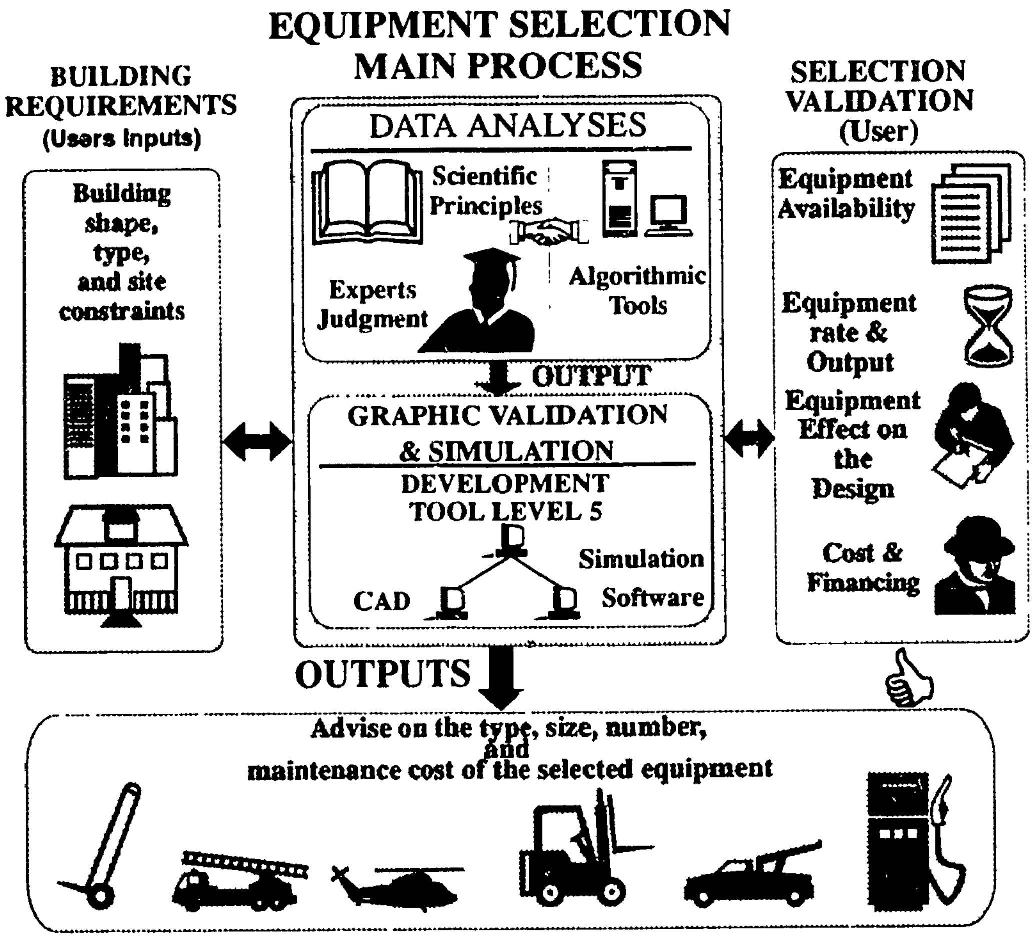


Figure 5.1 Illustration of the structure of an Integrated Computer System for lifting equipment selection

5.3 DESIGN TOOL REQUIREMENTS

The experts who were interviewed during the knowledge acquisition stage of this research, appeared to agree with the ideas that for a computerized system designed to work as an effective decision supporting tool in the area of crane selection, it should:

- Contain reliable knowledge selected from credible and experienced practitioners in the field.
- Cover a wide range of buildings.
- Consider the impact of the uncertain variables incorporating them in the selection process.
- Make use of currently utilized computing methods, and software.
- Minimize data input and presents the output in a visual way.
- Operate in a user-friendly environment using language familiar to the user.
- Allow for an easy update of data and knowledge.
- Provide explanations and reasoning for its decision.
- Provide assistance for variety of users (i.e. contractors, designers, owners, equipment operators, etc.).

5.4 SELECTION CRITERIA FOR THE DEVELOPMENT TOOL

Part of this study was spent on establishing a set of criteria for selecting the most appropriate tool to be implemented for developing the system.

In developing a decision supporting tool to solve material handling problems in construction, different variables had to be considered, such as the kind of lifting equipment to be used, the availability of the software to be used in developing an effective system, and the availability of expert knowledge and the methodology of selecting such knowledge.

KBES development tools were selected as possible environment for implementing the integrated system. A variety of these tools with different capabilities are currently available. Their capabilities vary significantly depending on the type(s) of their inference mechanism(s), the knowledge representation methodology, integration with other software and the user interface. Fig. (5.2) shows the selection process of the development tool that satisfies the previously described requirements with respect to the characteristics of the final decision support system.

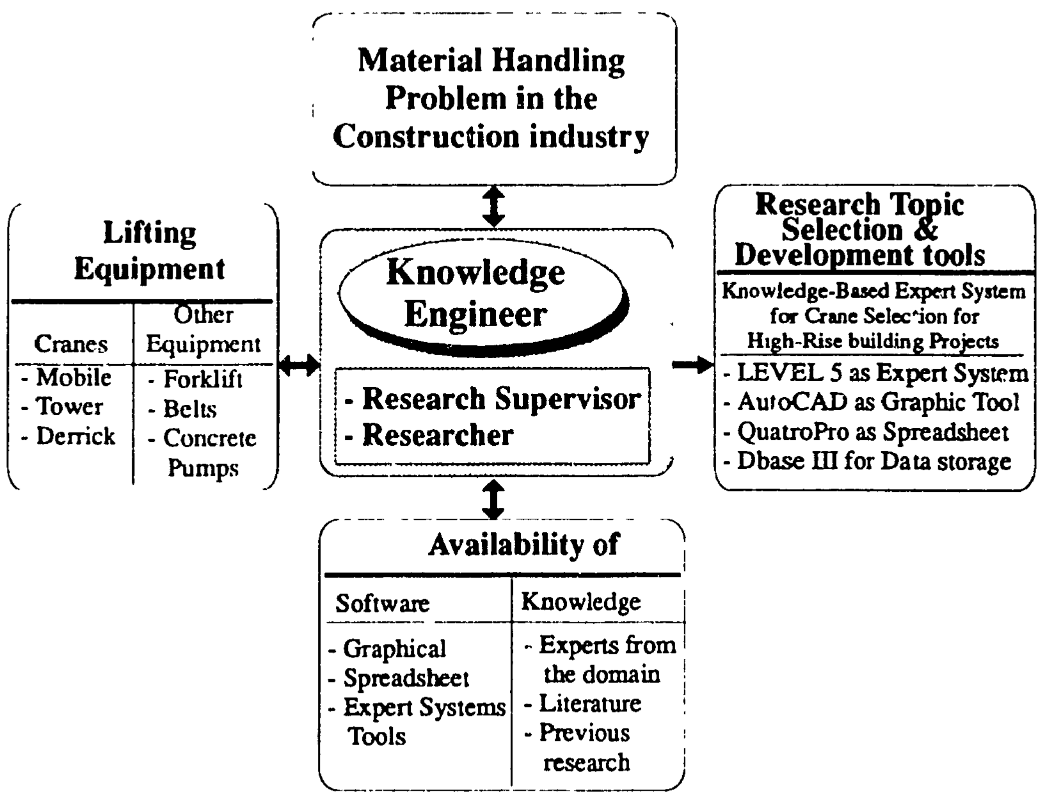


Figure 5.2 The selection criteria of the development tools for the research

The selection criteria for the tool required to develop a system for equipment selection can be described as follows:

a. Development

. **Expert System shell:** The development of a KBES can be accomplished in less time using an existing shell, as compared to the use of a programming language. Expert System shells provide environments that do not require the effort which is needed in order to learn and use symbolic programming languages like LISP and PROLOG. They can be used with limited computer programming knowledge.

. **Knowledge representation methodology:** the selection of the knowledge representation methodology requires special effort from the knowledge engineer, different knowledge representation techniques have been developed along the years. These include semantic networks, production rules, frames, objects and logic (Waterman 1986). The most widely implemented are based on production rules and frames or objects. Rules are useful in representing heuristic knowledge while objects can effectively model knowledge in a hierarchical manner, taxonomist, more closely to the way humans use to organize information in the domain. There are systems which combine both rules and objects thus providing a hybrid knowledge representation schema offering more flexibility for the development of a KBES. By integrating frames/objects and production rules into a single unified representation facility, the organizational and expressive power of OOP is made available to domain experts (Fikes and Kehler, 1985). As compared with rule-based systems, a hybrid knowledge-base system environment, supporting frames and rules, is considered more appropriate (Bedared and Ravi, 1991). To represent the knowledge in the domain of equipment selection in the construction industry, the descriptive knowledge about different objects, their attributes and values and the relationships among them interact with the procedural knowledge related to how the objects behave and their values change under various conditions. The facility for the hybrid programming incorporates the best of all methods without inherent disadvantages (Nicholas 1989). Therefore the selected development tool should support a hybrid knowledge representation technique combining frames or objects with production rules.

b. Functionality

. **Software Integration:** The equipment selection process in the construction industry is complex, and any decision is expected to involve predictions, rules of thumb and some calculations. Therefore, it is desired to adopt a system that combines heuristic methods, with algorithmic techniques, it should also interface with currently available and widely accepted graphical software such as CAD applications, Spread sheets applications, databases, and simulation software.

. **Multitasking:** Since there is a need for the integration of software which have to be activated at the same time sharing the limited capacity of the computer memory, special efforts to effectively utilize the memory should be made. Therefore, the development tool should be capable of running different applications, at the same time, allowing for exchange of information between them (Akhniotis 1992).

. **Access to Database:** Practical KBES would need many hundreds of rules or cases to reason from making engineering a database increasingly important task. The complexity of the equipment selection process requires a well-designed central database. Structuring such a database to be capable of effectively storing the information and displaying it to the user, is among the objectives of this research.

Since there is a need for integrating software and hybrid knowledge representation techniques combining frames or objects with production rules, the selected database is best structured using the advantage of exploring the objects in the domain i.e. OOP Database. Such a database minimizes the user input, and can be updated with new information whenever it is available.

c. Interface

. **Execution Time:** For a KBES to be effective, it has to contain information on a large number of cases and knowledge in a specific domain. At the execution time KBES require more machine cycles compared to conventional software to perform pattern matching, and searching to solve the problem in hand (Nicholas 1989). Hence lack of processing speed would cause irritation and frustrate the user. Thus the development tool should produce a system that offers different kind of interface that depends on the level of the knowledge of the particular user in the domain, by using databases capabilities of storing and retrieving data when needed.

. **Hardware requirement:** In construction most of the functions are carried out at a number of individual sites away from access to mainframes and networks. Therefore, it is preferred for the developed system to be able to run on Micro-computers or pc_s with reasonable memory consumption and hardware requirement.

. **Explanation Facility:** Many decisions have to be made on the construction sites, such decisions depend greatly on skilled judgment that account for all likely variables involved. Experienced practitioners may be able to explain the reasons behind their decisions. Unfortunately most of the time they are not available when needed, leaving the inexperience personal in difficult situations of accepting their decisions as they are. Therefore, the developed system should be capable of explaining its decisions using dialogues and recommendations. In doing so the system provides a disciplined method of transferring knowledge and expertise to lees experience construction engineers.

5.5 THE SELECTED DEVELOPMENT TOOL

LEVEL 5 as an Object-Oriented Expert System tool was used to develop the CRANE ADVISOR. It provides many features such as Rules, Object-Attribute-Value triplets, use of inheritance, capsulation and other Object-Oriented Programming characteristics useful for the knowledge representation. It is also capable of allowing the stored data to be accessed by all the members of the decision making process, to suite their needs. It is capable of providing friendly interface development by using hypermedia, including text and bit-mapped images. LEVEL 5 concentrates mainly on the programming need for building Knowledge-Based Expert Systems and provides an integrated set of tools to allow multiple paradigms in the same program. It is also capable of facilitating user friendly interface, and integrating a knowledge-base with traditional algorithmic, commercially available tools such as: DataBase, Spreadsheet applications, and Graphic applications.

5.6 SUMMARY

The construction industry rela; heavily on the experts knowledge in dealing with complex problems such as the crane selection. The complexity of the crane selection process for high-rise building projects is due to the large number of variables and data manipulation, with this respect the development of a practical computer program is essential. But computers are not robust in dealing with tasks which involve creativity and imagination, since the learning, the creative and the judgmental processes that comprise the selection process remains in the prerogative of humans (Garrava et al., 1990). The objective should not be to substitute human experts, who manage for many years to tackle successfully the crane selection problem, but to support them. It is not necessary to fully automate the process of crane selection, or to replace the human experts judgemental qualities. It is more expedient to establish a partnership process between the decision maker and the computer using the capabilities of both. Therefore, there is a need for a tool that can act as "intelligent" to assist the decision makers in selecting construction equipment. This chapter presented a discussion on the need for a computer integrated environment for crane selection for high-rise building projects. The established selection criteria for choosing the appropriate development environment was also discussed in this chapter.

CHAPTER VI

THE PROPOSED INTEGRATED SYSTEM (Crane Advisor)

6.1. GENERAL

Selection of the type, number, and location of cranes to be used on a high-rise building project is a central decision in organizing the construction operation. The crane selection process is complex due to variety of factors including: buildings shapes, their structures, type and size of the material to be handled, various crane types available in the market, their cost. The process requires expertise that might not be available to decision makers when needed. In an effort to facilitate this process and make the expertise available to assist the decision makers during the crane selection process, experts knowledge have been captured, classified and coded in a computer system called (CRANE ADVISOR). The system is developed in a computer integrated environment capable of assisting the owners, contractors, developers, design professionals, construction managers, and equipment suppliers in their decision regarding the selection of an appropriate crane type, number, and location for high-rise building projects. This chapters discribs the ingredient of the Crane Advisor and its modules: the Knowledge-Base, Case-Based Reasoning, Algorithms, and Graphic Simulations.

6.2. SYSTEM'S ARCHITECTURE AND STRATEGY

6.2.1. System Architecture

The system (Crane Advisor) as shown in Fig (6.1) incorporates two main modules. The first is the Knowledge-Based module that contains experts knowledge, heuristics and rules of thumb related to cranes selection. The second, is the Case-Based Reasoning module containing information on various cases representing already constructed buildings with pre selected crane(s). In addition to the knowledge-base, the system integrates procedural algorithms for performing routine calculations and graphic validation to support the crane selection process. These are incorporated in three modules: geometry calculations, graphic validation, and cost estimation modules. The first two of these modules calculate and validate the geometry of the selected crane(s) and their location(s) with respect to the building geometry and loads specifications. The cost estimation module provides intensive cost calculations for the selected crane(s). All the modules as shown in Fig (6.2), share a global database containing data on a large number of commercially available cranes: their types, their specifications, and cost data. The database also contains data on a number of already constructed buildings including information on problems related to cranes used in their construction. CRANE ADVISOR has been developed in an object-oriented environment. The system allows for information (plans, elevations, type of construction material to be handled, cranes types etc.) on building projects to be stored and retrieved as needed. The system benefits from the object oriented programming characteristics such as Inheritance, Modularity, and Encapsulation of data. LEVEL 5 as an Object-Oriented Expert System shell, have been used in developing the CRANE ADVISOR. It allows for the stored data to be accessed by all parties involved in the crane selection process. It is also capable of integrating the knowledge-base with traditional algorithmic and commercially available tools such as: Spreadsheet applications (QuatroPro), Graphics (AutoCAD), and database (DbaseIII) as shown in Fig. (6.2). The system is expected to assist the user in a user friendly atmosphere in selecting the appropriate type of crane(s) to maximize efficiency and minimize costs.

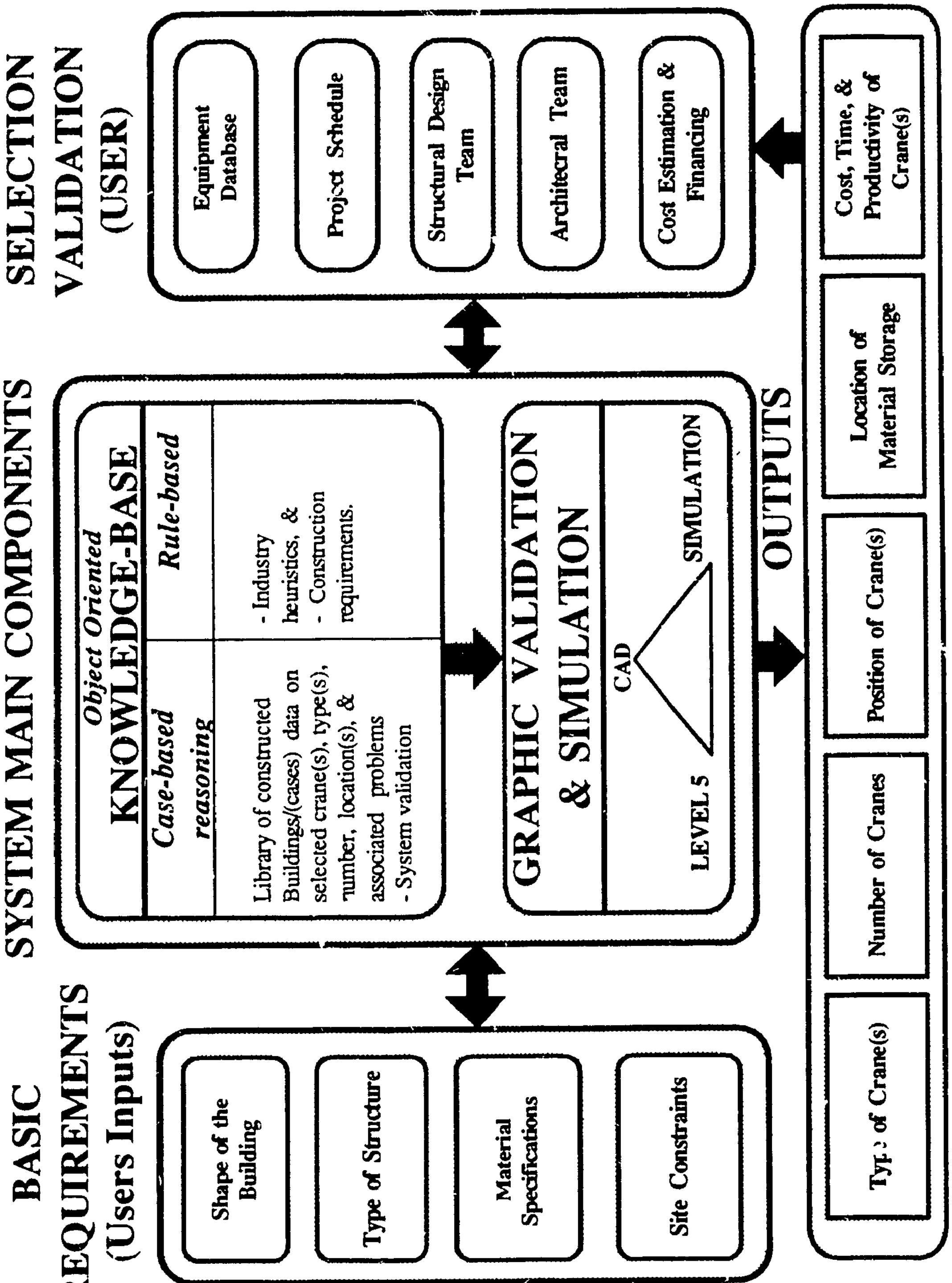


Fig. 6.1 Crane Selection Main Process

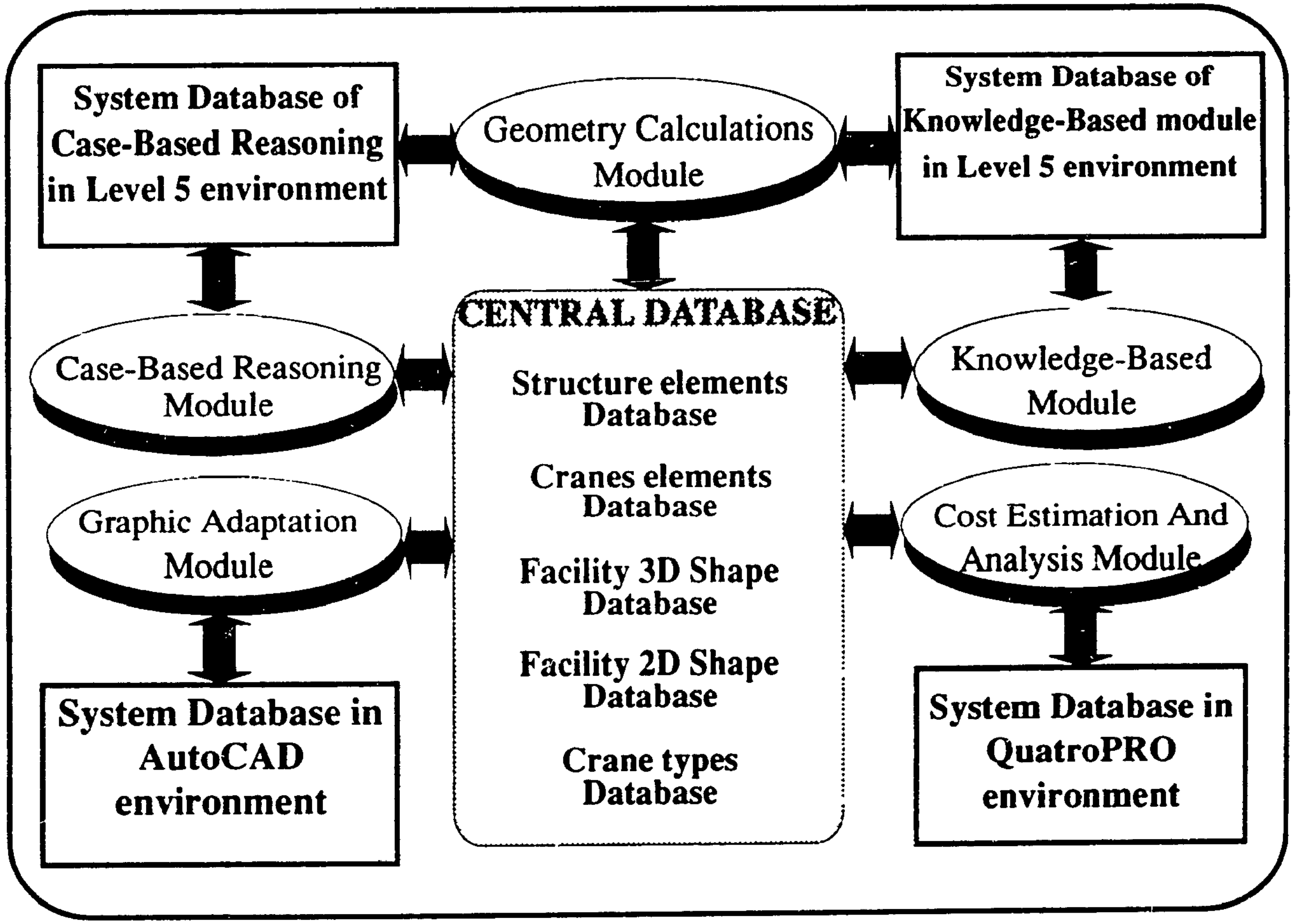


Fig. 6.2 Crane Advisor's Data-Bases

6.2.2. System's strategy

When selecting a crane the experts, in addition to heuristic and rules of thumb, they refer to solutions to similar cases, involving crane selection they faced in previous projects. Therefore, analogical reasoning to identify the most common cases is required in order to establish a methodology for crane selection for high-rise building construction. During the Knowledge Acquisition stage it was found that experts in the domain of crane selection use different strategies (explained in chapter 4) to solve problems related to crane's selection. These strategies have been used in developing the Crane Advisor.

Fig. (6.1), shows the main components of the system and the procedure followed during the selection process. The process starts, with the user, investigating the factors affecting the technical feasibility of a crane to be selected. This is based on the user's input as answers to a set of questions on different features of the project posed by the system including: (shape of the building, type of the structure, i.e. concrete or steel, construction program, site constraints, and financing method). Based on the user's inputs, the system will guide the user through the selection process using either the KBES or the Case-Based Reasoning (CBR) modules. Details of these two modules are presented in a later section. At the end of the session the user is presented with different alternatives of technically feasible cranes for the given building. These alternatives are therefore, graphically validated using simulations, to establish their position and working range on site. The system finally decides on the number, type(s), positions of crane(s), their operational methods and costs. This output is further validated with the user interface against the effect of the contractual and the economical factors such as: The availability of the selected crane, wether it can meet the construction program in terms of capacity and production rates, the effect of the selected crane(s) on the structural and architectural design, and finally the cost of operating the selected crane(s).

6.3. SYSTEM COMPONENTS

To formulate a methodology for crane selection, Crane Advisor incorporates, artificial intelligence (AI) techniques including Expert Systems (ES) and case-based reasoning (CBR), where cases and heuristics in addition to algorithmic techniques are used. In addition to the knowledge-base, the system integrates a Case-Based reasoning, procedural algorithms, and a Data-Base management system for performing routine calculations needed during the selection process. Following is a detailed description of the system's components and modules:

6.3.1. System's Data-Bases

Manipulating the vast amount of data and information involved in the crane selection process requires a well-designed central database. This database to be capable of manipulating the way in which the system stores this data and information in the computer and displays it to the user and is structured using database management systems and Object Oriented Programming (OOP) techniques.

Part of this research concentrates on designing a database capable of storing, indexing and retrieving data on building cases and to perform communication between the other system's components. Fig (6.2) shows the integration between the database and the other system's modules. Each individual module uses its own database, in addition to that, all the modules can share a global database that contains information related to the factors affecting the crane selection for high-rise buildings construction projects such as: shape of the building site constraints, terrain condition, design drawing specifications, cranes types, cranes sizes, material handling specifications, material storage, etc. This information can be amended and updated as soon as new information becomes available. Details on the relations between these databases and the way the system manipulates data between them will be presented in later sections.

6.3.2 Knowledge-Based Expert System Module

Knowledge-Based Expert systems are computer programs capable of manipulating experts knowledge in a narrow area to solve problems efficiently and effectively. Logic and heuristic (rules of thumb) are stored in a knowledge base of an expert system. Human experts' knowledge gained over period of time is the main source of this information. Expert knowledge related to cranes has been collected, classified, coded, and stored in the Crane Advisor's knowledge-base. Following is a description of the knowledge-based system used in the crane selection process.

a. Knowledge-Based Expert System Main process

Experts in the domain of the crane selection consider the building shape and its dimensions to be the most critical factors affecting the crane selection. With this in mined the KBES has been designed similarly to give priority to buildings shapes and dimensions. Buildings are three dimensional objects, with this respect, buildings have been classified into three groups as following:

- Height (low, medium, high)
- Length (short, medium, long)
- Width (short, medium, wide)

Fig. (6.3) illustrates this classification, which generates 18 combinations as shown in fig (6.4) These groups can be further studied taking into consideration the site constraints, for example each building may be restricted from, one, two, three, or all sides which generates up to 120 scenarios. These scenarios are stored in the global data-base as a three dimensional (3D) images. For each scenario related to site constraints there has been ten alternatives generated and stored in the global data-base, providing the user with a total of 1320 alternative solutions for crane selection, location, working range, and material handling storage.

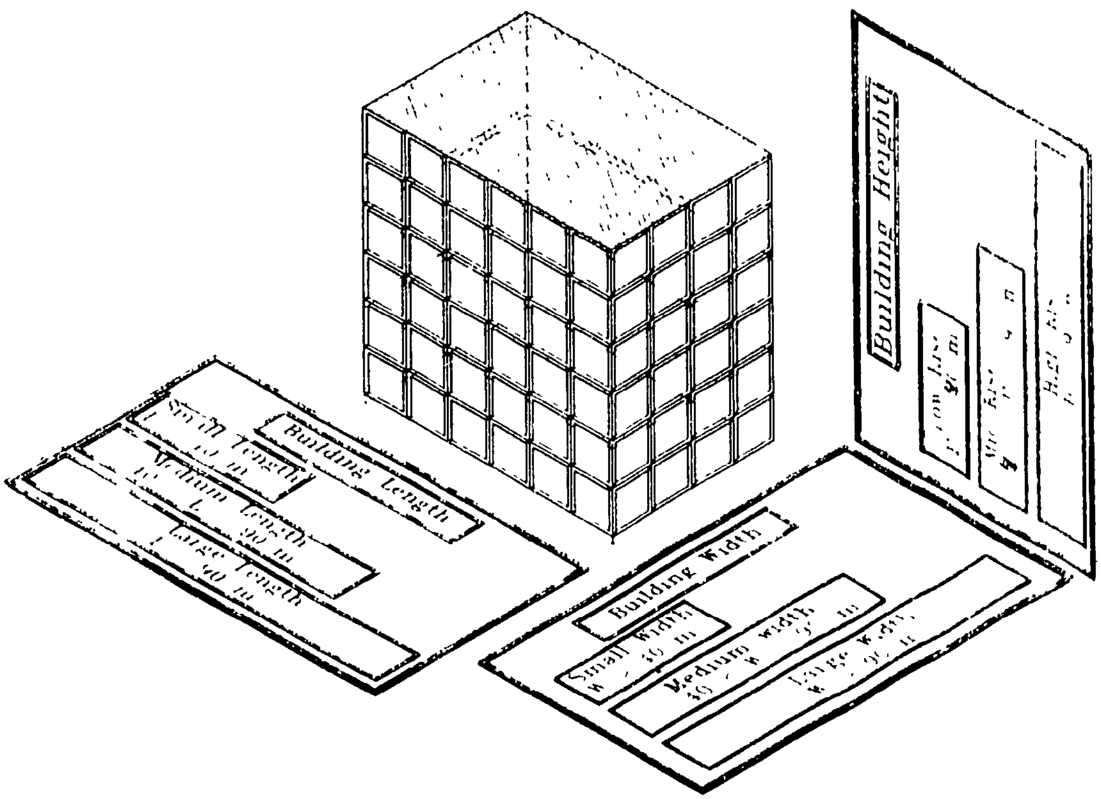


Fig. 6.3 Building Shapes Classifications Based on their Dimensions.

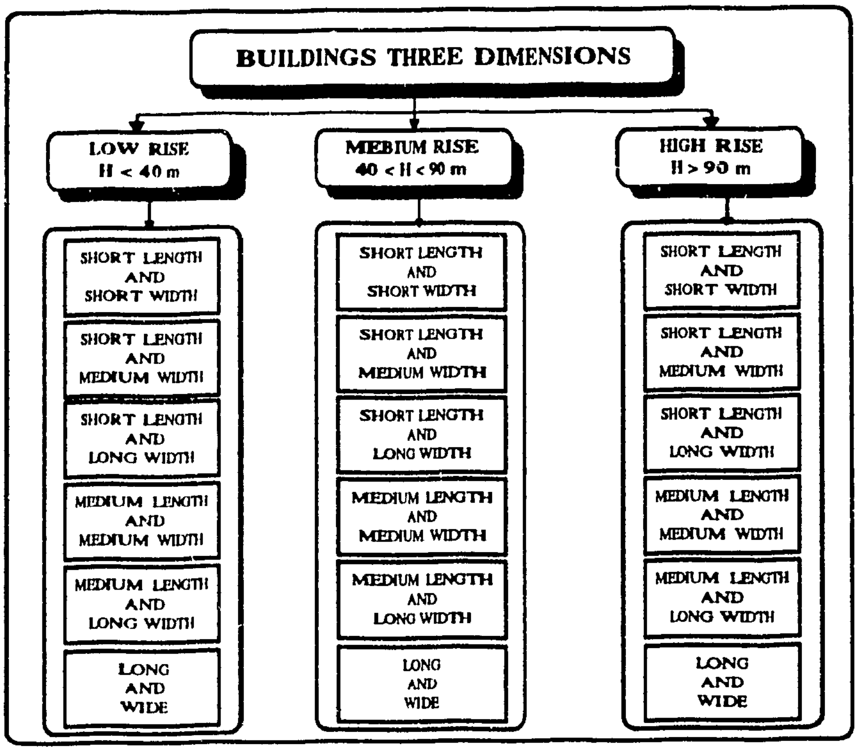


Fig. 6.4 Building Combinations.

Fig. (6.5), shows the system's breakdown structure (SBS). The priority is given to Building Height (low, medium, high) Each one of the height groups generates six combinations with the other two dimensions, lowest level of SBS. Site constraints and other factors affecting the crane selection are provided to the user in the third and the forth level of (SBS).

Based on the their dimensions, buildings are classified into two main groups: in the first group both Mobile and Tower Cranes can be used, and are investigated for both types of cranes. In the second group mobile cranes are not technically feasible, and they are investigated only for the use of Tower Cranes as shown in fig. (6.6).

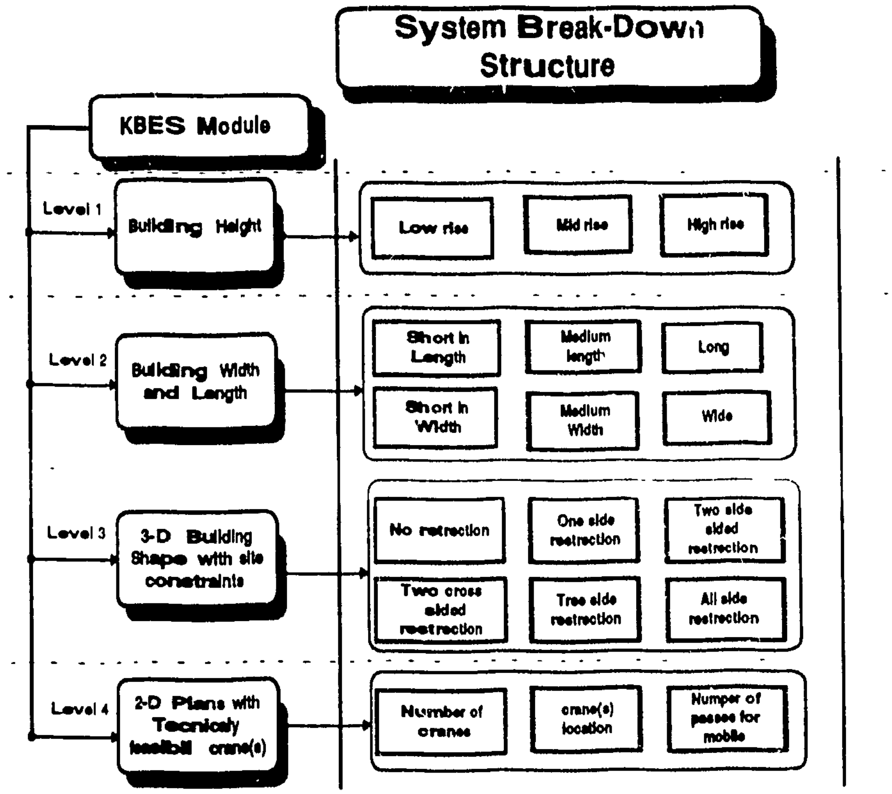


Fig. 6.5 System Break-Down Structure

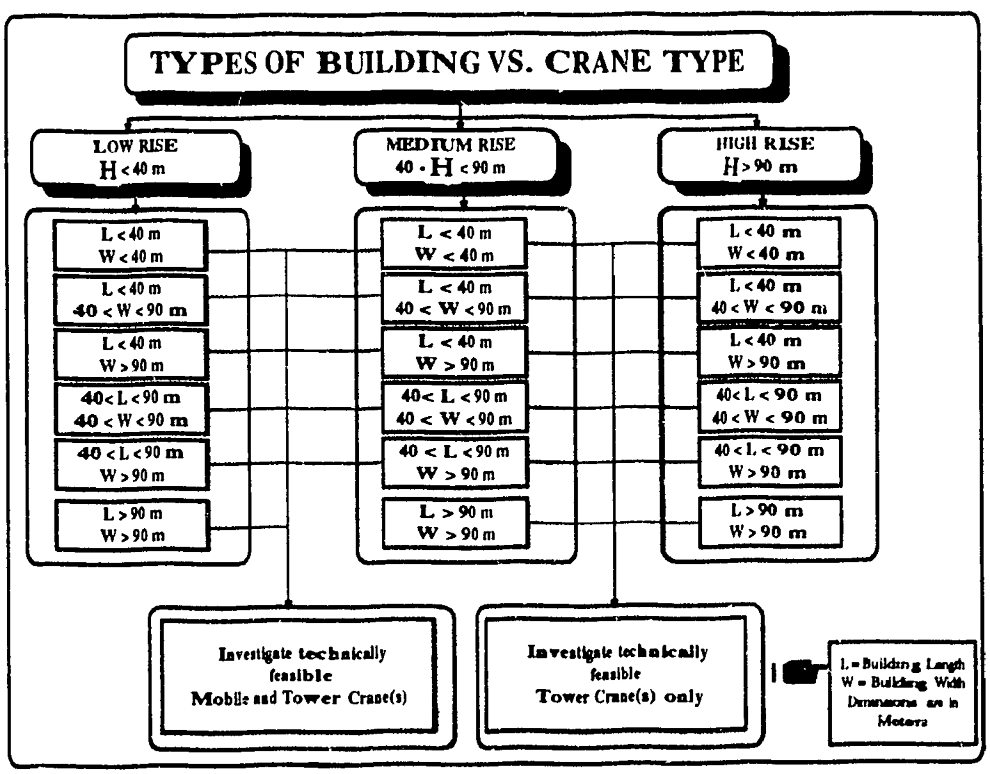


Fig. 6.6 Building Groups Vs the Type of the Crane

With the determining variable being the crane's size and type, the system investigates all the likely involved variables and factors affecting the crane selection and provides the user with a list of feasible alternatives that include cranes sizes and their types. The decision is based on the building groups, site constraints, and the availability of the feasible alternative as shown in fig. (6.6). Furthermore, the system investigates the factors affecting the jib size and its kind, cranes location, number of cranes to be used, and number of times the mobile crane may be relocated. The flowcharts in [appendix D] show all the likely variables and factors considered in the crane selection process. Fig. (6.7) illustrates a flowchart describing the procedure followed to select a tower or mobile crane.

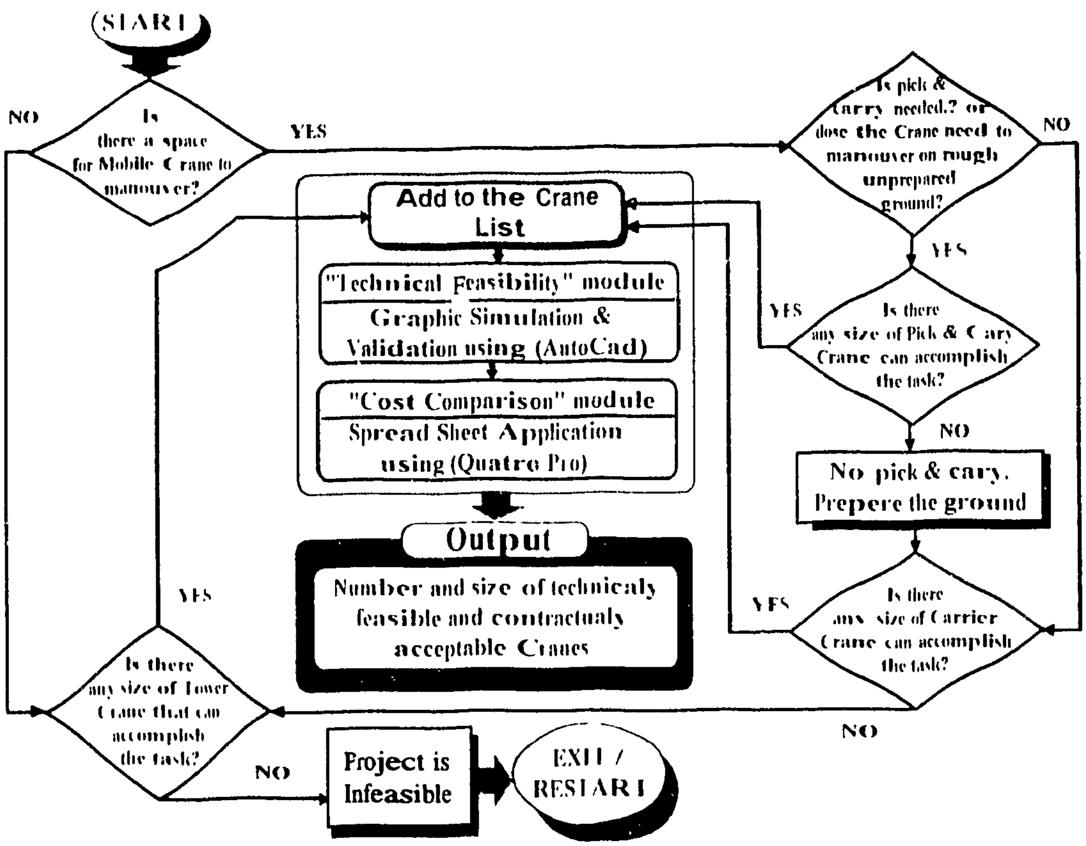


Fig. 6.7 Flowchart of the Procedure Followed by the System for Crane Selection.

b. Knowledge-Based Expert System Environment

The Knowledge-Based module (KB) has been developed in an object-oriented environment. This module allows for information on building projects (plans, elevations, construction material to be handled, cranes types etc.) to be stored and retrieved as needed. This is done through the integration between the knowledge-base, each module's database, and the global database (dbaseIII) as shown in Fig. (6.8). The module operates in a user friendly interface.

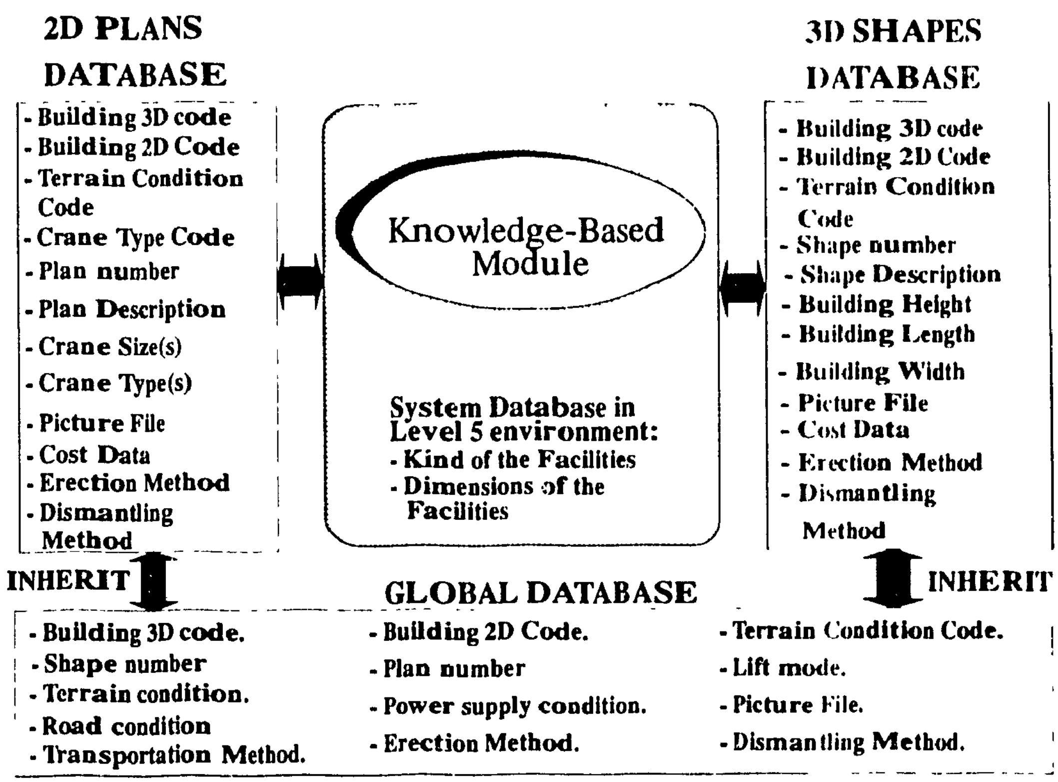
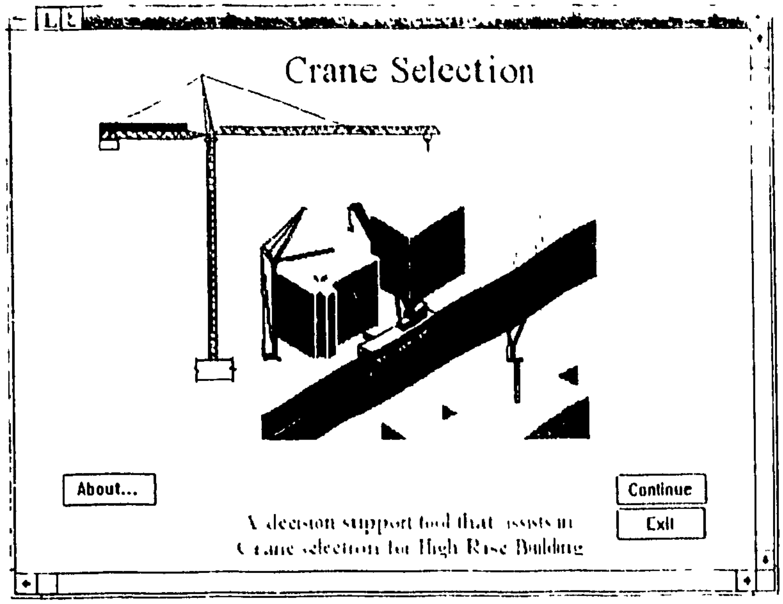


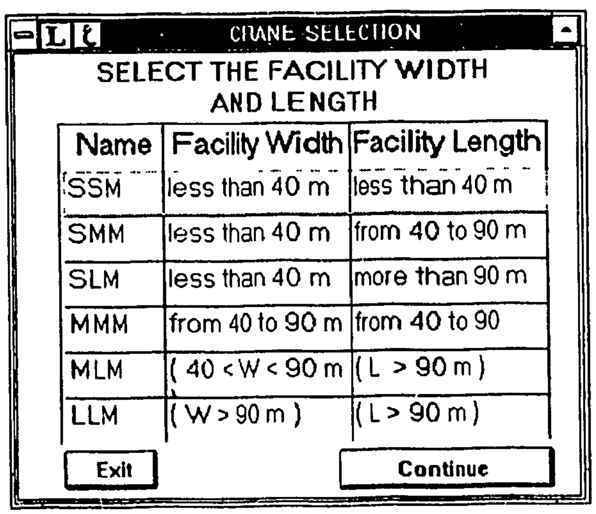
Fig. 6.8 Knowledge-Based module's Data-Bases

The process starts with selecting the **CONTINUE** option, from the title display as shown in Fig. (6.9 a), which cause for the **APPLICATION MAIN MENU** to be opened, providing the user with the option to activate one of the system's modules (KBES, CBR, Geometry Calculation Module, or Cost Estimation Module). Selecting the **Knowledge based system** opens the **building hight group display** as shown in Fig. (6.9 b). A building height among the three groups (H<=40 m, 40 < H < 90, H>=90 m) has to be selected.

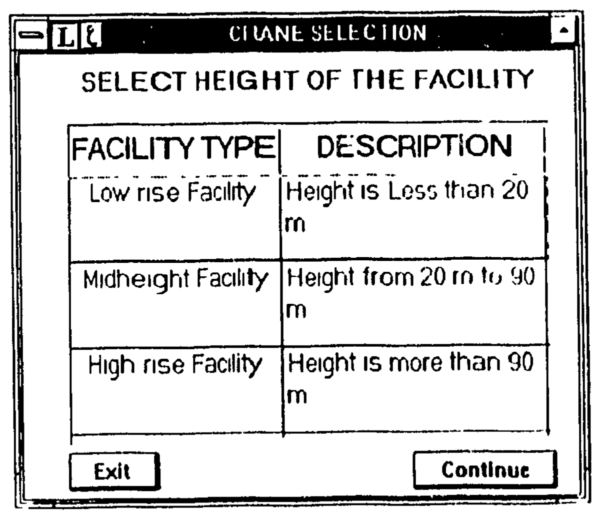
After selecting the building height, the **building width and length display** will appear as shown in Fig. (6.9 c). A table containing six combinations based on the other two horizontal dimensions is displayed for the user to choose from. This data is stored in the system's database as an instance of **CLASS building dimensions** as shown in Fig. [B.3 APPENDIX B]. Selecting the **CONTINUE** option activates the external database and retrieves the three dimensional shapes database file that is related to the selected building (width & length) and opens the modules **MAIN DISPLAY**.

(a)





Name	Facility Width	Facility Length
SSM	less than 40 m	less than 40 m
SMM	less than 40 m	from 40 to 90 m
SLM	less than 40 m	more than 90 m
MMM	from 40 to 90 m	from 40 to 90
MLM	(40 < W < 90 m	(L > 90 m)
LLM	(W > 90 m)	(L > 90 m)



FACILITY TYPE	DESCRIPTION
Low rise Facility	Height is Less than 20 m
Midheight Facility	Height from 20 m to 90 m
High rise Facility	Height is more than 90 m

(b) (c)

Fig. 6.9 KBES Module's Introductory Displays

c. Module's Main Display

The Main Display of the module has been structured to demonstrate the physical aspects that are inherited in the crane selection process such as: shape of the building, site constraints, adjacent buildings, etc. which are considered the most critical factors affecting the crane selection. Number of scenarios are generated, based on different site constraints such as adjacent buildings, power supply cables, and terrain condition as shown in Fig. (6.10). The MAIN DISPLAY provides the user with information on the selected case based on the user's responses to questions posed by the system. The user can activate other options or make changes to his/her previous responses by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**). Sample of these scenarios are presented in [APPENDIX D]. Such an action is controlled by **WHEN CHANGE METHOD**, as illustrated by the example shown in Fig. [B.10 Appendix B]. Information regarding site constraints, related to the three dimensional (3D) shapes and scenarios are stored in the database containing 120 records. Each record consists of a number of fields, containing unique codes for indexing purposes. Reference to the selected crane, such as the AutoCAD file name and path, and procedural link to the other modules from the system is displayed in the **selected shape panel**.

d. Plans Display

The three dimensional shapes with their associated knowledge and base information clearly carries the crane selection process half the way, analyzing the data and assuring the accuracy of the results resemble the other half. Locating the crane(s) and material to be handled on a construction site involves complex managerial decisions associated with high level of risk. Plan views which are presented in the **Plan Display**, become essential in this process. A number of scenarios can be generated, containing presentations of different plan views with locations of the crane(s) and the material to be handled. Each scenario becomes a new case, it may be selected for further investigation, and implementation. Fig. 6.11, illustrates an example of the plan display screen from the module. Implicit knowledge and methodology of solving the crane location problem, and detail design solutions regarding crane erecting on site are available in the AutoCAD as it will be described later in the chapter.

The final out-come of the consultation with the module is a list of all the technically feasible cranes supported by their geometry calculations for the selected site and its constraints (boom length, boom angle, jib size, location, number of relocating the mobile crane). In addition the **All plans list panel** contains a list of other scenarios that are available in the database to be retrieved by the user. The user can activate other options and retrieve extra information or make changes to his/her previous responses by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**) as shown in Fig. (6.11). The information on the two dimensional (2D) plans and scenarios are stored in a database containing 1200 records in order to facilitate different solutions. The user can brows through the system's different solutions, and may select one or more of them by using ADD command to generate a list of the feasible alternatives.

The selection can be further analyzed based on a cost comparison between renting or purchasing alternatives, using a cost module that is linked to the system. The system also provides the user with access to the geometry calculation module by clicking on the CALCULATE option.

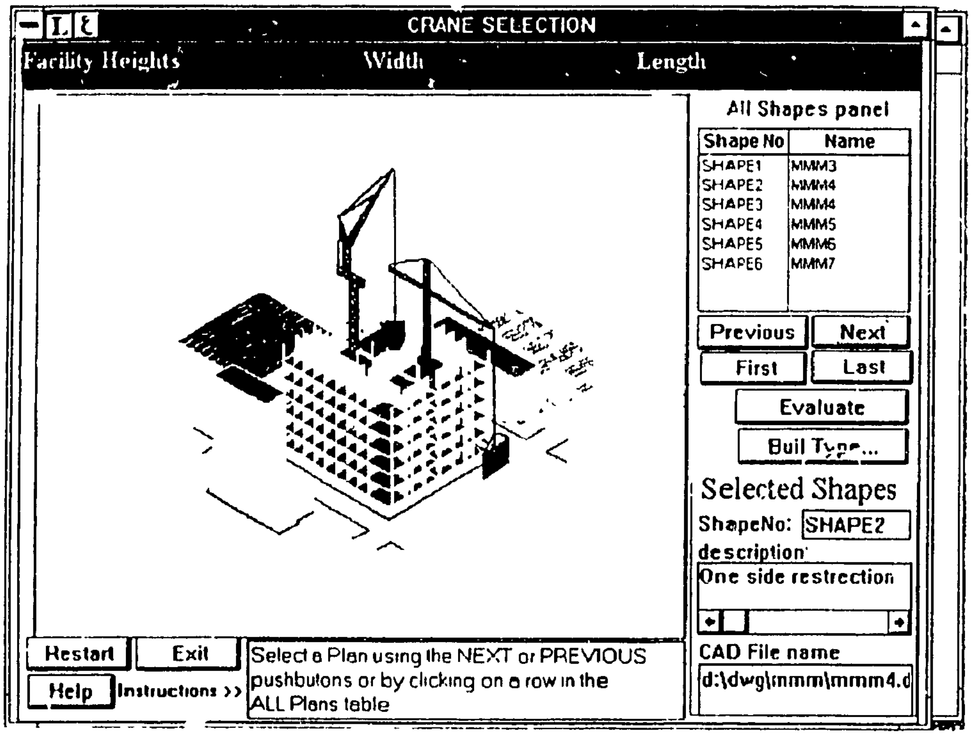


Fig. 6.10 KBES Module's Main Display

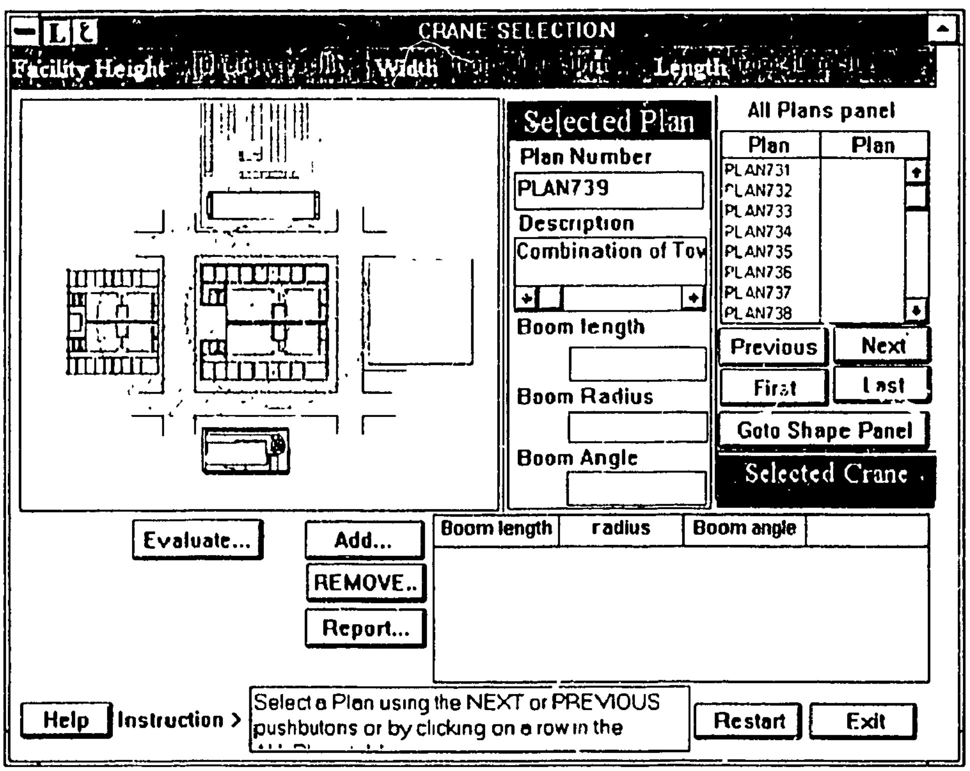


Fig. 6.11 KBES module's Plan Display

6.3.3 CASE-BASE REASONING MODULE

In addition to heuristic and rules of thumb experts refer to solutions from similar cases, involving crane selection they faced in previous projects. Therefore analogical reasoning to identify most common cases is required in order to establish a methodology for crane selection process for high-rise building construction (Al-Hussein, et, al 1995-B).

a. CBR Module Main process

To facilitate the process of selecting cranes for a new project a library of information on constructed buildings (cases) with data on cranes used in their construction such as, type(s), Number(s), location(s), and associated problems due to decisions made during the crane selection process, has been established and stored in the system's global data-base. To simplify the process, the actual cases are classified according to their types into office or residential buildings. Further, the cases are subdivided according to their height, length, and width.

The selected case is presented in a three dimensional display (3D Display) to enable the user to visualize it in three dimensional drawing (3D image). The original case is presented along with different scenarios generated based on different possible site constraints, site lay-outs, and designs. All these cases are further evaluated and the selected crane is presented in plan views. This is carried out in the plan display.

b. CBR Module Over-View

CBR has been developed in an object-oriented methodology. This module allows for information, on actual constructed buildings along with the different scenarios and information on cranes used in their construction to be stored in the module's database, which inherits from the system global database, as shown in Fig. (6.12). The data is available to be retrieved and modified as needed. The module is also capable of facilitating user friendly interface.

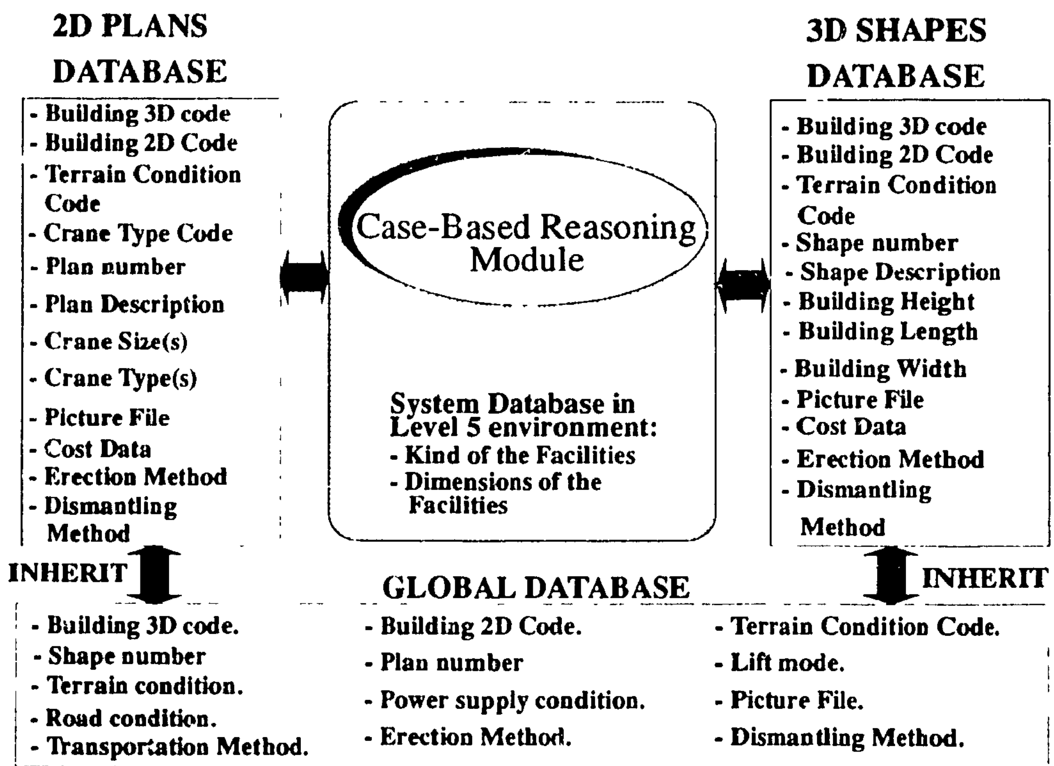


Fig. 6.12 Case-Based Reasoning module's Data-Bases

When the user selects the **Case-Based Reasoning (CBR)** option from the **APPLICATION MAIN MENU**, a display called **Facility Type and Kind Display** is opened as shown in Fig. (6.13). The user is requested to select a facility type similar to the one that is to be constructed. In a display called **Facility Hight-Width-Length** the user can narrow the search through the data, which is stored in the system's database in the **CLASS building dimensions** as shown in fig. (3 APPENDIX B). Based on the selected building's dimensions, the system activates an external database i.e. three dimensional facility shapes database file and opens the **3D Facility Main Display**.

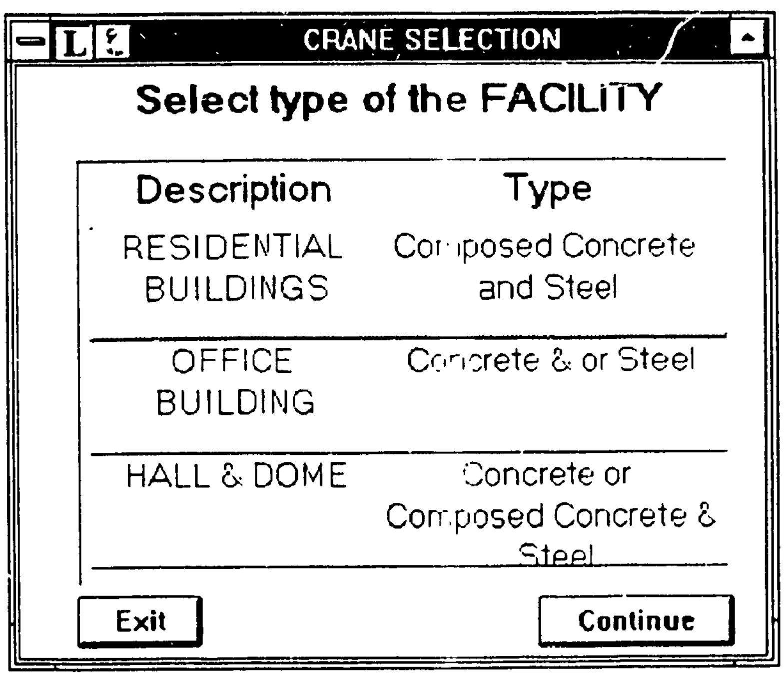


Fig. 6.13 CBR module Introductory Display

c. 3D Facility Main Display

An actual case with the descriptions of the site constraints, terrain condition, site accessability,...etc. is presented to the user in the **3D Facility Main Display** as shown in Fig (6.14). The three dimensional (3D) facility Main Display's activation is controlled by **When Change Method** which allows for inheritance of data from the KBES module, making the Case-Based Reasoning module acting as an expert system to allow the user to browse through the Crane Advisor's database to display similar, by dimension, cases representing different scenarios of the selected case. These scenarios have been generated by changing the site lay-out and constraints to form new selections. The system present them in a table, shown on the screen, in a panel called **All Facilities shapes list panel,** which contains the list of other scenarios available in the database to be retrieved. The user can activate other information or make changes to his/her previous responses by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**). The information on the three dimensional (3D) shapes and scenarios are stored in a database of 188 records that includes 28 actual cases generating 160 scenarios. Also the system inherits all similar cases from the KBES module's database.

The **EVALUATE** option is controlled by the "when change method", which deactivates the three, dimensional database, activates the two dimensional databases, and also opens the **FACILITIES PLANS DISPLAY.**

d. Facilities Plans Display

Facility main display presents the user with the three dimensional (3D) view of the actual case. The **(2D) Facility Plan Display** presents the plan view of the selected actual case and the cranes locations. Number of scenarios are inherited from KBES module's database, which contains different plan views with the locations of the crane(s) and the material to be handled. Methodology of locating the crane, and detail design solutions regarding crane erection on site is also presented as shown in fig. (6.15). Each scenario becomes a new case, it may be selected for further investigation for a possible solution to the crane selection.

The final out-come of the consultation with the module is a list of all the cranes considered to be technically feasible for the selected site and its constraints. Detail geometry calculations such as (boom length, boom angle, jib size, location, number of relocating the mobile crane) are also presented. The **All plans list panel** contains the list of other scenarios available in the database, and can be retrieved by the user. The user can activate other options to get new information or make changes to his/her previous responses by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**) as shown in the fig. (6.15). The information on the two dimensional (2D) plans and scenarios are stored in a database containing 720 records in order to facilitate different solutions. The user can brows through the system's different solutions, and may select one or more of them by using ADD command to generate a list of feasible alternatives.

The selection can be further analyzed based on cost comparison between renting or purchasing option, using the cost module that is linked to the system. It also provides the user with access to the geometry calculation module.

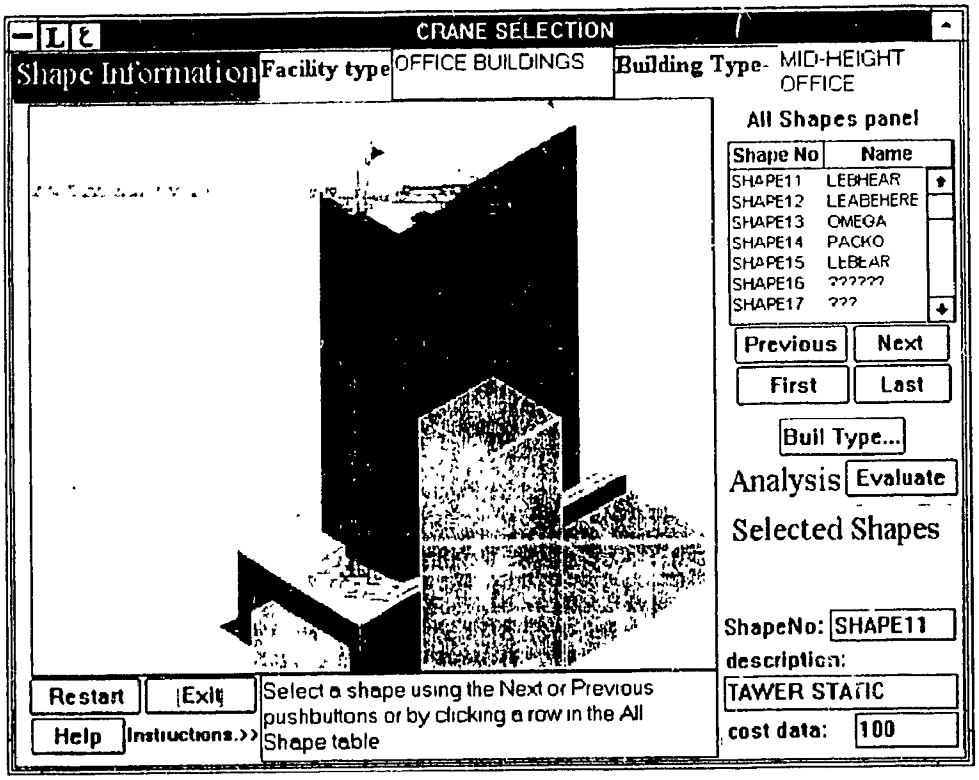


Fig. 6.14 CBR Facility 3D Main Display

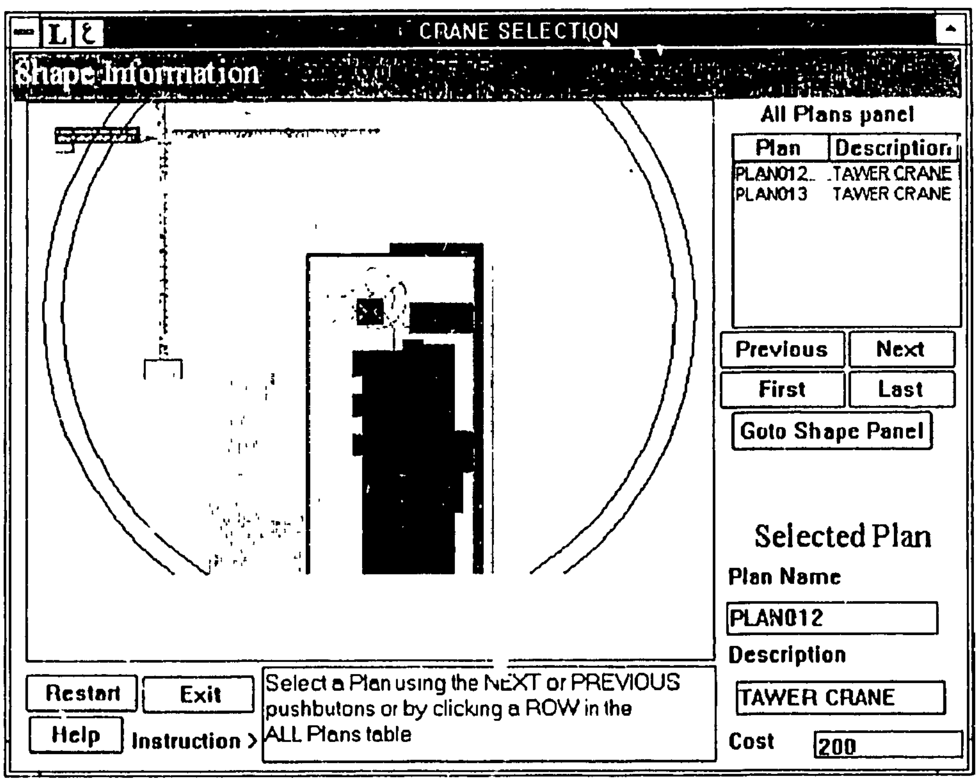


Fig. 6.15 CBR Facility 2D Plan Display

6.3.4 GEOMETRY CALCULATION MODULE

Both the KBES and the CBR modules assist the user in selecting the most appropriate crane for a given project based on its definition and constraints, it also advises in locating the crane(s) for efficient use. Locating a crane(s) on construction site for optimal use is challenging task. In practice, mainly this is done by trail and error, leading to mistakes and extra cost. The crane advisor can assist the user in locating the selected crane(s) using the geometry calculations module, which is capable of carrying out geometry calculations for the optimal crane location. These calculations can be validated graphically to examen their accuracy.

Module's Structure and Strategy

On construction site, several pieces of equipment are found to be usually working in conjunction with a crane. Relocating the crane could cause down-time for these equipment. Also a wrong choice is likely to have serious consequences in terms of high cost and possible delays. The geometry module within the Crane Advisor supported by graphical representation, provides the user with the accurate boom length, radius, boom angle to ground, number of cranes, single lift planning, production works etc.. In the case of a mobile crane, the module provides the user with the optimum number of the crane(s) locations around the building. As shown in Fig. (6.16), the user is guided while inputting data regarding building dimensions and load descriptions. The user may select the default data for the number of times the mobile crane is relocated in either side of the building, and for the crane geometry descriptions (boom offset to ground, boom offset to the rotation centre, boom cross section, and boom offset to the age of the building). However, after showing the boom length in the guide panel, the user is advised to change the default values to match the manufacturers's specifications for crane geometry and descriptions as shown by "warning" screen illustrated in Fig. (6.17). The default is reliable data for a small crane, but it is over-estimated, although feasible, for a large crane.

In summary the system assists the user in planning the crane(s) operations on site in the following aspects:

1) In the case of a mobile crane, the system calculates the boom length, radius, boom angle to ground, location of the crane, and number of times the selected crane, may be relocated.

2) In the case of a tower crane the module calculates the jib size, the optimum use of the combination between luffing jib, crane's mast, and crane's location.

3) planning for single critical lifts, using one crane lift or multi crane lift.

The system is capable of assisting the user in selecting more than one crane for a major job and perhaps other crane(s) for certain single critical lifts. However in many occasions the site is limited, and the selected radius is not feasible. Therefore the system is equipped with a facility called SITE-LIMIT where the user is asked to answer questions about the building's dimensions, load descriptions, and maximum radius where the crane can be located. The new location will be investigated and the new boom length and the boom angle to ground will be calculated.

In other cases, however, the selected alternative may not be available the AVAILABLE option within the system enables the user to investigate the next available crane.

Using the GRAPHIC command within the Crane Advisor a list of the feasible alternatives can be visualized and graphically simulated using AotoCAD in a module called CRANE-CAD.

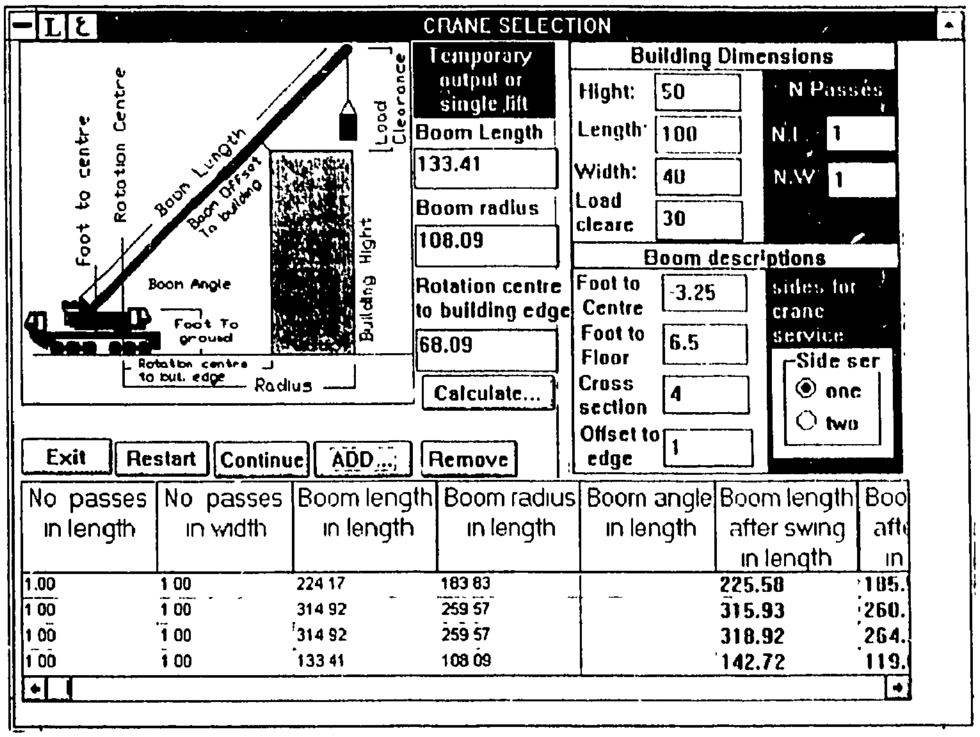


Fig. 6.16 Geometry Calculation Module' Interface

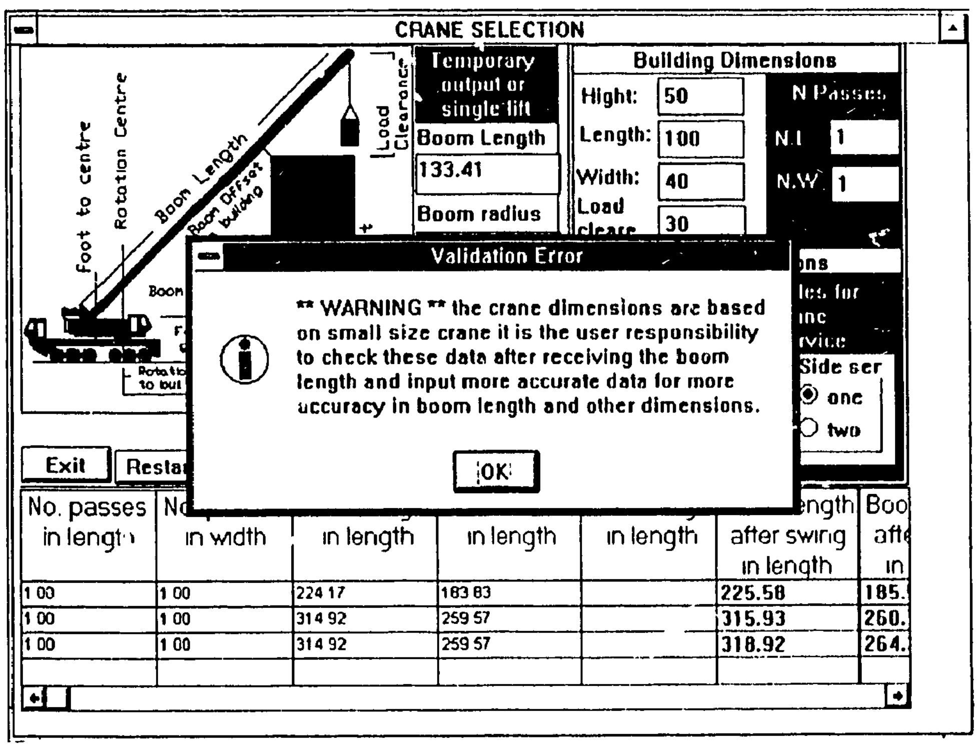


Fig. 6.17 Geometry Calculation Modules' "Warnings"

6.3.5 GRAPHIC SIMULATION MODULE CRANE-CAD

Computer-aided design (CAD) are capable of formulating domain knowledge and design, AutoCAD, has the capability of linking to databases such as DBase III, and spreadsheet applications such as QuatroPro, providing the Crane Advisor with flexibility and effectiveness.

a. Modules' Structure and strategy

On construction sites the final position of a selected crane to perform task or tasks, is normally arrived at after many trials, which tend to be a time consuming and expensive exercise. This exercise can be effectively carried out using computer simulations. These simulations require detailed data on crane working range, site restrictions, shape of the building, material specifications including masses, and sizes. Crane Advisor is capable of performing such simulations using the computer-aided design (CAD) package that is linked to its database. Using the knowledge stored in the system's knowledge base, and optimization techniques, relationships between the jib size, boom size, mast height, and building floor layout are automatically generated. During the process the user may modify the case to suit any new restrictions and site constraints. The user can also modify the jib size and height of the crane that is recommended by the system by selecting other components using the system's pull down menu as shown in Fig. (6.18). The user however, may chose to select a different crane from the database or specify his/her own crane, in this case the user will be assisted in identifying the crane's location using the graphical simulations.

b. Modules' Overview

Validation and simulation of the location and manoeuvring of the selected crane on a construction site is an elaborate exercise. Computer-aided design (CAD) is capable of presenting cranes structure and other elements as a set of primitives components and attributed blocks that offer a great deal of flexibility to achieve tasks such as crane simulation.

CRANE-CAD assists in selecting a mobile crane by calculating the optimum boom length, radius, boom angle to ground, location of the crane, and number of relocating the crane. The module also calculates the jib size, the optimum use of the combination between luffing jib, crane's mast, and location of the tower crane. Further, the module assists in planning single critical lifts, using one or multi cranes lifts.

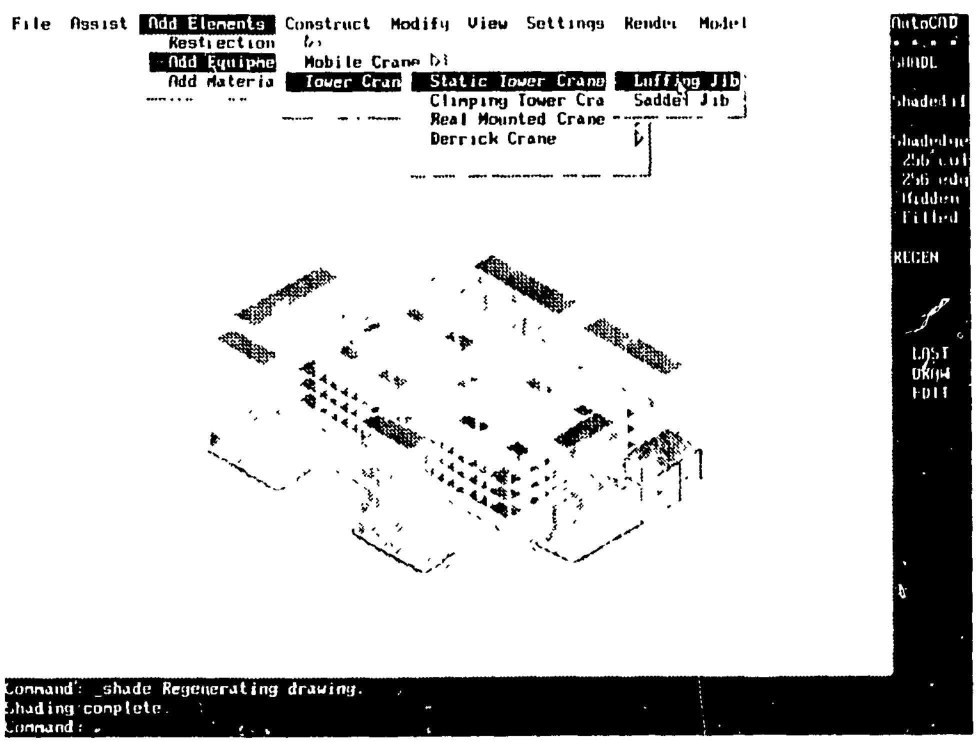


Fig. 6.18 Graphic Simulation Module's Interface for Building and Cranes Elements

6.3.6. EQUIPMENT COST ESTIMATOR MODULE

Selecting a crane among many alternatives depends on its owning and operating costs or on its rental cost. Estimating equipment costs is a difficult task due to the lack of information on the equipment ownership costs. In most of the time the decision makers rely on their knowledge and expertise in predicting such costs. Published manuals such as the Corps of Engineering manual (Construction Equipment ownership and Operating Expense Schedule) are also used, few of these manuals include adjustment factors depending on the conditions surrounding the equipment operation (William, 1988). In this work, in order to arrive at a reasonable owning and operating costs for selected equipment, in addition to such manuals, supporting information was also gathered from different sources including machine performance and specifications manuals produced by equipment manufacturers, periodical services and spare parts costs along equipment lifetime and equipment rental companies' cost data.

This section addresses the impact of the crane's acquisition costs on its selection process in the construction industry. A module called Equipment Cost Estimator and Analyzer (ECEA) that can be integrated within the CRANE ADVISOR environment is presented for equipment's owning and operating costs estimation. Knowledge and experience possessed by planning engineers and equipment specialists has been acquired and structured in a form suitable for manipulation by the system.

a. ECEA Structure

The Equipment Cost Estimator and Analyzer "ECEA" is a prototype PC-based computer model designed as a stand alone module or to be integrated within the knowledge based equipment selection environment. It utilizes a cost database, and a spreadsheet to perform economic analysis on different alternatives including cranes. The model is written in Macro language and run in the Quatro spreadsheet. ECEA would mainly be used as a decision support tool to assist contractors in their decisions on equipment acquisition considering the two major options i.e. purchasing or renting equipment. It can make use of the output from the Crane Advisor in terms of type of recommended cranes to assess their cash flow in order to narrow down the selection process to a precision limit.

As is shown in Fig. (6.19) ECEA consists of two modules: the cost estimation module that deals with the owning and operating and rental costs, and the cost analyzer module which deals with economic analysis, comparing alternatives and sensitivity analysis. These two modules are further subdivided into sub modules to help in segmenting the various cost components for easy input, access and manipulation. The module is not limited to a specific type of equipment, moreover it is flexible enough to be used in selecting between equipment of different types such as cranes and concrete pumps.

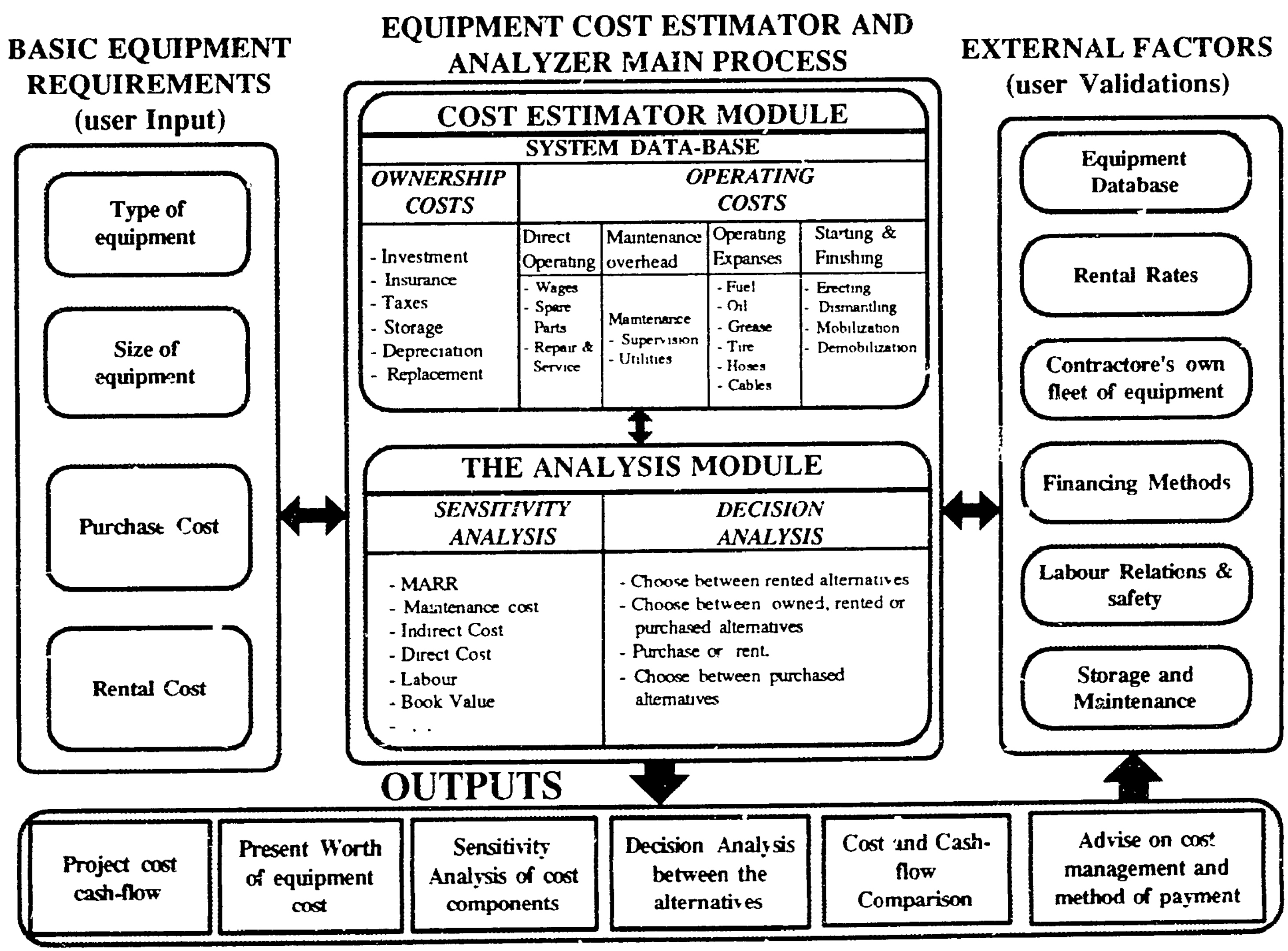


Fig. 6.19 Equipment Cost Estimator and Analyzer (ECEA) Main Process

b. ECEA Model Outline:

The ECEA benefits from the spreadsheet proficiency in cost data manipulation, sorting, calculation, linking, and presentation. The cost calculations implemented in ECEA are based on the economic engineering formulation that compute owning cost components. The model has a built-in database that stores equipment operating costs, hence, minimizing the user's inputs. Table (6.1) presents a list of the available equipment and data on their cost stored in the module's database. This data is based on published sources such as the U.S. army corps of engineering manual, rental rate blue book, Dataquest Inc, however, the users can also store their own data.

	Equip.#	discreption	manufacturer	capacity	power	boom	Type
1001	1	Crane	Gendron	1 Ton		40 ft	Mobile
1002	2	Crane	Hewitt	3 Ton		65 ft	Mobile
1003	3	Crane	GAY	8 Ton		95 ft	Croler
1004	4	Crane	GAY	9 Ton		140 ft	Static
1005	5	Pump	MAYCo/c-30hd	25 cu yd/hr		V 30ft H 40ft	Mobile
1006	6	Pump	Morgan/100-n	100 cu yd/hr		V 60ft H90ft	Mobile
1007	7	Pump	Mayco/lst-60s	60 cu yd/hr		V 40ft H60ft	Mobile
1008	8	Pump	Morgan/140-n	140 cu yd/hr		V 90ft H110	Mobile

Table 6.1 Information on a List of Cranes Stored in the ECEA Module

The main features of ECEA are:

It incorporates a user friendly interface that facilitates user inputs on equipment and cost data. ECEA performs depreciation and tax calculations for equipment. It also incorporates breakdown cost calculation feature, that takes into account the cost of unscheduled equipment failures while working on productive tasks. Further ECEA consists of database feature that cover running cost components, and provides the user with an easy to edit, add, or update database.

In addition, the module applies a sensitivity analysis with graphical representation on various equipment cost scenarios.

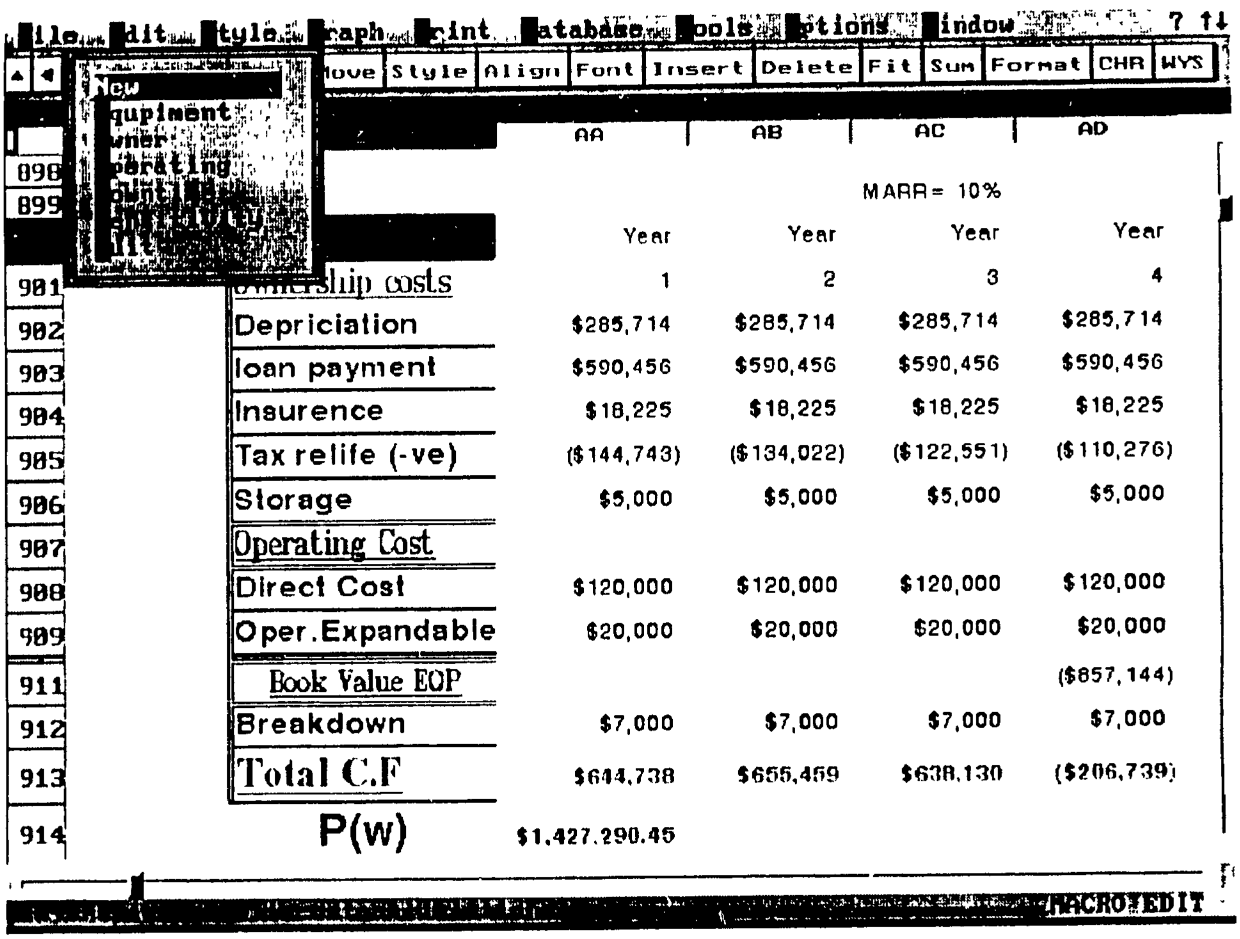
The module, consider different cost components including: Consequential costs, Owning costs, Taxes, Depreciation, and Operating costs which include maintenance direct cost, maintenance overhead cost, fuel consumption cost, lubrication and filters. A detail study on these costs components is presented in [APPENDIX E].

c. ECEA's mode of operation

As soon as the user accesses the ECEA module, she/he would be asked either to access the system's database in order to select an equipment, or to choose an input mode to specify her/his own equipment which could be the output for the Crane Advisor. In the first case a list of equipment is displayed for the user to choose from, as shown in table (6.1).

Selecting the required option, the cost estimator asks the user to input data such as a purchase price, method of financing, interest rate, equipment life, insurance, and method of depreciation (i.e. Straight line, Sums of Years Digits, or Declining Balance method), data on all other costs including the running and operating costs. The user has the option to access this data and update it or use it as is and let the system calculate the Net Present Value of the equipment cash flow using the cost analyzer module.

In addition to the stored information in the database, the user is asked to input data on direct and indirect costs, and operating and maintenance costs. The system thereafter would suggest the best alternative based on its calculated Net Present Value as shown in Fig. (6.20). Sensitivity analysis is also carried out during the calculation and finally the system suggests a better option among the alternatives under consideration as will be describe in chapter (7).



		AA	AB	AC	AD
898					
899				MARR= 10%	
		Year	Year	Year	Year
901	ship costs	1	2	3	4
902	Depriciation	$285,714	$285,714	$285,714	$285,714
903	loan payment	$590,456	$590,456	$590,456	$590,456
904	Insurence	$18,225	$18,225	$18,225	$18,225
905	Tax relife (-ve)	($144,743)	($134,022)	($122,551)	($110,276)
906	Storage	$5,000	$5,000	$5,000	$5,000
907	Operating Cost				
908	Direct Cost	$120,000	$120,000	$120,000	$120,000
909	Oper.Expandable	$20,000	$20,000	$20,000	$20,000
911	Book Value EOP				($857,144)
912	Breakdown	$7,000	$7,000	$7,000	$7,000
913	Total C.F	$644,738	$655,459	$638,130	($206,739)
914	P(w)	$1,427,290.45			

Fig. 6.20 Net Present Value of an Equipment Generated by the ECEA

d. Cost estimation module

Equipment costs are primarily broken down into categories: owning and operating and consequential costs as shown in Fig. (6.21). The owning cost covers expenditures such as purchase, insurance, and storage. It also involves the decrease in the resale value of the equipment verses time, which is normally termed as depreciation. The operating costs are related to the operation of the crane including labour wages, spare parts, fuel, repairs and maintenance. Consequential costs are defined to cover the intangible costs arising from delays caused by machine breakdown.

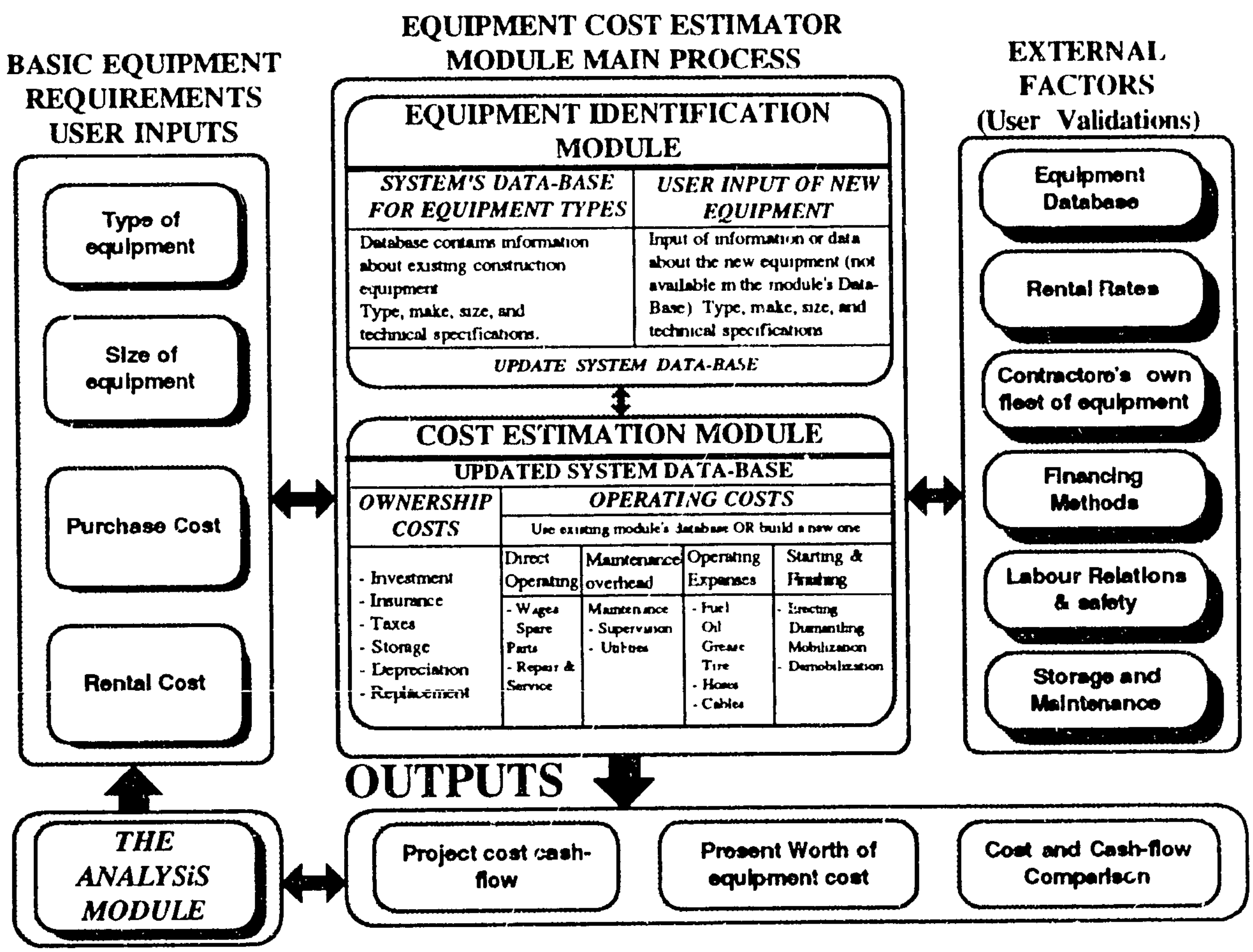


Fig. 6.21 Equipment Cost Estimator Module Main Process

e. THE COST ANALYZER MODULE

The outcome of the Cost Estimation Module is a set of Net Present Values of the cash flows. These values are further investigated using the Cost Analyzer module, which performs the Sensitivity analysis and Brake even analysis. This module as shown in Fig. (6.22) is designed to take into account the most likely variables that might affect cash flow components. The final output of this part of the module includes sensitivity analysis graph together with a recommendation to select the most cost effective crane among the alternatives.

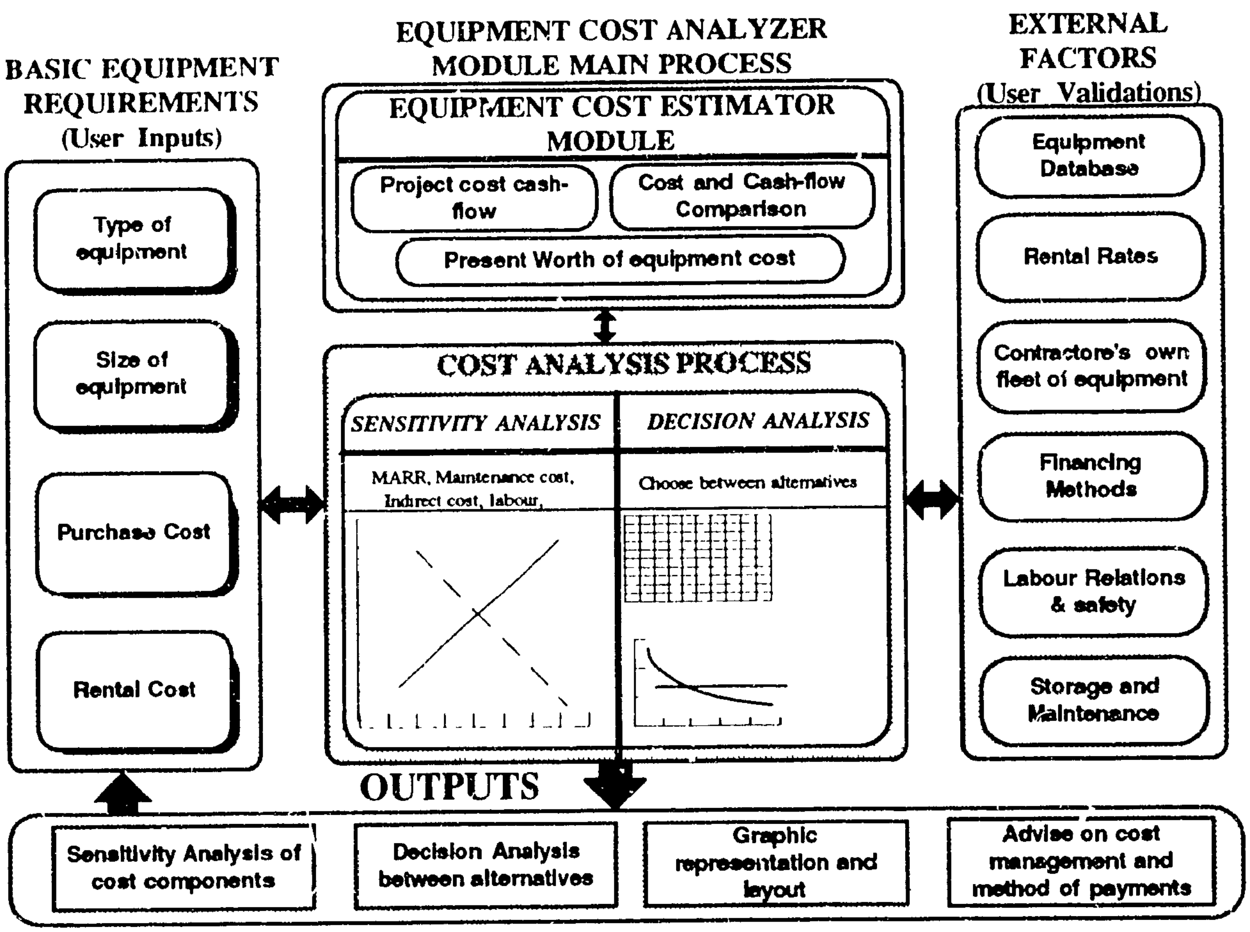


Fig. 6.22 Equipment Cost Analyzer Module Main Process

6.4 SUMMARY

This chapter described the ingredients of the Crane Advisor, which is an integrated computer system environment for crane selection. The system integrates AI methodology represented by an object oriented expert system with algorithmic techniques. Crane Advisor benefit from commercially available software used in the construction industry including, Level 5, Database (Dbase III), Spreadsheet application (QuatroPro), and Graphics (AutoCAD).

Crane Advisor consist of five modules: Case-Based reasoning, Knowledge-Based module, Geometry Calculation module, Graphic validation module, and Cost estimation module.

Table (6.2) shows the input data required by these modules, the action causes and the output of these modules.

Crane Advisor can be accessed by different users involved in the crane selection process as shown in Fig. (6.23).

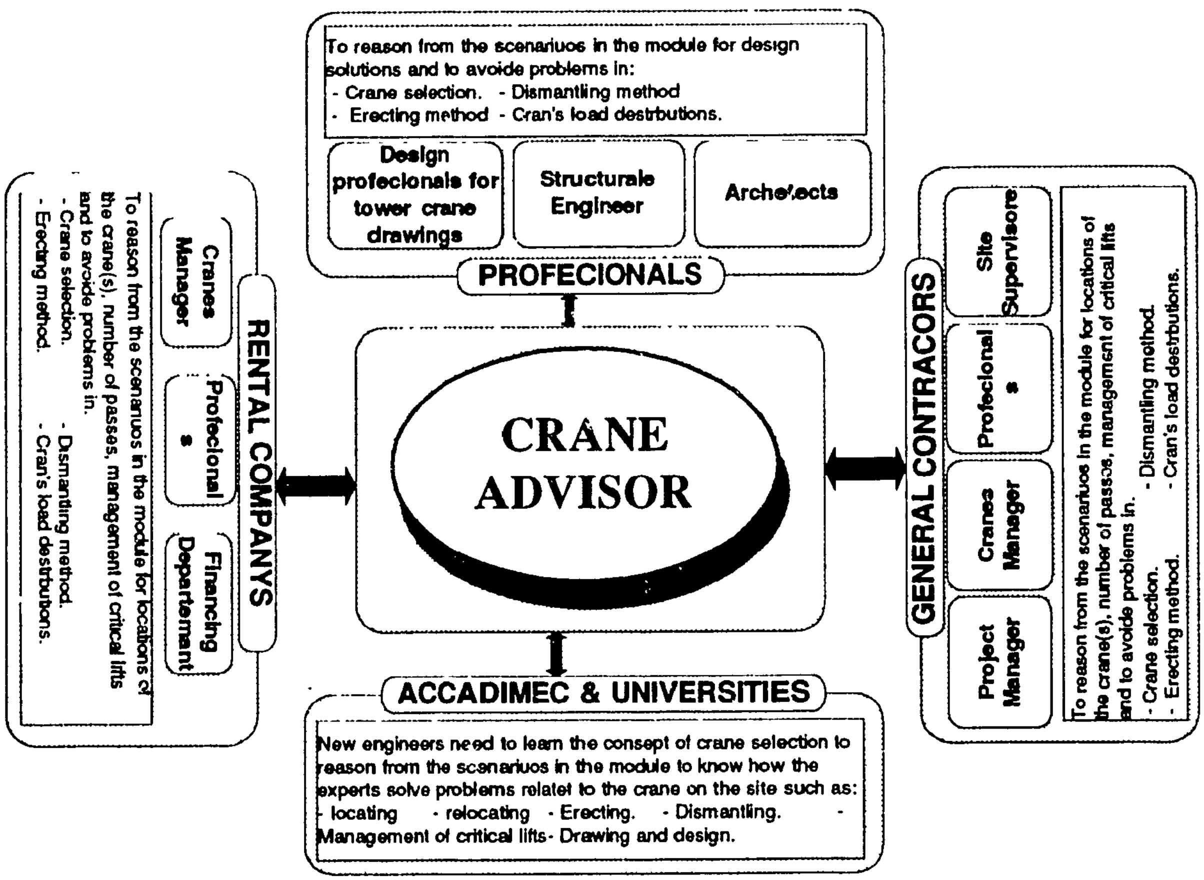


Fig. 6.23 Users of the CRANE ADVISOR

Module Name		Input Data	Actions	Output Data
Graphic Module	Crane-CAD module	Selected crane from CBR or KB Starting a new case.	Case adaptation Generate new case.	3D module with selected crane(s) type(s), size(s), location(s) To the plan for the working range and crane location.
	Optimum cane CAD	Accurate building dimensions length, width, height Surrounding building specifications and their distances to the new building under construction Crane specifications boom foot to ground, boom foot offset to rotation center, boom offset to the edge of the building. Load specification dimensions weight, location and clearance required	Input dimensions Ask for calculation. Add to the list Compare. Number of passes for mobile	Optimum crane size Optimum boom lenght Optimum combination between jib and mast in the case of luffing jib Optimum location(s) of crane(s) Optimum location of material storage
Cost module		Crane type, size, number Methods of payment, taxes, and depresiation Project time and schedule	Cost calculation for all cranes cost components Cost comparison Cost analysis	Equipment cost cash flow for the period of the project Sensitivity analysis for cost components Decision analysis to select between alternatives buying vs purchasing or renting

Table 6.2 System Components Input-Actions-Outputs

Module Name		Input Data	Actions	Output Data
Case Base Reasoning	3D Module	Shape of the building, site layout, site constraints, etc	Match with existing case or selected scenario case or activate the KB	Selected case to reason from
	2D Plan View	Site layout, selected 3D case, etc	Match with existing case or selected scenario case or activate the KB	Selected case, plan view, crane type, number, location size, and material storage location
Knowledge Base	3D Module	Type of structure, shape of the building, site layout, and constraints	Investigate general factors affecting crane selection	Structure, type, size, and facade Adjacent building Road and terrain accessibility and condition.
	2D Plan	Plan view of site layout	Investigate factors affecting cranes, and those affecting jib, boom, and mast. Caranes location, workability range, number, type, size.	Crane(s) type(s), size(s), location(s), workable range(s) Kind and size(s) of jib, boom, mast.
Calculation Module		Accurate building dimensions: length, width, height Surrounding building specifications and their distances to the new building under construction Crane specifications: boom-foot to ground, boom-foot offset to rotation center, boom offset to the edge of the building. Load specification: dimensions, weight, location, and clearance required	Input dimensions. Ask for calculation Add to the list Compare Number of passes for mobile.	Optimum crane size Optimum boom lenght Optimum combination between jib and mast in the case of luffing jib. Optimum location(s) of crane(s) Optimum location of material storage

" Continue" Table 6.2 System Components Input-Actions-Outputs

CHAPTER VII

CASE STUDY

7.1 GENERAL

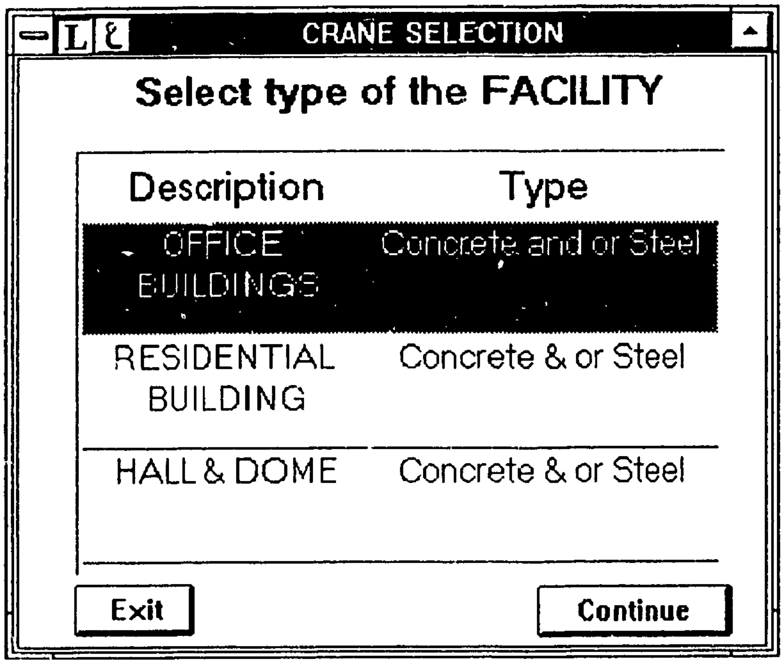
Validation and verification of a computer program in general, are necessary and sufficient conditions for evaluation a system. Verification is defined, as an area of validation with the distinction being that verification is concerned whether the system operates correctly and validation whether the system is correct for the problem to be solved.

The objective of this chapter is to validate the effectiveness of the CRANE ADVISOR using a case which consists of an office building with a composite steel and concrete construction. The building is 45 meeters height, 45 meeters in length, and 45 meeters in width. These dimensions fall in the group of mid-height, mid-length, and mid-width category of building groups. It is required to select a crane or cranes to be used in constructing this facility, using CRANE ADVISOR. Information on the case has been stored in the system's database.

7.2 CASE STUDY USING THE CASE BASED REASONING MODULE

Selecting **CONTINUE** option from the Crane Advisor's title, displays information on different kind of facilities stored in the system, and displayed in the **Facility Kind Display,** as shown in Fig. (6.7.1 a), in this case an office facility option is selected. Further, the facility's dimensions are determined from the **Facility Height Display**, the mid height is selected as shown in Fig. (7.1, b). This option activates the **3D FACILITY MAIN DISPLAY**.

(a)



(b)

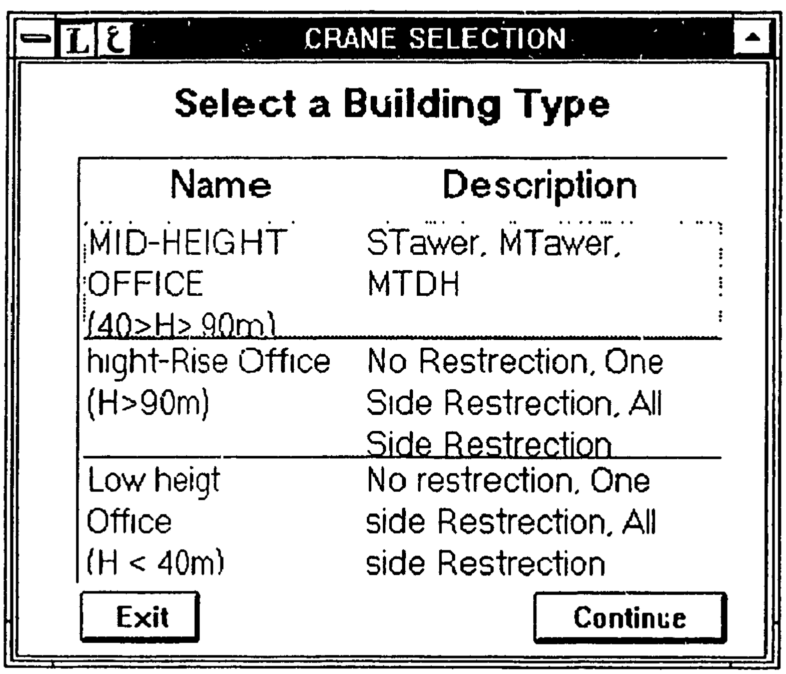


Fig. 7.1 Crane Advisor's Introductory Displays

7.2.1. 3D FACILITY MAIN DISPLAY

The **3D Facility Main Display** provides the user with information on the selected case based on the user's previous responses to questions posed by the system. The type of the facility, i.e. Office Building, and its group is displayed as shown in Fig. (7.2). At this stage the user can activate other options or make changes to his/her previous responses by choosing the command back to building types **(BACK-type). ALL SHAPES PANEL** contains a list of other scenarios, as was described in chapter (6). Having selected the current case as shown in Fig. (7.2), for further evaluation the system activates the **Plan Display** option.

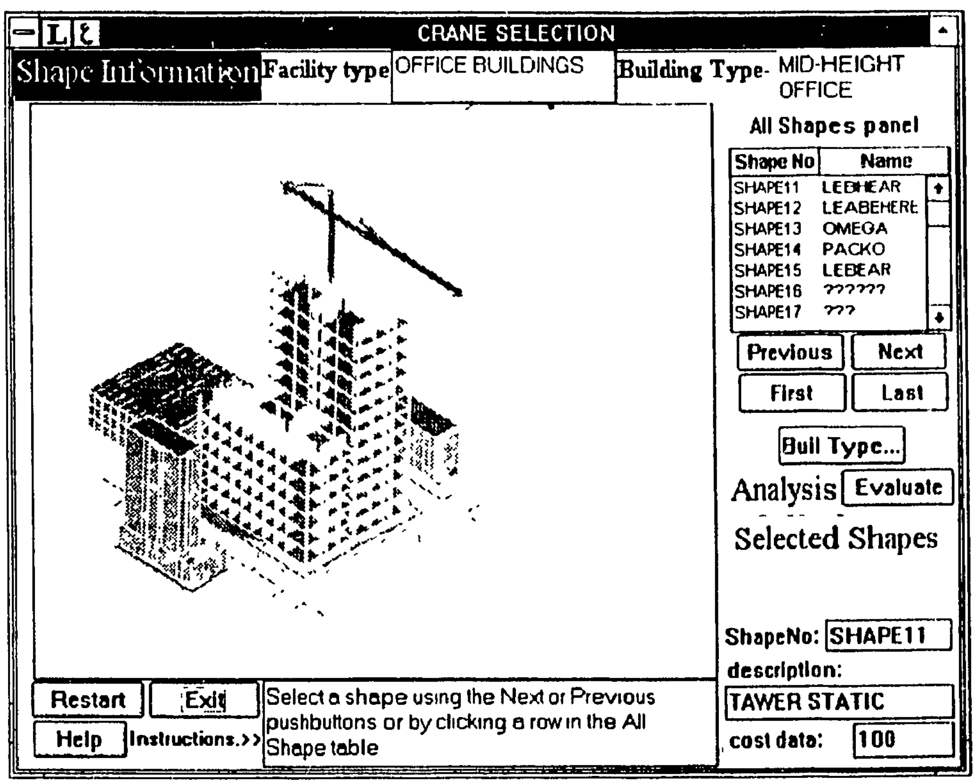


Fig. 7.2 The case study represented in the CBR module's Main Display

7.2.2. 2D Facility Plans Display

In the Facility Plan Display the actual case appears first showing that for this case one tower crane was selected as shown in Fig. (7.3). The type of the selected crane is shown in Fig. (7.4), which is a large climbing tower crane with saddle jib. The shape of the building and the site constraints, as shown in Fig. (7.2), were the determinant factors in selecting this crane. The building has irregular shape, it starts with a wide bodiume and continue with a single tower. The load capacity chart for the crane is included in the AutoCAD drawing as shown in Fig. (7.4). Additional information regarding the necessary reinforcement, slabs openings and the additional support for the slab to be able to bare the total crane's load, is presented in a separate drawing as shown in Fig. (7.5).

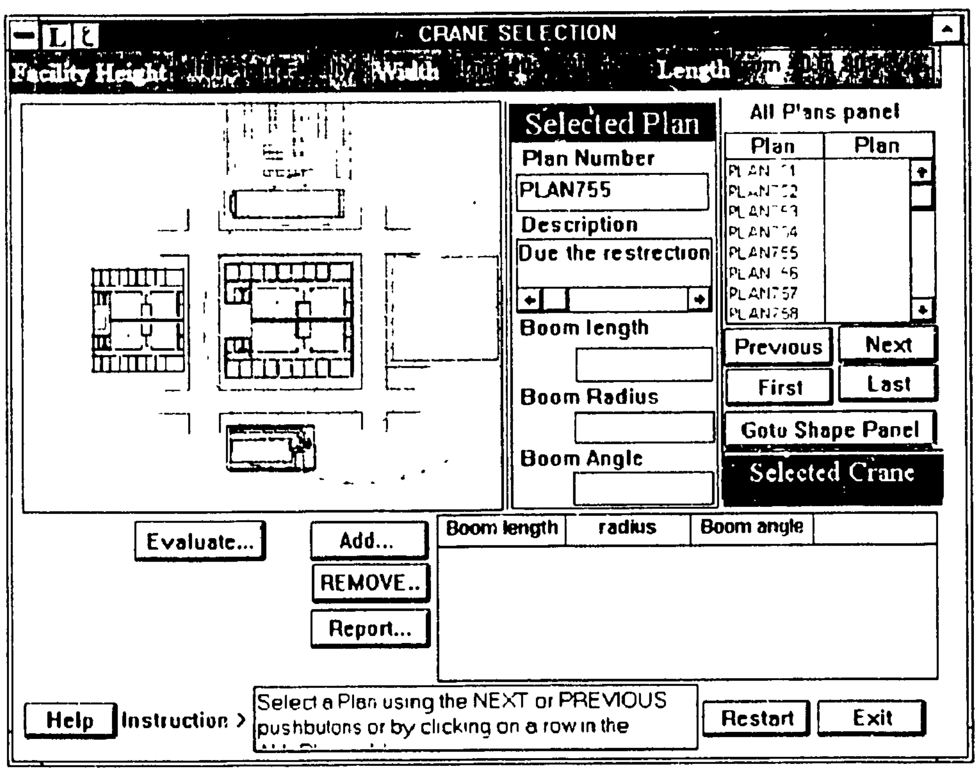


Fig. 7.3 The Actual Case Represented in the CBR Module's Plan Display

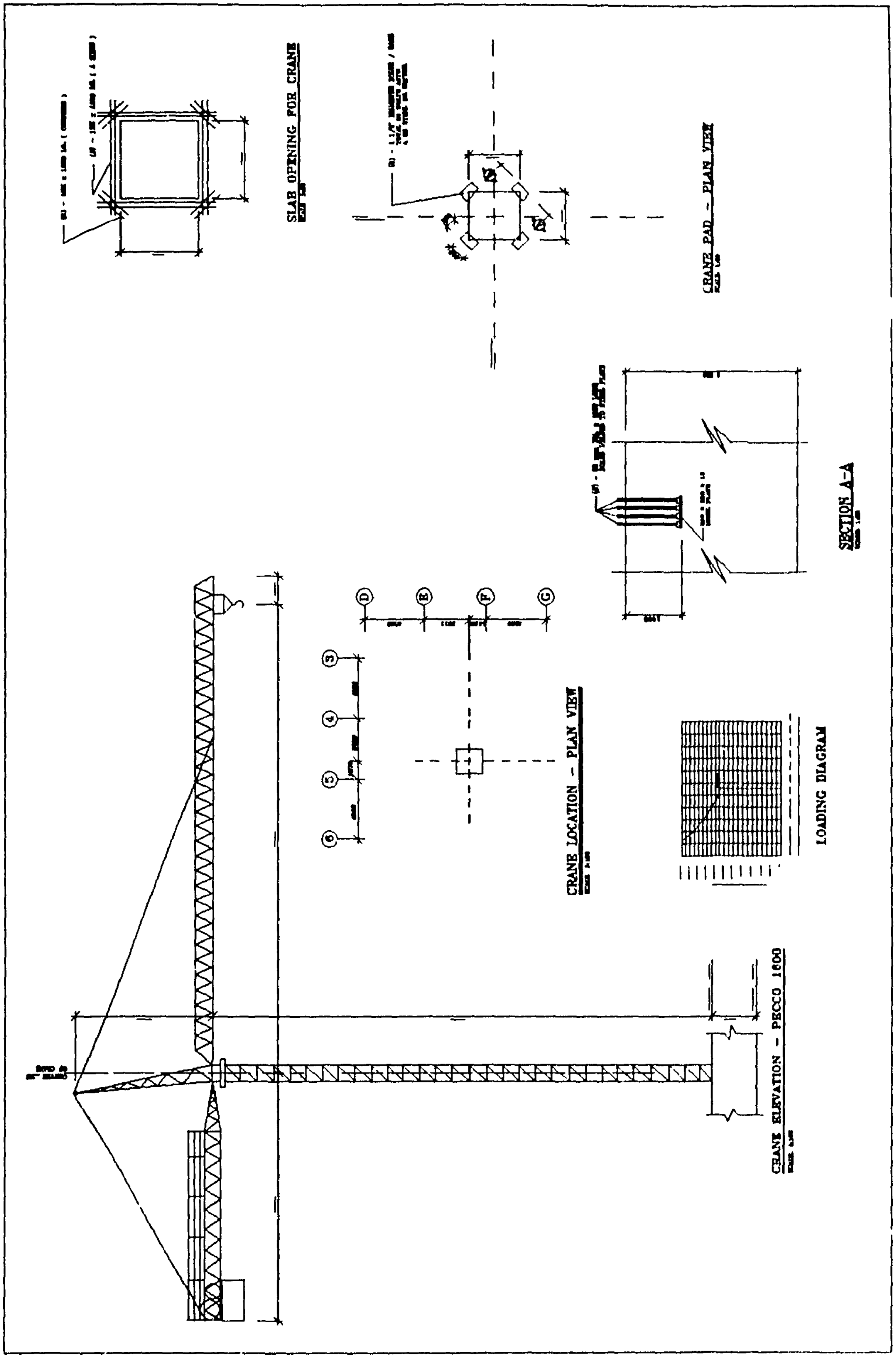


Fig. 7.4 Actual Design for the Case, Working Range and Load Charts

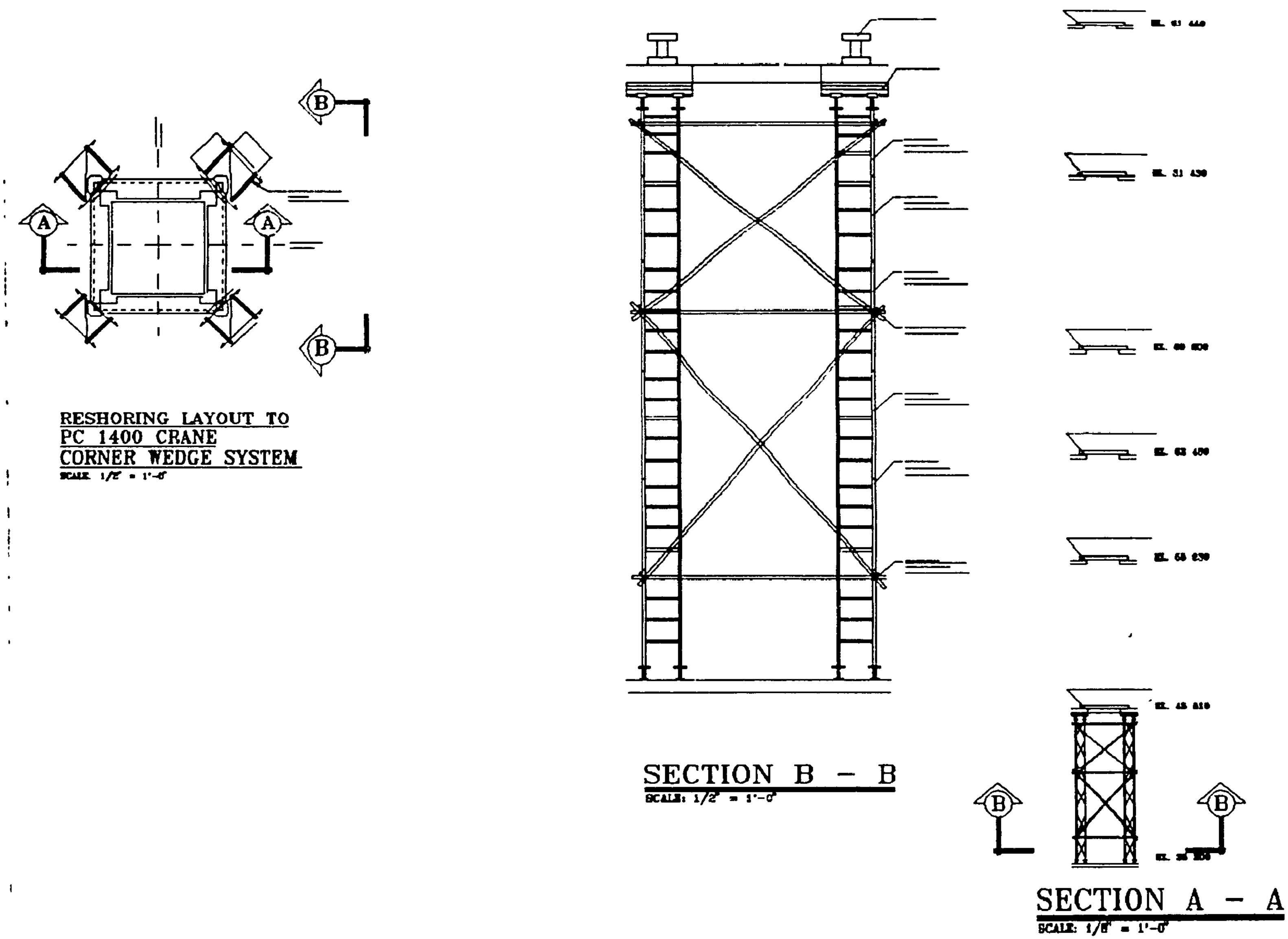


Fig. 7.5 Additional Design Information from the Actual Case

7.2.3. Module's Validations

A consultation with the Crane Advisor using its knowledge-base revealed that two tower cranes are technically feasible. Fig. (7.6) shows a 3D view of the building and the selected cranes, and Fig. (7.7) shows the plan view of the facility and the selected cranes. The first crane is a static tower crane, with luffing Jib, located in the back area of the facility to serve the construction stages up to the completion of the boduom, which has been designed for commercial spaces, and the other is a climbing tower crane to be located in the centre portion of the tower building (both jib configurations, Luffing and Saddle are accepted, in this case the saddle is selected). The climbing configuration has been chosen because the height of the tower building is beyond the reach of the free stand of the static tower crane. The drawing shown in Fig. (7.8) contains information about the cranes working ranges, and the load capacity chart for each crane. Other information about the reinforcement of the base of the static tower crane and the slabs' openings, and the shoring below the climbing crane is shown in Fig. (7.9) and Fig. (7.10), respectively. These designs are based on the crane's manufacturer's specifications.

Both cranes will be erected using mobile cranes. However, dismantling the static tower crane, after completing the construction of the bodiume (the commercial building), will be done by the climbing tower crane. The Climbing tower crane will be dismantled by a mobile crane. In the case where the site constraints do not allow for a mobile crane to be used, a derrick can be erected on the roof of the facility using the tower crane which can be used for dismantling the tower crane. Knowing this in advance enables the designer to take into consideration in the design of the roof of the building.

The system provides different alternative solutions to the locations of the selected tower crane, and their sizes, based on changes to the site constraints as shown in Fig. (7.11). Fig. (7.11, a) shows that in a case where the site is not restricted from all sides, the lowest part of the building can be constructed using two mobile cranes working in conjunction with the climbing tower crane.

In the case where the structural design does not allow for additional reinforcement of the slabs, and/or the cost of the shoring becomes very high, a large external static tower crane can be a solution. The tower crane will be located close to the building tower as shown in the plan view in Fig. (7.11, b), using Tid-Incert to the external wall of the building to allow for height increasing. A tower crane together with a mobile crane(s) can be another solution as shown in the same figure. Other scenarios can be generated and graphically evaluated as shown in Fig. (7.11, c) and Fig (7.11, d), which show the selection of three and four tower cranes.

More detailed analyses of the case is included in [APPENDIX D].

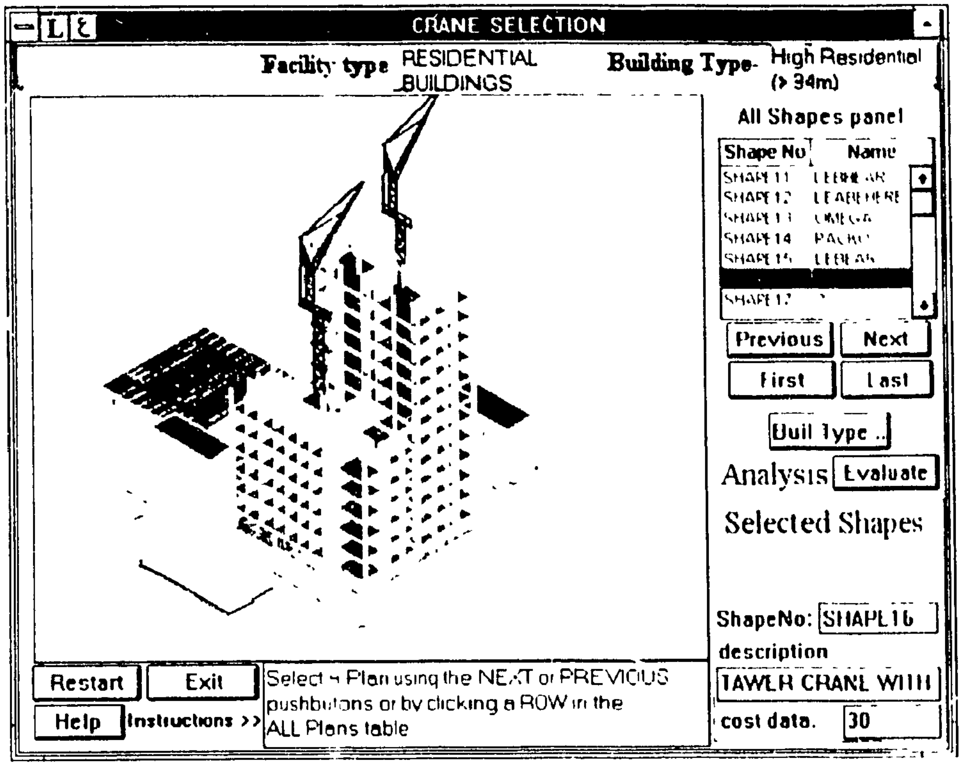


Fig. 7.6 Case Validation in the 3D Main Display

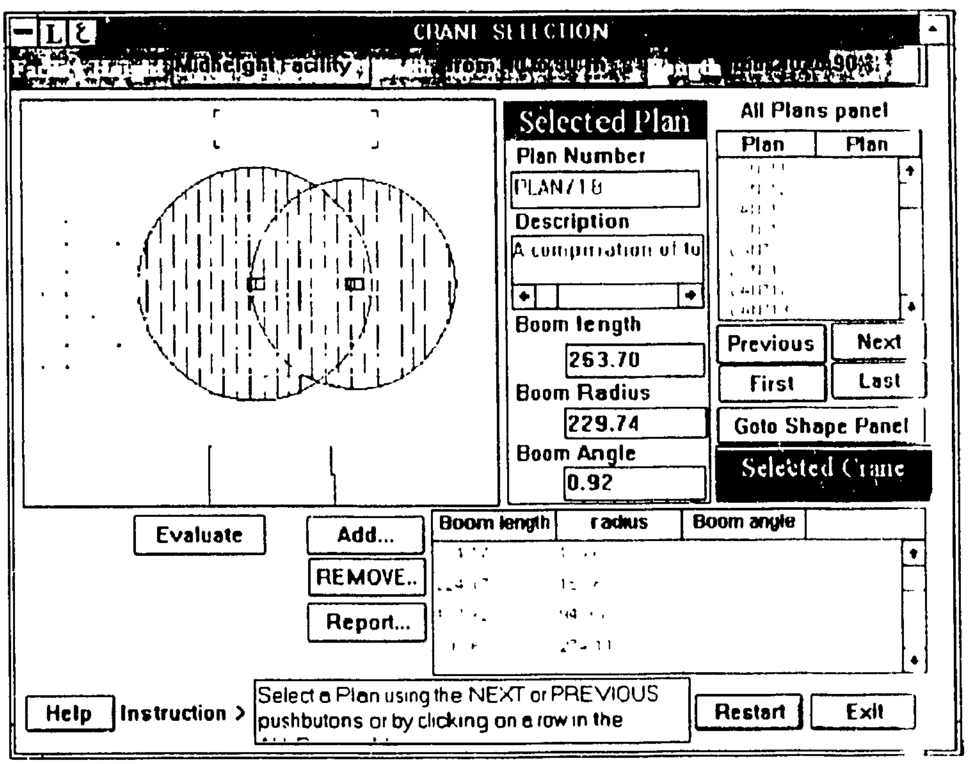


Fig. 7.7 Case Validation in the 2D Plan Display

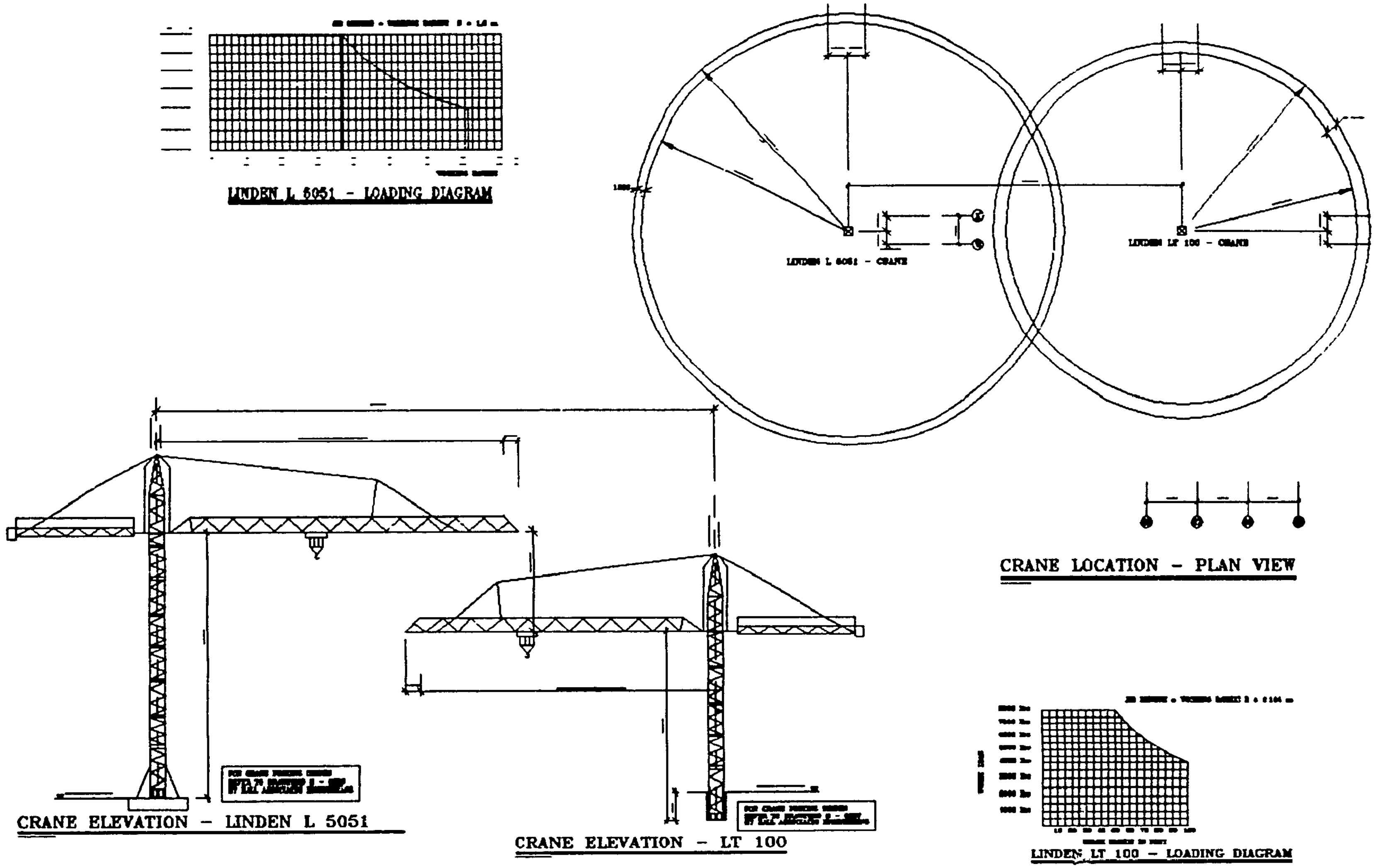


Fig. 7.8 Proposed by the System Design for the Selected Cranes

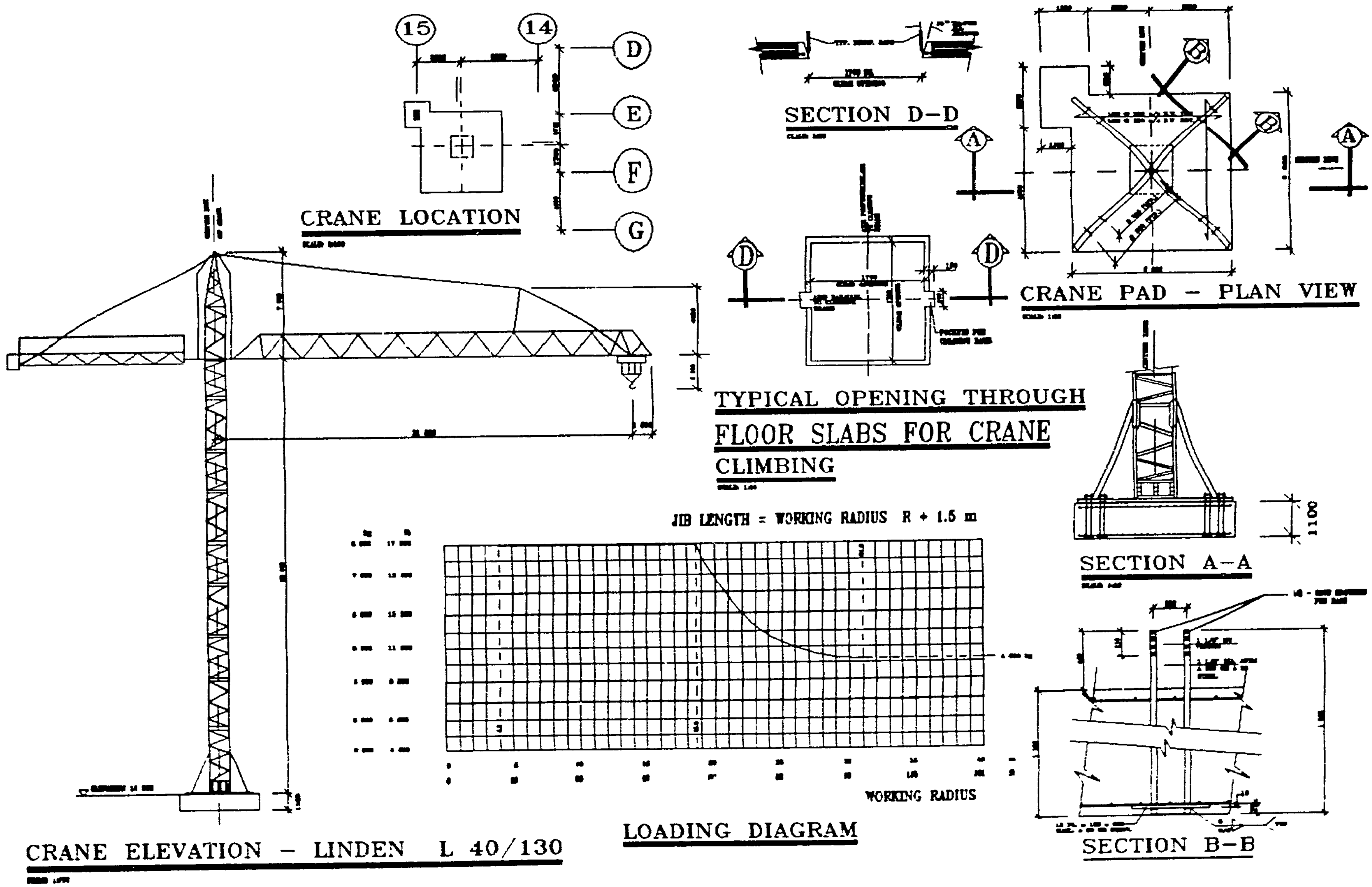


Fig. 7.9 Proposed by the System Design for the Static Tower Crane

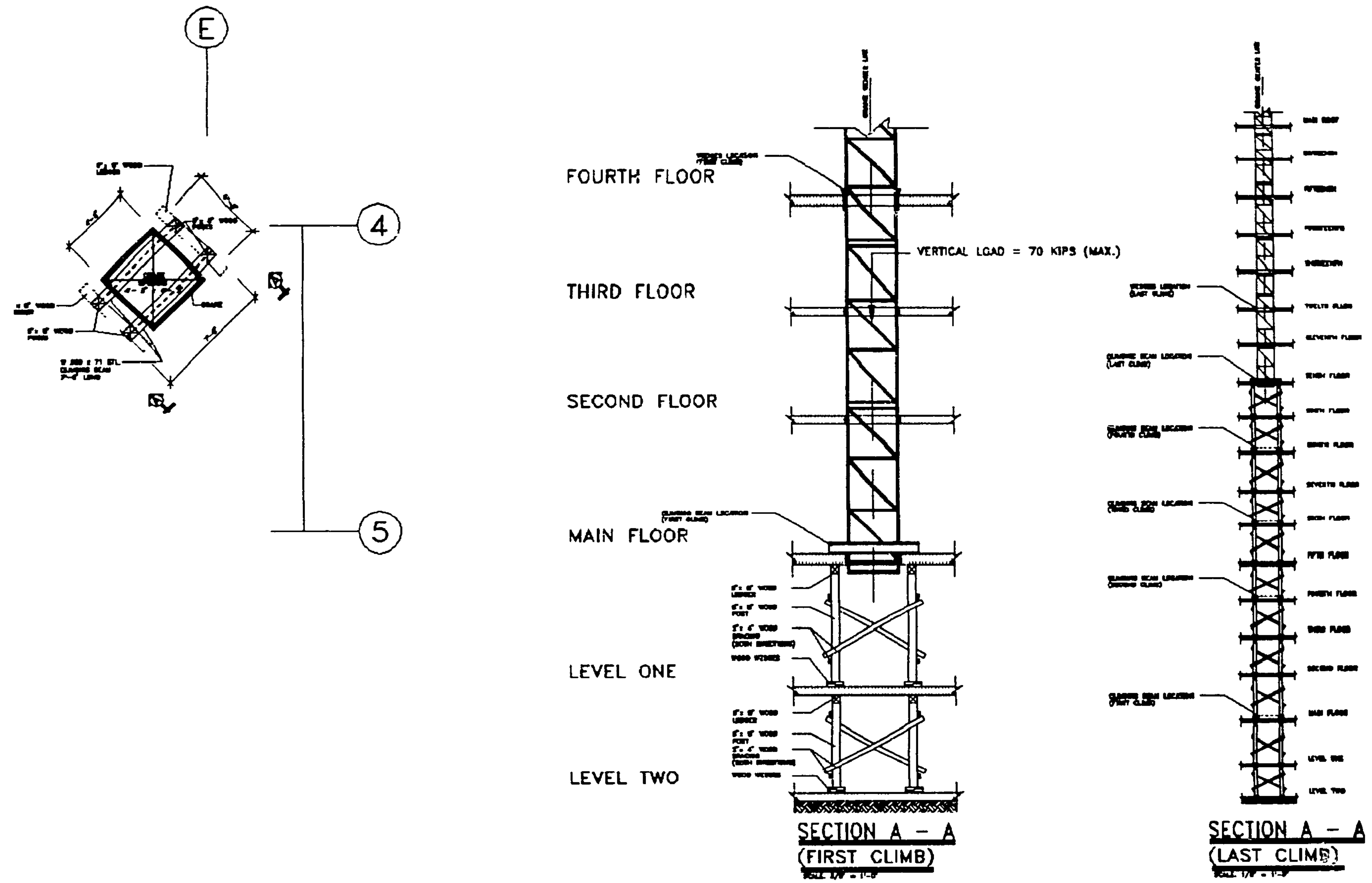
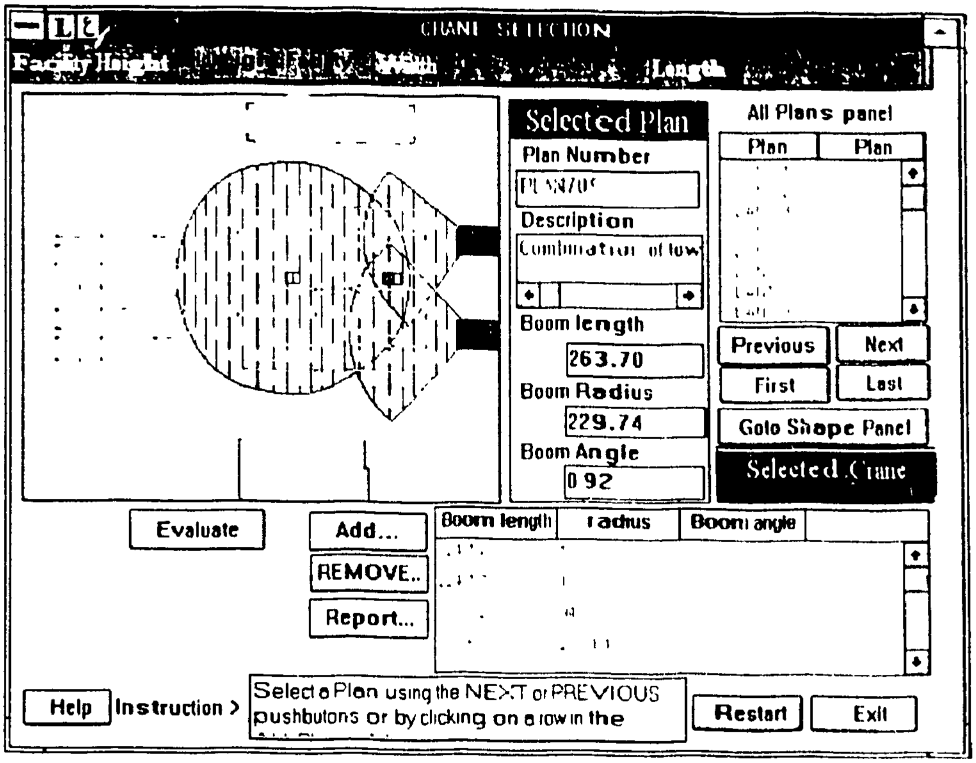


Fig. 7.10 Proposed by the System Design for the Climbing Tower Crane

(a)



(b)

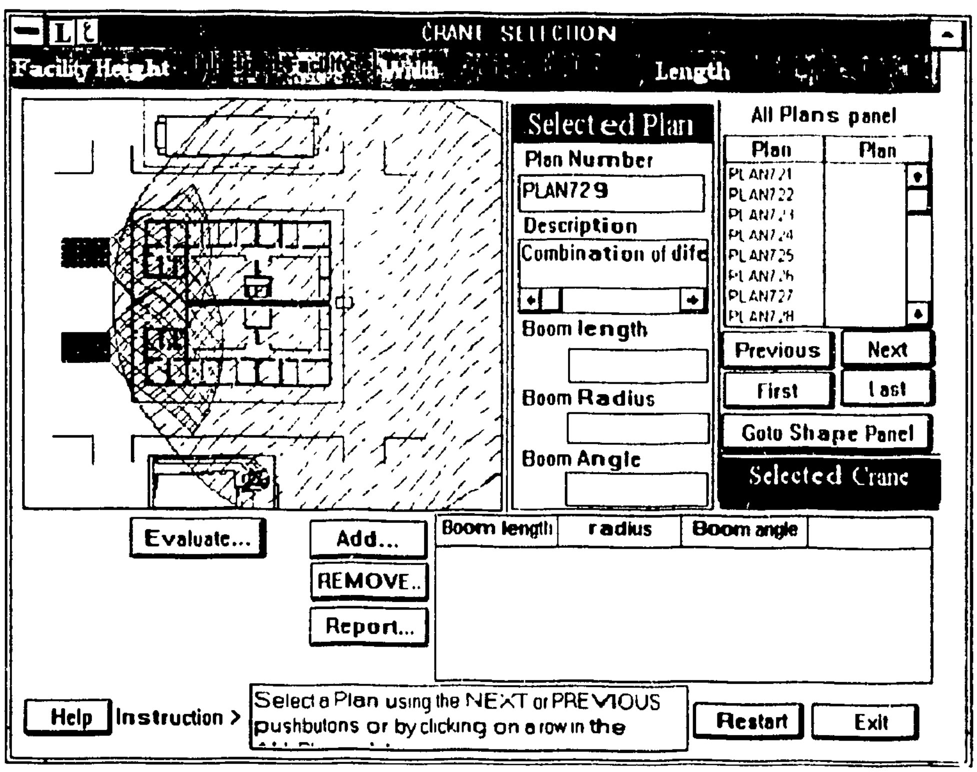
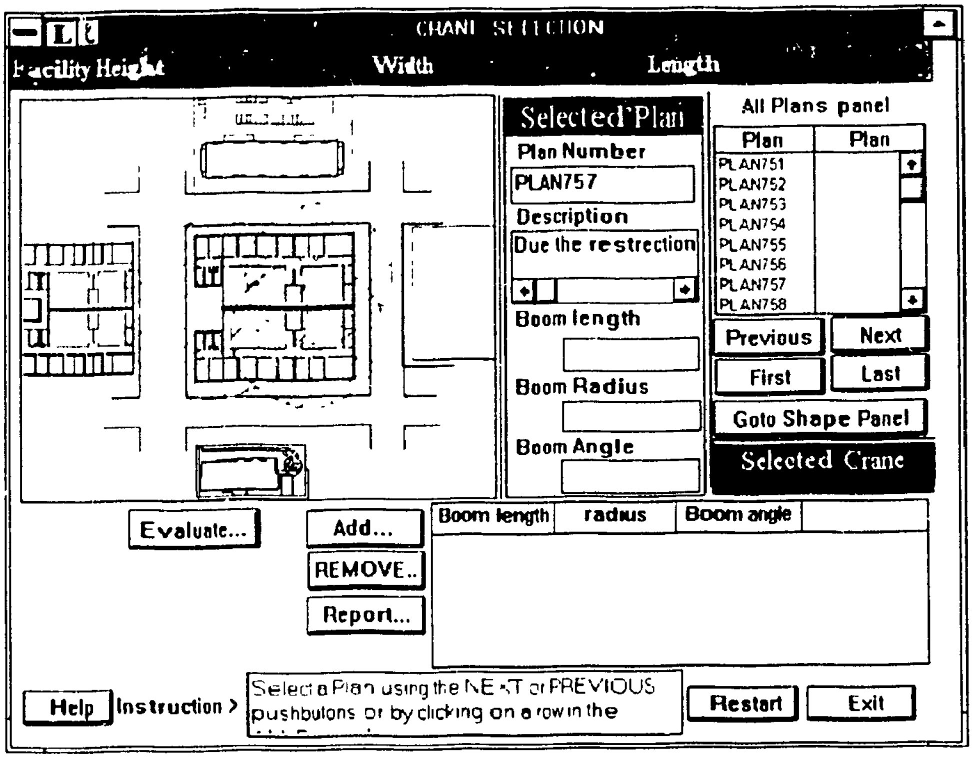
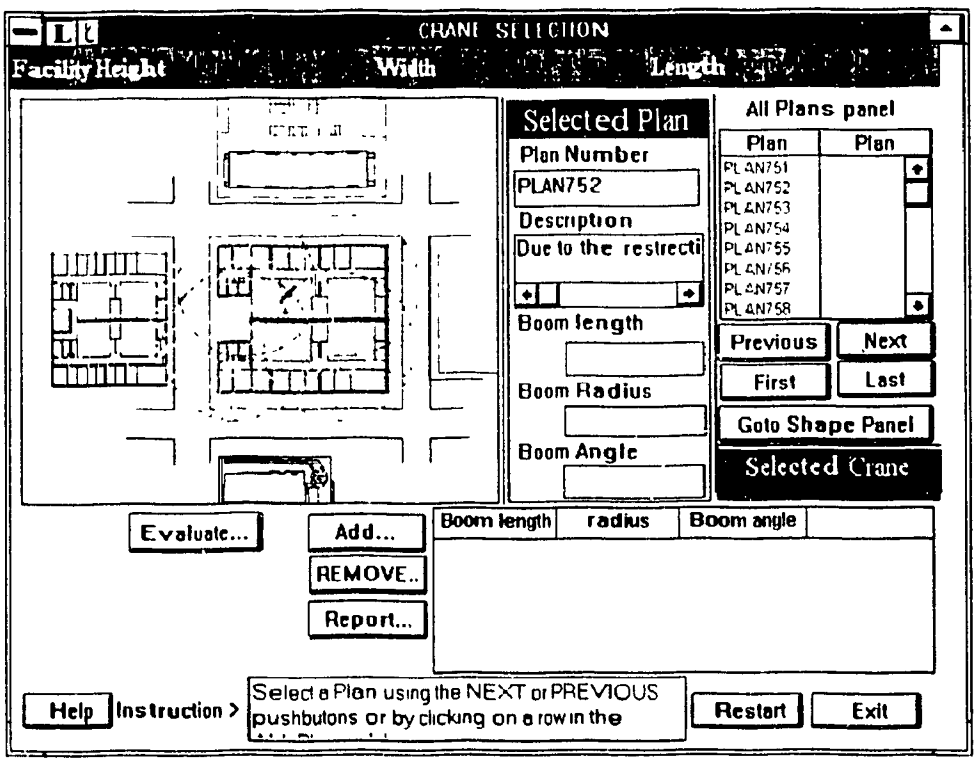


Fig. 7.11 Case Scenarios Generated by the System

(c)



(d)



"Continue" Fig.7.11 Case Scenarios Generated By the System

7.3 THE CASE STUDY USING THE GEOMETRY CALCULATION MODULE

Both the KBES and the CBR modules advise the user to select the most appropriate crane(s) for a given project based on the project definition and site constraints. However, their locations on site is increasingly important. In practice mainly this is done by trails and error. In order to overcome this deficiency Crane Advisor integrates algorithmic module, capable of carrying out geometry calculations to determine the crane's location(s), using a module called GEOMETRY CALCULATION MODULE as shown in Fig (7.12).

The user can input the actual dimensions of the selected building, and the system calculates geometry related to the selected crane (i.e. locations, boom length, boom angle to ground, boom radius, etc.), needed for the given facility. The GEOMETRY CALCULATION MODULE is a powerful tool capable of assisting in planning single lifts as is mentioned in the previous chapter, such a lifts might be known in advance or needed to be determined at delivery time.

The final outcome of the module is a list of all technically feasible alternatives supported with crane's geometry calculations for the selected site and its constraints (boom length, boom angle, jib size, location, number of relocating the mobile crane). The selection can be further validated graphically and analyzed based on cost comparison between renting or purchasing alternatives, using the GRAPHIC SIMULATION AND THE COST MODULES that are linked to the system.

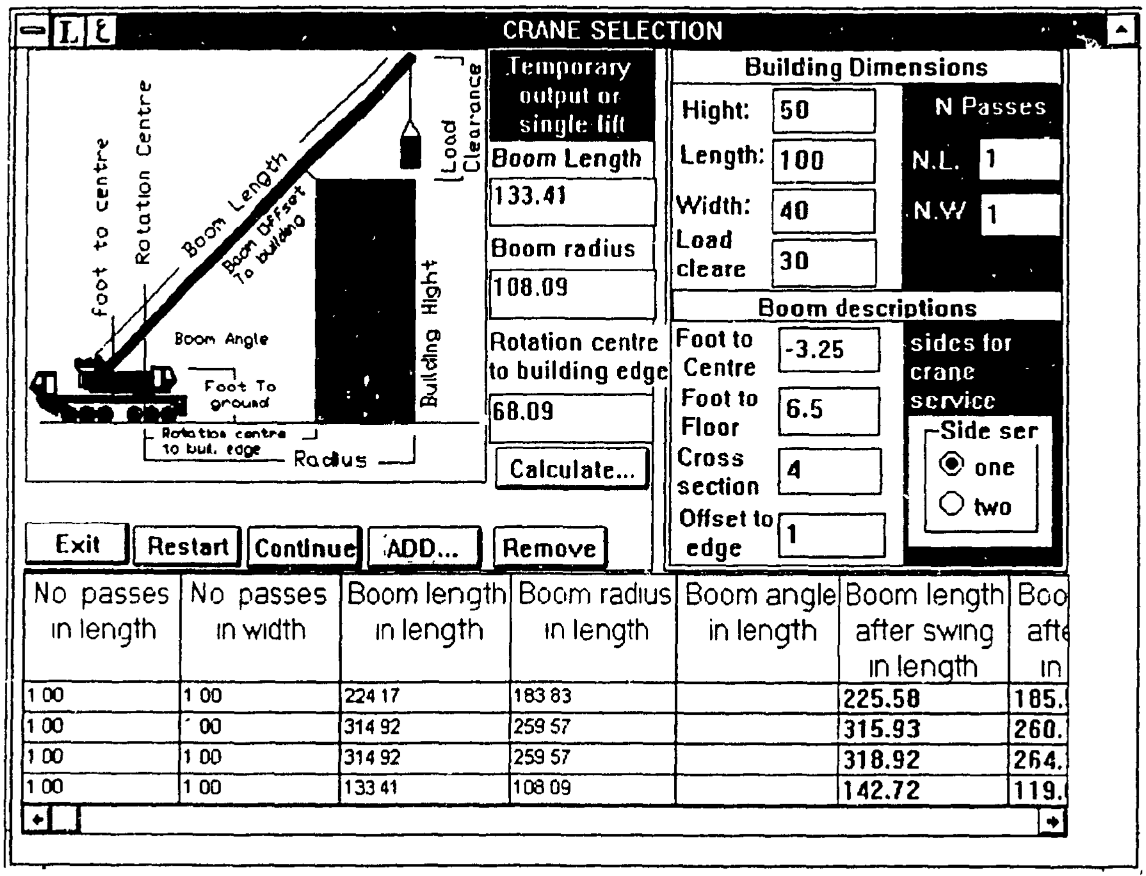


Fig. 7.12 Geometry Calculation Module Interface For the Case Study

5.4 THE CASE STUDY USING THE GRAPHIC SIMULATION MODULE CRANE-CAD

The KBES and CBR modules provide the user with the name and the path of the AutoCAD drawing related to a particular case that is selected in the system's database. These drawings are stored in a module called CRANE-CAD. The user can access this module through the AutoCAD, which facilitates case creation and allows visualization of a case during the adaptation process. Menus within the AutoCAD are used to control CRANE-CAD as shown in Fig. (7.13). The user can open the AutoCAD and retrieve the given drawings in order to adopt it to the constructed facility. These drawings contain all likely variables and factors affecting the crane selection. These variables are included in different layers to benefit from AutoCAD capability of **FREEZING**, and turning **OFF** layers in order to produce different scenarios of the given case, such scenarios are used in facilitating the KBES and the CBR module as was mentioned in the preceding chapter.

Cases can be adopted also through graphic input of structural elements, equipment elements, material handling elements, and site constraints, which are stored as attributed blocks. For example using structural elements the user can add components to the given building such as additional tower(s), or change the facade of the given facility. It also allows for adding restrictions around the building such as additional power supply cable or adjacent buildings. Plan view is also available to determine the cranes working ranges and design specifications as shown in Fig. (7.14). These blocks are represented as objects having starting points, end points, depth, width, and material specification. The global structural abstraction of the implemented case is therefore a collection of many of such elements. The layout and dimensions of spaces can be defined and viewed through the use of standard AutoCAD commands.

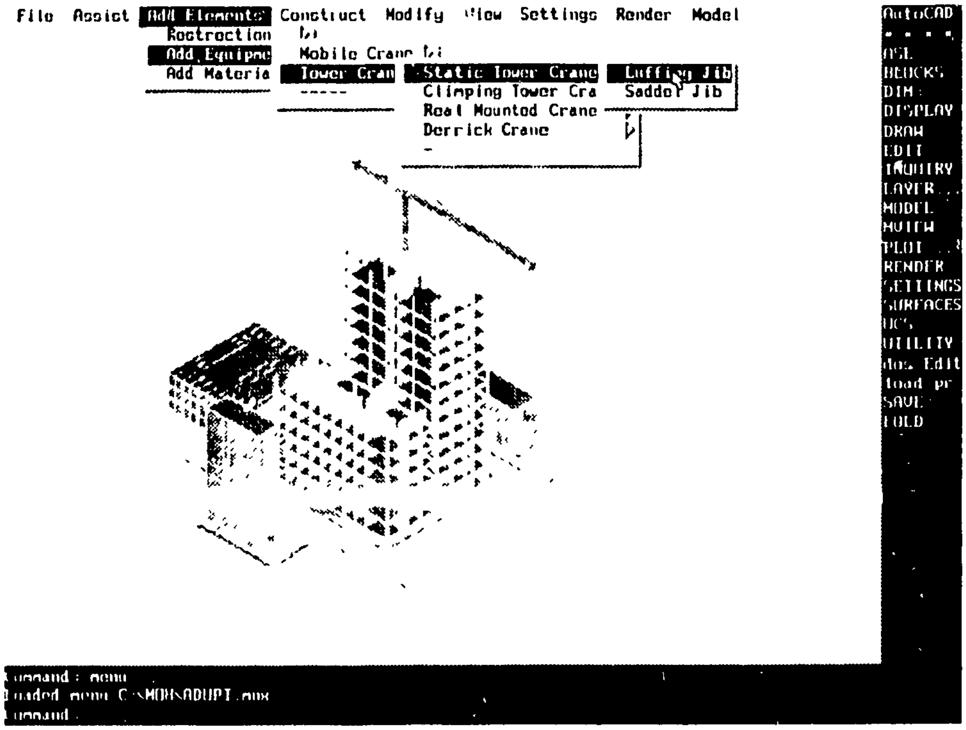


Fig 7.13 (3D) Case Appearance using the Graphic Validation Module

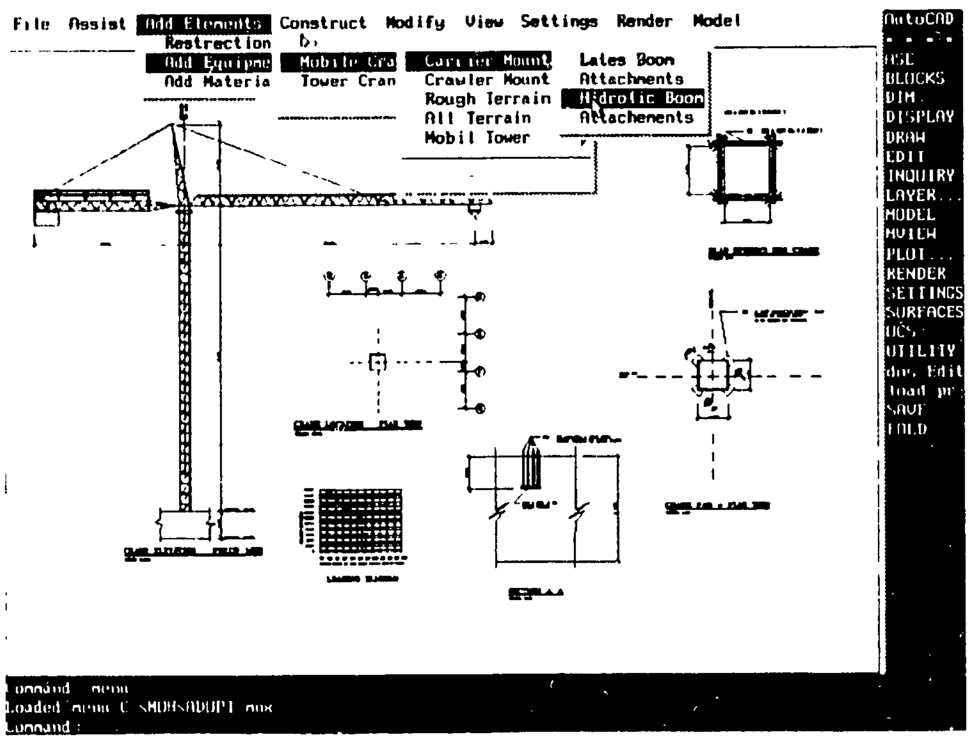


Fig.7.14 The Actual Design for the Case Study

The actual case is adopted and modified using the stored information in the system and is made available using the customized AutoCAD menu. Fig. (7.15) shows the three dimensional (3D) view of the case after it is been adopted, i.e. after adding the additional static crane in the area of the bodum (the commercial building). Fig. (7.16) shows the proposed design and the working range of the selected cranes, where Fig. (7.17) shows the detailed design drawings for the static tower crane, and Fig. (7.18) shows the detailed design drawing for the climbing tower crane (the design drawings for the climbing tower crane were accepted from the actual design).

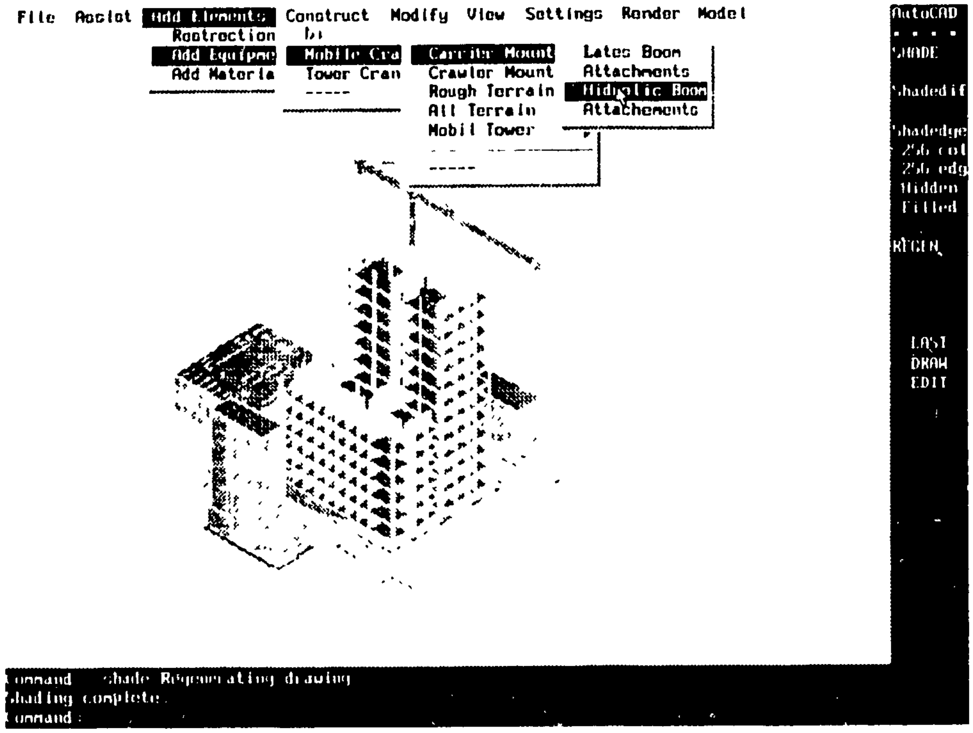


Fig. 7.15 The Case Study After Adaptation

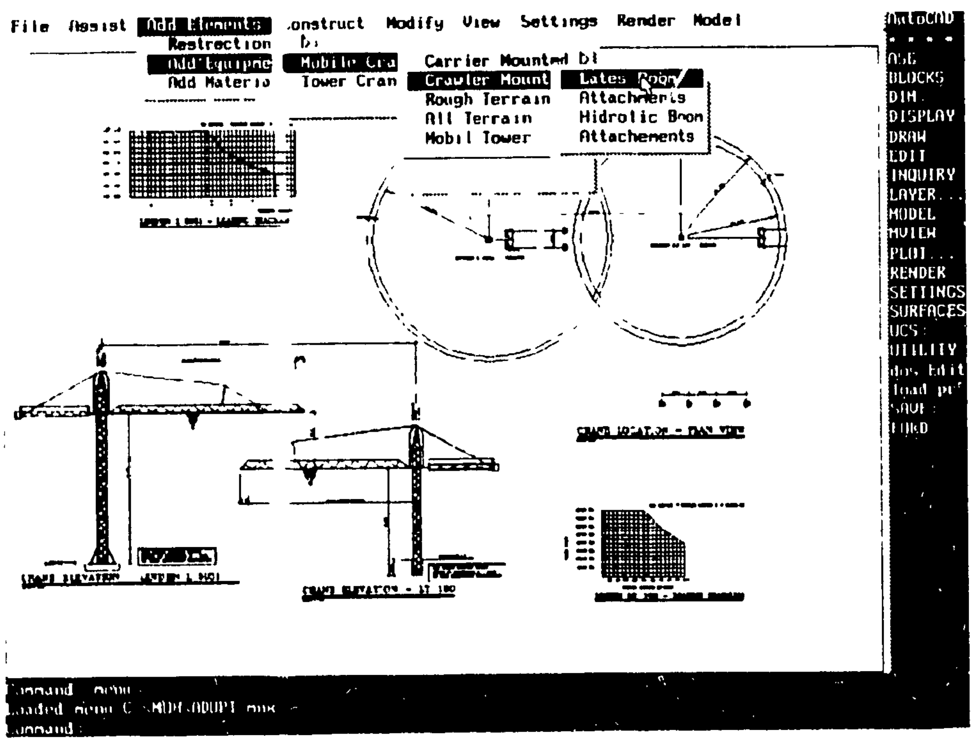


Fig. 7.16 The Proposed Design for the Selected Cranes

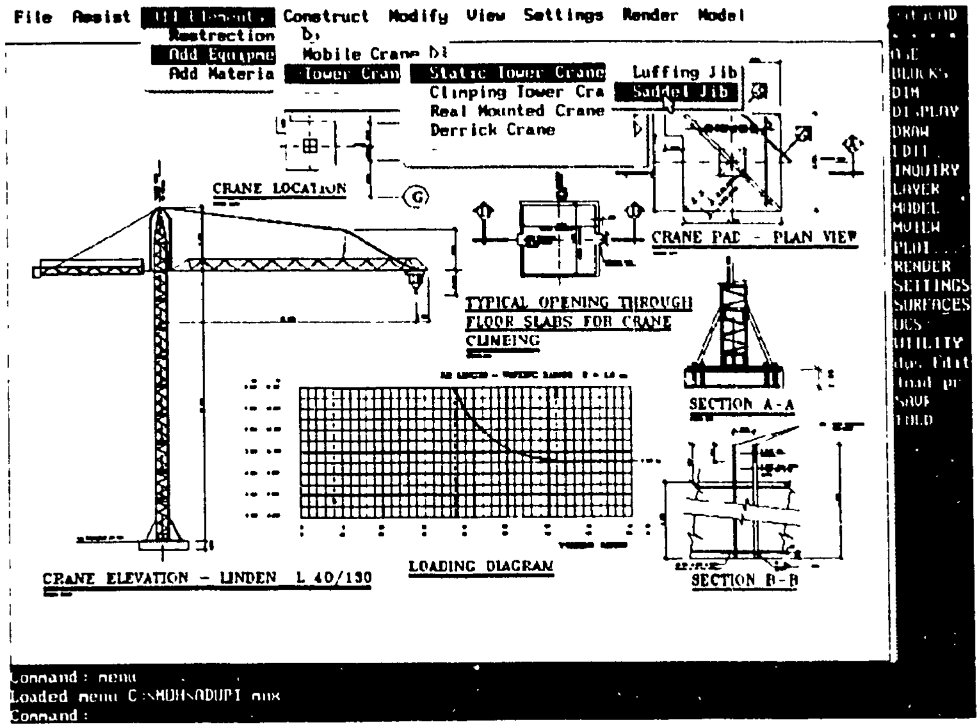


Fig. 7.17 The Detail Design Drawings For the Selected Static Tower crane

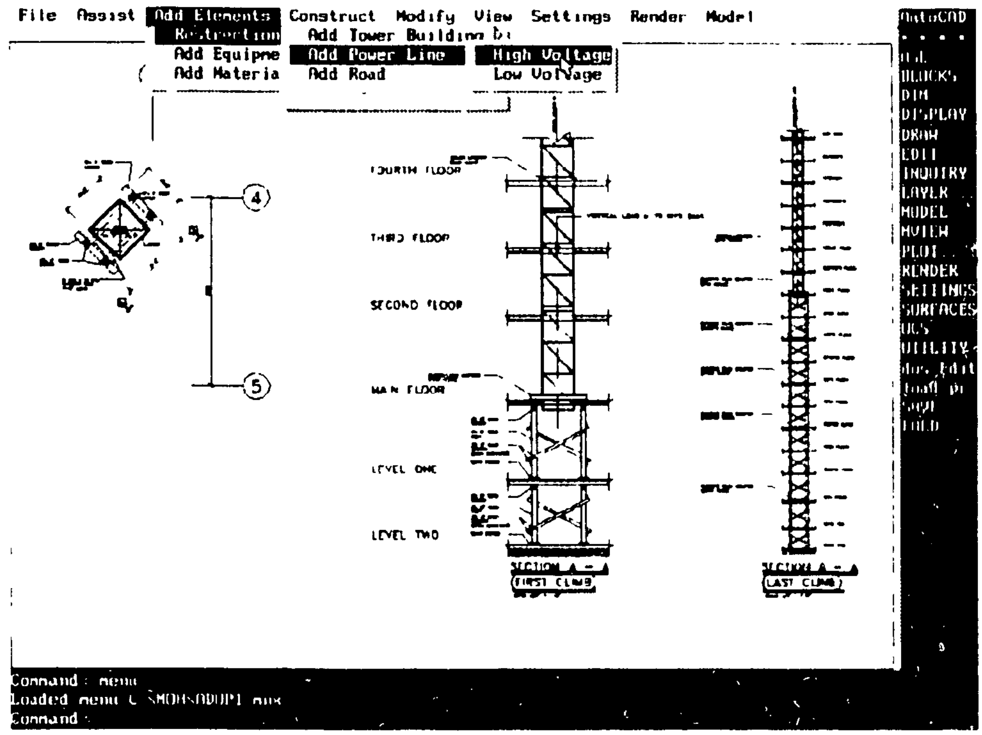


Fig. 7.18 The Detail Design Drawings For the Selected Climbing Tower crane

5.5 THE CASE STUDY USING EQUIPMENT COST ESTIMATOR AND ANALYZER

In most cases, as it is in the current one the user is faced with the option of selecting the least cost crane among different feasible alternatives. Crane Advisor is linked to a computerized model called Equipment Cost Estimator and **Analyzer** (ECEA) capable of performing equipment's owning and operating costs estimation. ECEA can be used as a stand alone module to calculate the Net Present Value of an equipment based on the input from the user or on the data related to the variety of the equipment that is stored in its database. ECEA consist of two modules: Cost Estimator and Cost Analyzer module.

7.5.1. Cost Estimations module

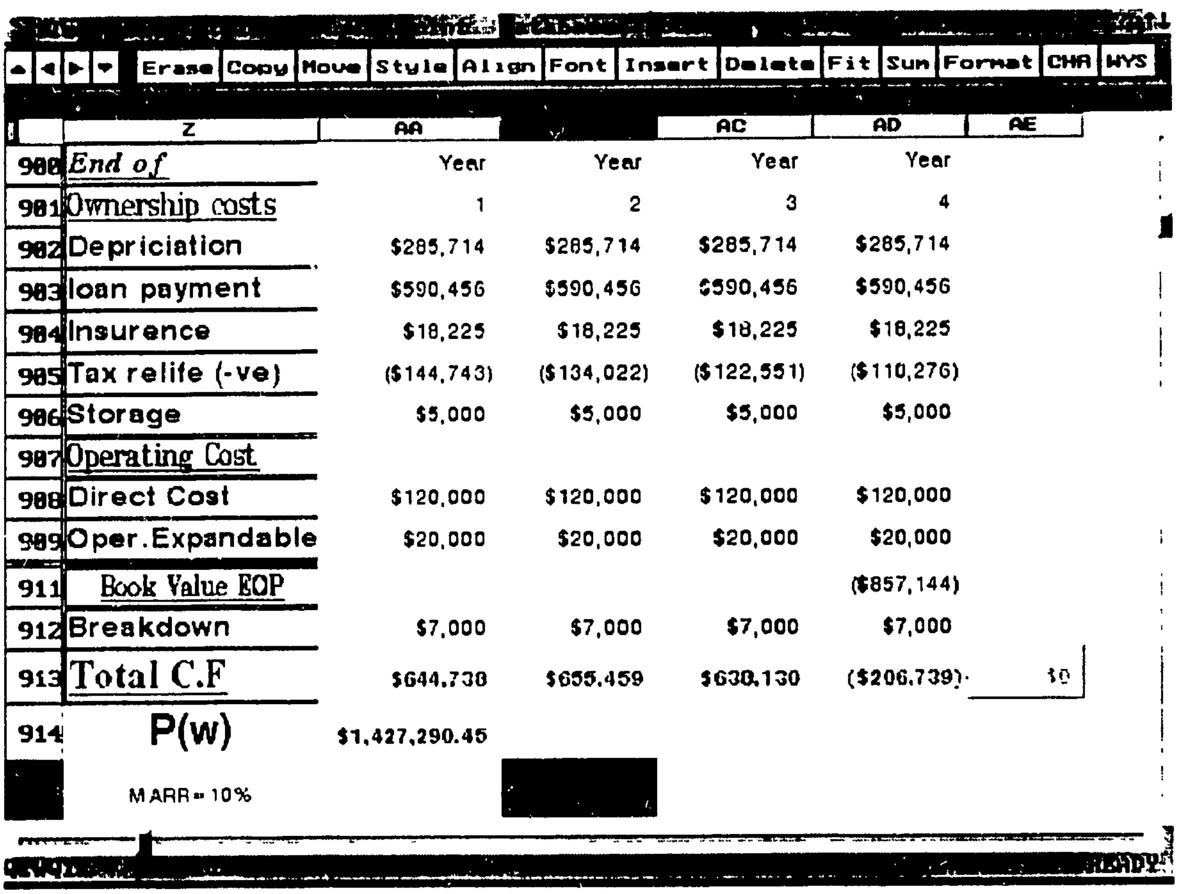
As soon as the Crane Advisor recommend the use of a crane or cranes, ECEA would be used to calculate their costs. For the purpose of this case study, three types of cranes were selected as an output from the Geometry Calculation Module, they have the lowest hiring costs and are capable of carrying out the task (concreting) as advised by CRANE ADVISOR. Table (7.1) illustrates the three types of cranes and their associated rental and purchase costs.

From table (7.1) only crane type 1 that has a lowest purchase price is compared to crane type 2 with the minimum rental rate and crane type 3 is discarded from the analysis.

Table (7.1) Types of cranes recommended by CRANE ADVISOR and their corresponding rental and purchase costs

Crane type	Cost of acquisition	
	Rent $/hr	Purchase $
Crane type 1	320	2,000,000
Crane type 2	270	2,300,000
Crane type 3	350	2,150,000

The system prompts the user to respond to few questions including checking and/or updating the costs of cranes 1 and 2 in the database. The system calculates the Net Present Value for each alternative along with a suggested life of four years for the equipment as is illustrated in the screen printout shown in Fig. (7.19). Tables (7.2) and (7.3) show the output data obtained from the system for both cranes, the purchase and the rent options respectfully. This data was used to calculate the present worth of costs for each individual crane.



	Z	AA		AC	AD	AE
900	*End of*	Year	Year	Year	Year	
901	Ownership costs	1	2	3	4	
902	Depriciation	$285,714	$285,714	$285,714	$285,714	
903	loan payment	$590,456	$590,456	$590,456	$590,456	
904	Insurence	$18,225	$18,225	$18,225	$18,225	
905	Tax relife (-ve)	($144,743)	($134,022)	($122,551)	($110,276)	
906	Storage	$5,000	$5,000	$5,000	$5,000	
907	Operating Cost					
908	Direct Cost	$120,000	$120,000	$120,000	$120,000	
909	Oper.Expandable	$20,000	$20,000	$20,000	$20,000	
911	Book Value EOP				($857,144)	
912	Breakdown	$7,000	$7,000	$7,000	$7,000	
913	Total C.F	$644,738	$655,459	$630,130	($206,739)	10
914	P(w)	$1,427,290.45				
	MARR = 10%					

Fig. 7.19 Net Present Value Presented by the ECEA Module

(7.2) **the cost cash flow of acquisition of crane type 1 from 1-4 years**

Project time		1	2	3	4
Acquisition cost		$ 2,000,000			
Depreciation/year		285714	285714	285714	285714
Book value		(1714286)	(1428571)	(1142857)	(857144)
Loss in Book Value		285714	571428	857142	1142856
Loan payments		2200000	1106184	762103	590456
Insurance		25000	22500	20250	18225
Storage		5000	5000	5000	5000
TAX Relief	4 years	(144743)	(134022)	(122551)	(110276)
	3 years	(144743)	(129937)	(114094)	
	2 years	(144743)	(121747)		
	1 years	(144743)			
Direct cost		120000	120000	120000	120000
Operating cost		20000	20000	20000	20000
Break down		7000	7000	7000	7000
PRESENT WORTH		470883	812107	1094960	1427290

Table (7.3) the cost cash flow of renting crane type 2 fro the period of 1-4 years

Hire rate $/hr	270/hr.			
Rental period in years	1	2	3	4
Rent cost/year	$648,000	$648,000	$648,000	$648,000
Operating labour	$108,000	$108,000	$108,000	$108,000
Tax relief	($260,000)	(260,000)	(260,000)	(260,000)
Insurance	$15,000	$15,000	$15,000	$15,000
Present Worth	$459,091	$876,446	1,255,860	1,600,782

A cumulative cost Vs time graph for both options was constructed as shown in Fig. (7.20) which illustrates that the rental option is better for short period of time. A break-even point between the rental and purchase options at 13 months shows that for crane type 2, the rental cost is justified compared to the cost of owning crane type 1 for the same period of time. This means that if the crane is needed up to 13 months then the rental option is more economical whereas the purchase option is better thereafter as shown in Fig. (7.20).

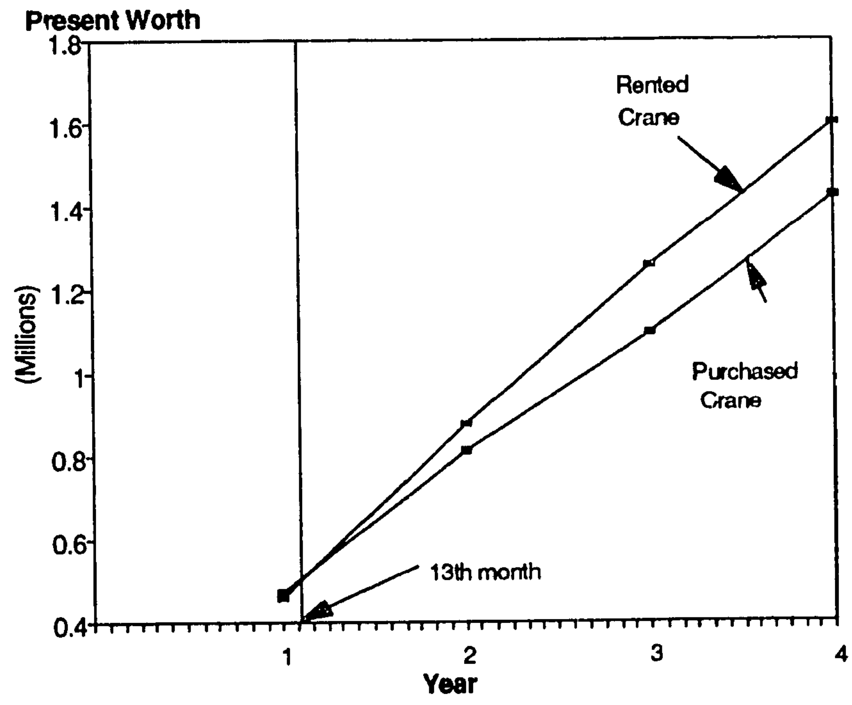


Fig 7.20 Break-Even Analysis

7.5.2. Sensitivity Analysis

Comparing equipment alternatives is normally based on a forecasted cash flows especially when operating costs are involved. The forecasted cost normally carry some degree of risk that need to be identified during the analysis. Sensitivity analysis techniques are used to evaluate the effect of variation of different variables. Fig. (7.21) shows the sensitivity graph generated to account for errors in estimates in the range between -10% to + 10% in the value of four factors affecting the present value of the equipment. These factors are the book value, the direct cost, the Minimum Attractive Rate of Return (MARR) and indirect costs. It is noted from the graph that the direct costs are more sensitive to the error in estimates which means that a great deal of attention should be paid in estimating such costs.

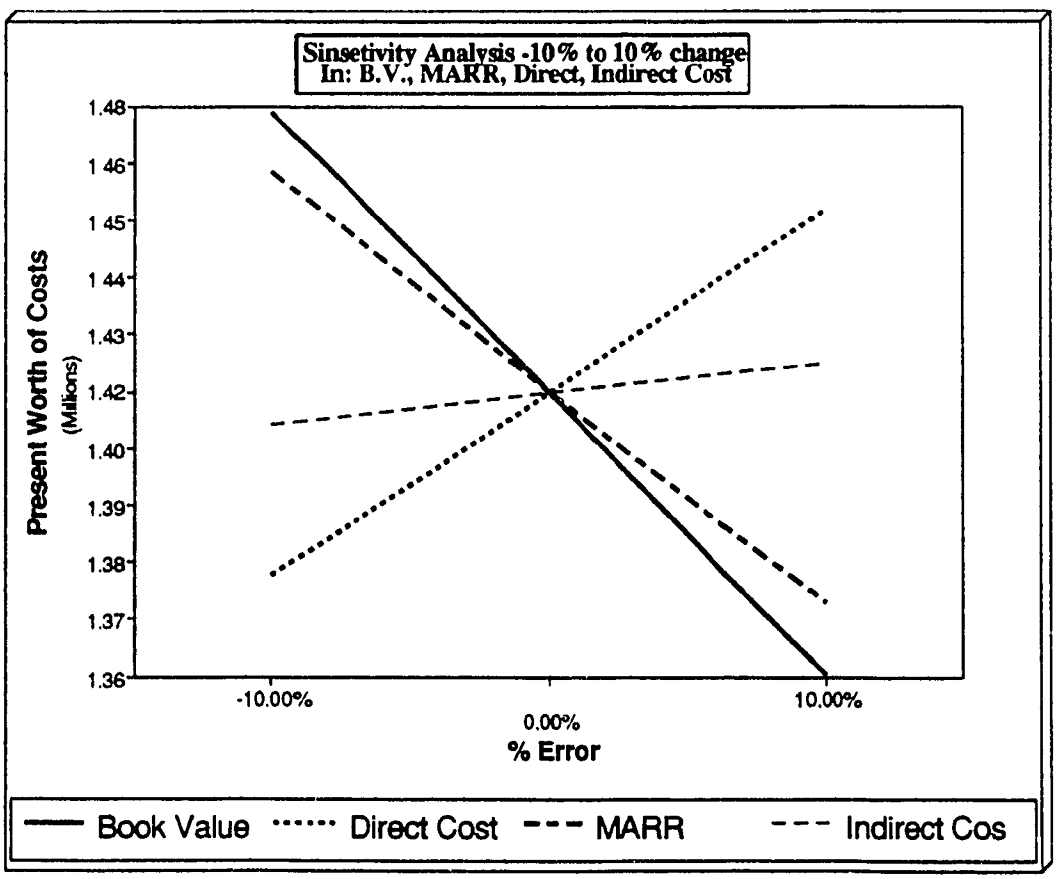


Fig. 7.21 Case Studies Sensitivity Analysis

CHAPTER 8
CONCLUSIONS AND FUTURE RESEARCH

8.1 CONCLUSIONS

Selecting cranes for building construction and locating them on site depend greatly on skilled judgment that accounts for all likely involved variables. Much information is available to assist in this process in terms of: work study data, manufacturers' machines performance specifications, guidelines on methods of calculating production output, labour resources and equipment requirements, etc.. Unfortunately this information is scuttered and incomplete forcing the decision maker to make bold decisions on job conditions and categories of cranes.

The system (CRANE ADVISOR) described in this thesis is an attempt to overcome this deficiency by combining this information with expert's knowledge and conventional calculations and present them effectively to the user with dialogue and advices on crane selection and their use on high rise building projects. CRANE ADVISOR, is now undergoing detailed evaluation using major building projects to demonstrate its effectiveness and validity. The results of test-case studies are encouraging, cranes recommendations are fairly accurate and the selected cranes' locations, in particular, are correctly determined. The system operates in an integrated computer environment. It integrates an expert system, routine calculations, and graphic simulations. Crane Advisor is capable of advising the user on crane selection, in order to:

- Assist in planning and executing of the construction activities that involve cranes.
- Assist in establishing the owning and operating costs of the selected crane.
- Assist the owner, developers, contractors, managers, design professionals, and equipment suppliers, in selecting the appropriate crane, therefore, improving productivity and

reducing cost.

In addition the system has the following interesting features:

- Early trials with users indicate the advantages of using real cases within the system.
- The system can be used as a training tool through transferring knowledge and expertise to inexperience construction engineers.
- Crane Advisor assists the user in selecting cranes during the design and construction phases of a facility.
- It incorporates a user friendly interface that facilitates the user's inputs.
- It consists of a database that contains information on constructed buildings, and on the factors affecting the crane(s) selection. Data on a number of commercially available cranes, and cost data are also included in the database.
- It incorporates sensitivity analyses to account for the uncertainty that might be associated with owning and operating costs of the selected crane.
- It facilitates integration within the systems' modules to perform a combination of algorithmic calculations and industry heuristics, forming a comprehensive crane selection process.

It must be emphasized that the system is strictly limited by the knowledge stored in its knowledge base and the information stored in its database and is therefore only applicable to multi-story building construction. Also it is a decision support system designed to assist practitioners in the construction industry in selecting the appropriate cranes and is not a replacement of human experts.

8.2 FUTURE RESEARCH

CRANE ADVISOR, although being an operational system capable of assisting the user in selecting appropriate cranes and planning their operations on high rise buildings projects. There is however, a potential for further improvements. These may include:

- An enhancement to the Geometry Calculation Module, by providing it with a facility for updating its database with information on new equipment.
- The concept of the Graphic Adaptation Module could be developed in a more detailed and comprehensive manner, to be used in the design stage of the facility.
- Include more cases in the system's database.
- Other modules, such as crane capacity and its load charts, cranes' safety, hoisting devises, and rigging could be developed and integrated with the system. It can also be linked to other commercial software that deal with resource scheduling and levelling.
- Further study, on the factors affecting cranes' productivity and other equipment working in conjunction with it is required.
- The methodology could be applied to other construction equipment.
- The research could be expanded to include selecting cranes for other construction projects, a heavy construction for instance.
- The cost estimation module could be modified to run directly within the LEVEL 5 environment.

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APPENDIX A

CRANE TYPES USED IN THE CONSTRUCTION INDUSTRY

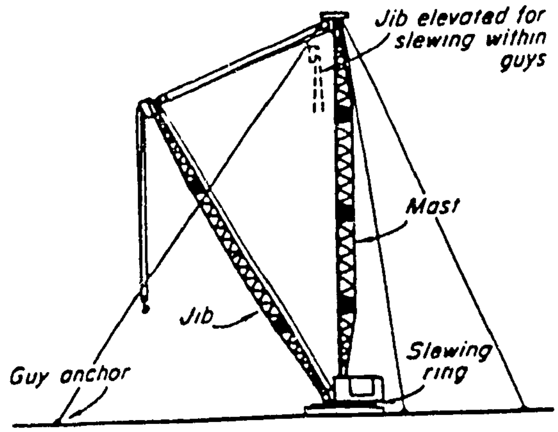


Figure 1 Derrick Crane

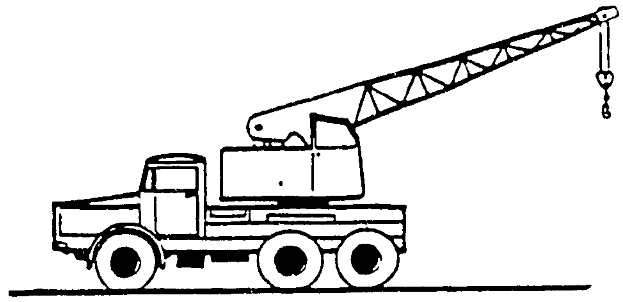


Figure 2 Truck Mounted Crane

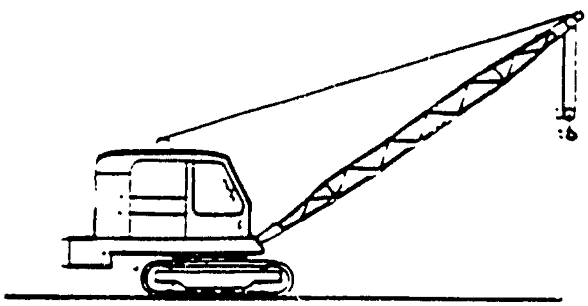


Figure 3 Crawler Mounted Crane

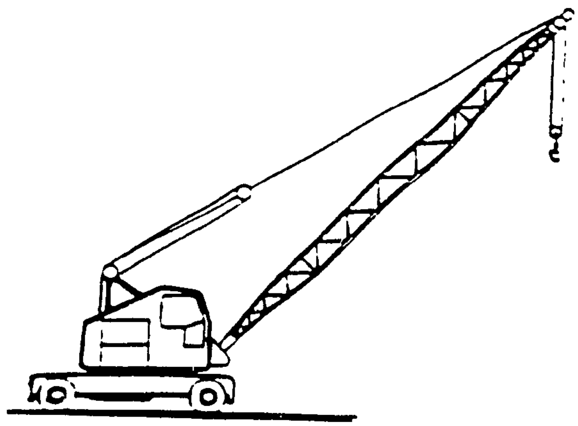


Figure 4 Tier Mounted Crane

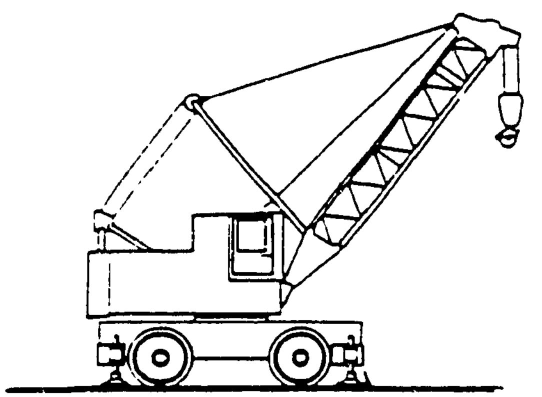


Figure 5 Strut Jib Crane

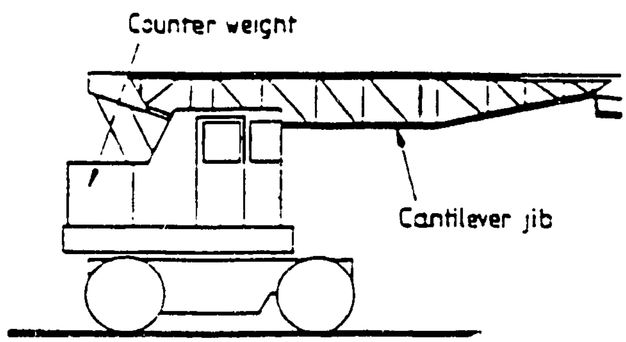


Figure 6 Cantilever Jib Crane

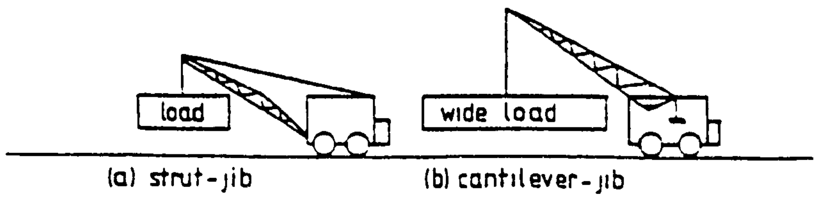


Figure 7 Cantilever jib takes wider load size than strut jib.

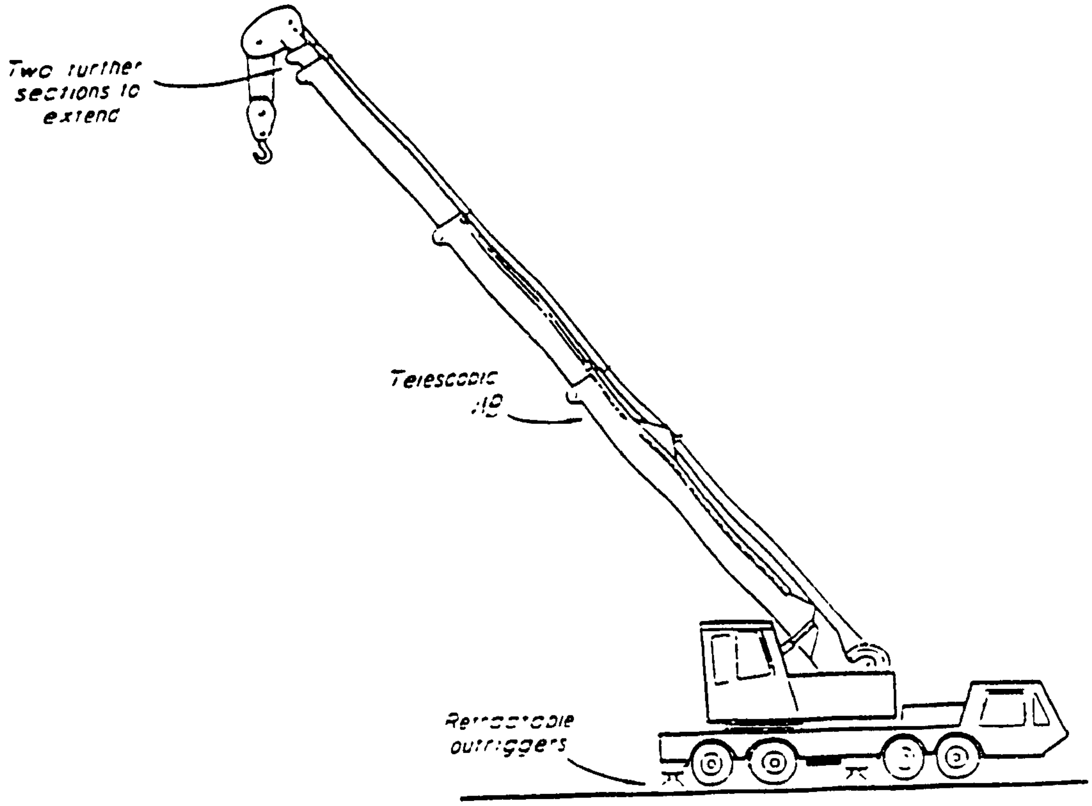
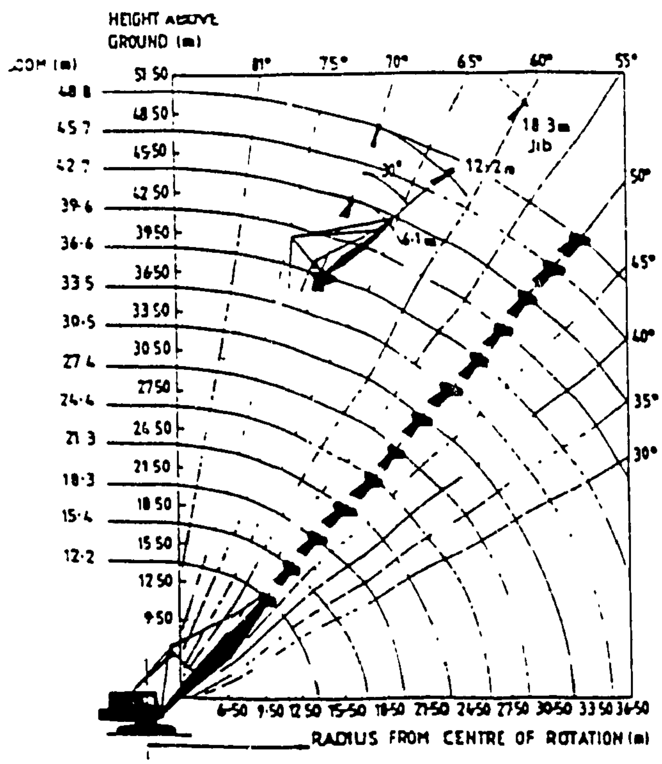


Figure 8 Telescopic Jib Crane



Boom (m) / Radius (m)	Main Boom Rating · 10 Tonnes Crane							
	10.82 Jib	12.19 Jib	13.72 Jib	15.24 Jib	16.76 Jib	18.28 Jib	19 81 Jib	21 34 Jib
3	10.0	10.C						
4.5	7.0	7.0	7.0	6.9	6.9	6.5		
6	4.6	4.6	4.5	4.5	4.5	4.5	4 4	4.4
7.5	3.5	3.4	3.4	3 4	3 4	3.4	3.3	3.3
9	2.8	2.6	2.6	2.6	2.6	2.5	2.5	2.5
10.5		2.1	2.1	2.1	2.1	2.1	2.0	2.0
12			1.8	1 8	1.7	1.7	1.6	1.5
13.5				1 4	1.4	1 4	1.3	1.3
15					1.0	1.0	1.0	1.0
16.5							0.7	0.7
18								

Figure 9 Relationship between crane's jib length, jib Radius and the load the crane can carry

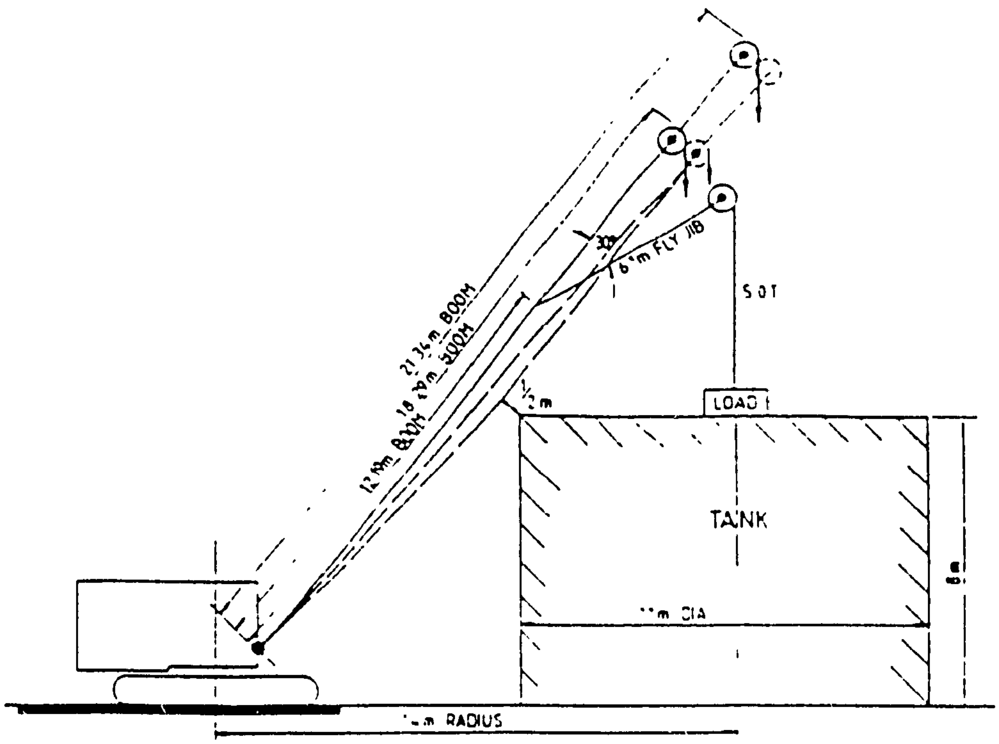


Figure 10 Crane ability varies due to jib length and angle, crane position and distance to the load, as well as load size.

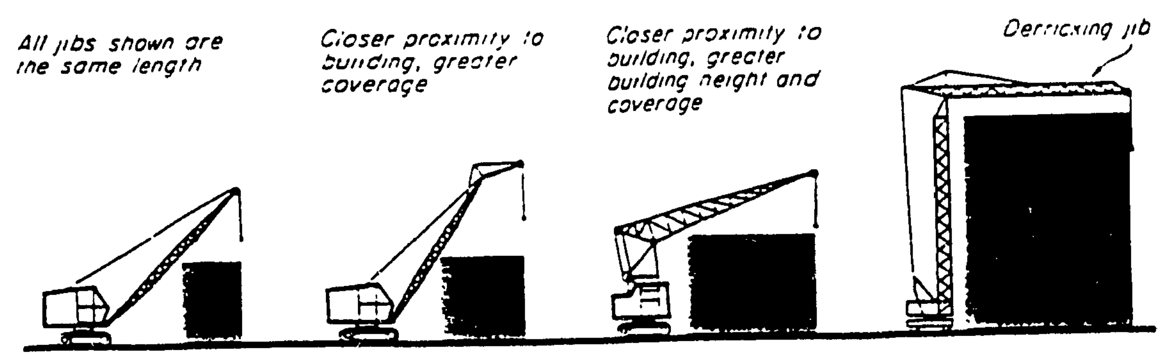


Figure 11 Different crane types cover different working area.

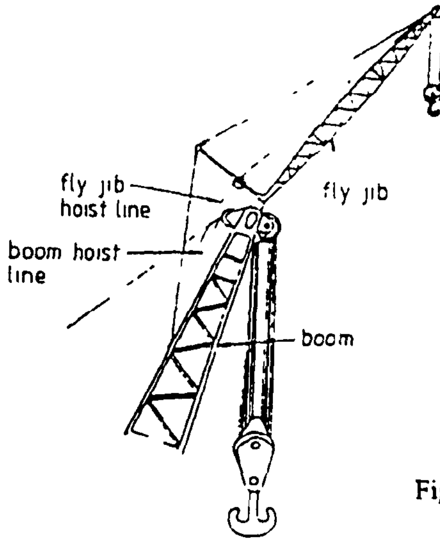


Figure 12 Flying Jib added to the Crane Boom

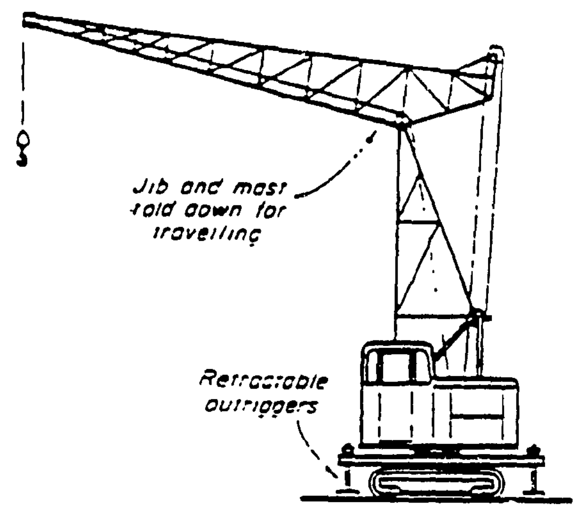


Figure 13 High Pivoted Jib Crane

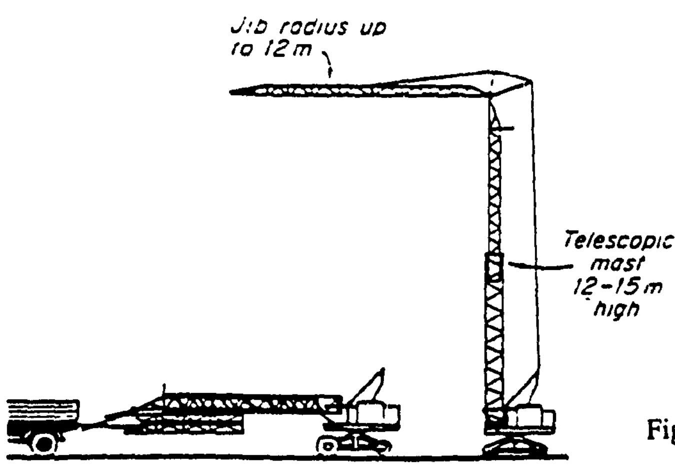


Figure 14 Mobile Tower Crane

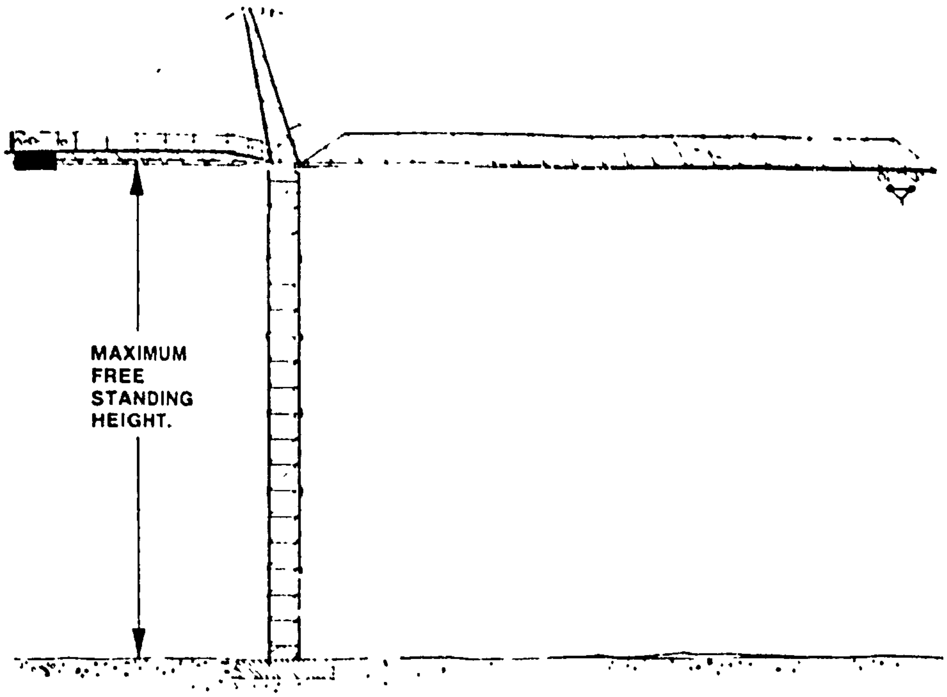


Figure 15 Free Standing Fixed Tower Crane

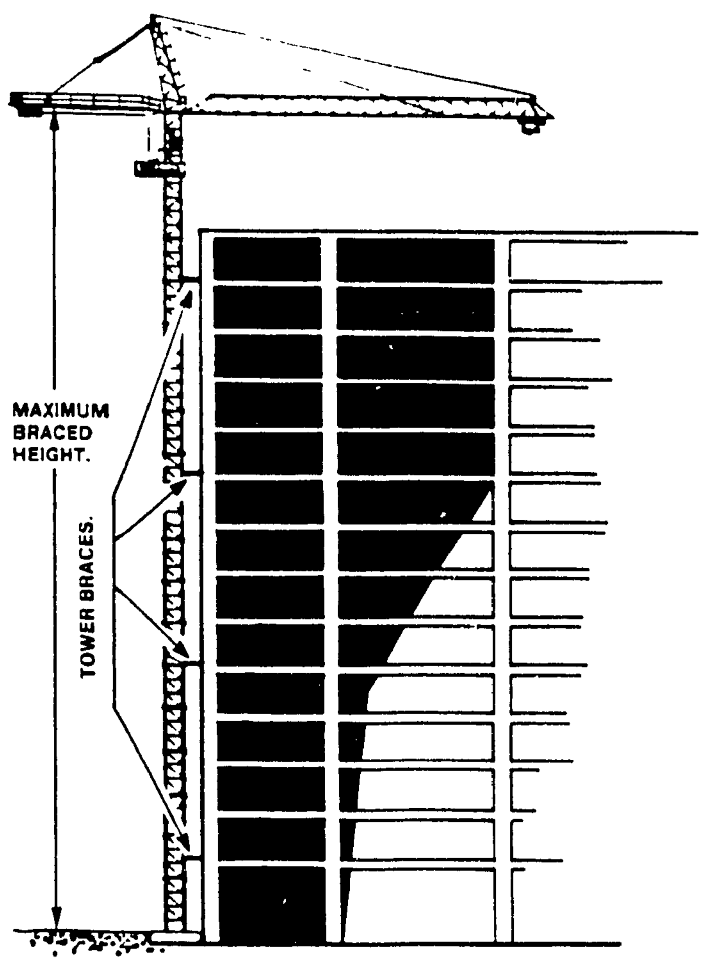


Figure 16 External Fixed Tower Crane Tied to the Building Facade

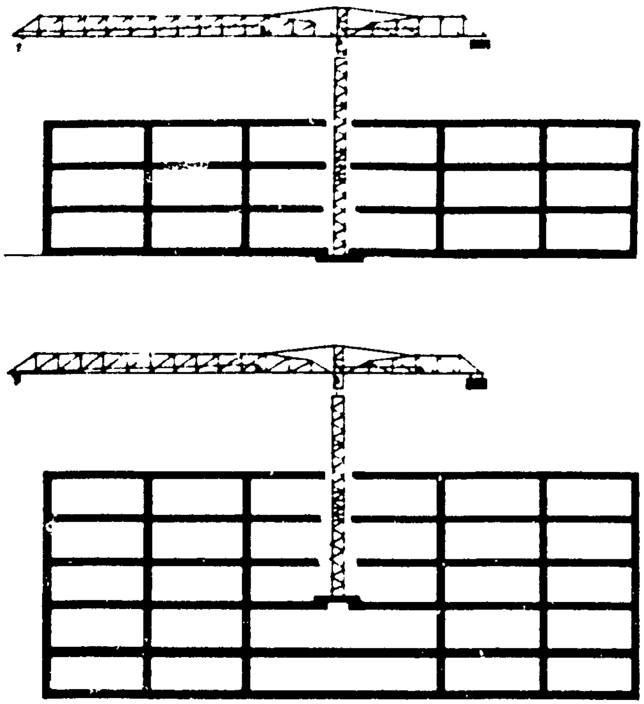


Figure 17 Climbing Crane Configuration

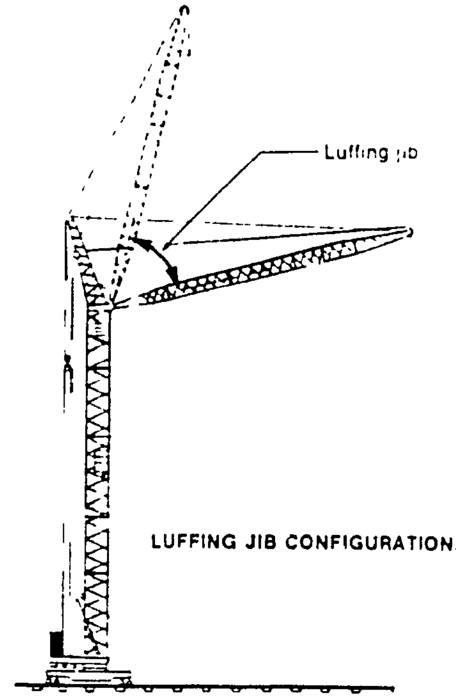


Figure 18 Rail Mounted Tower Crane

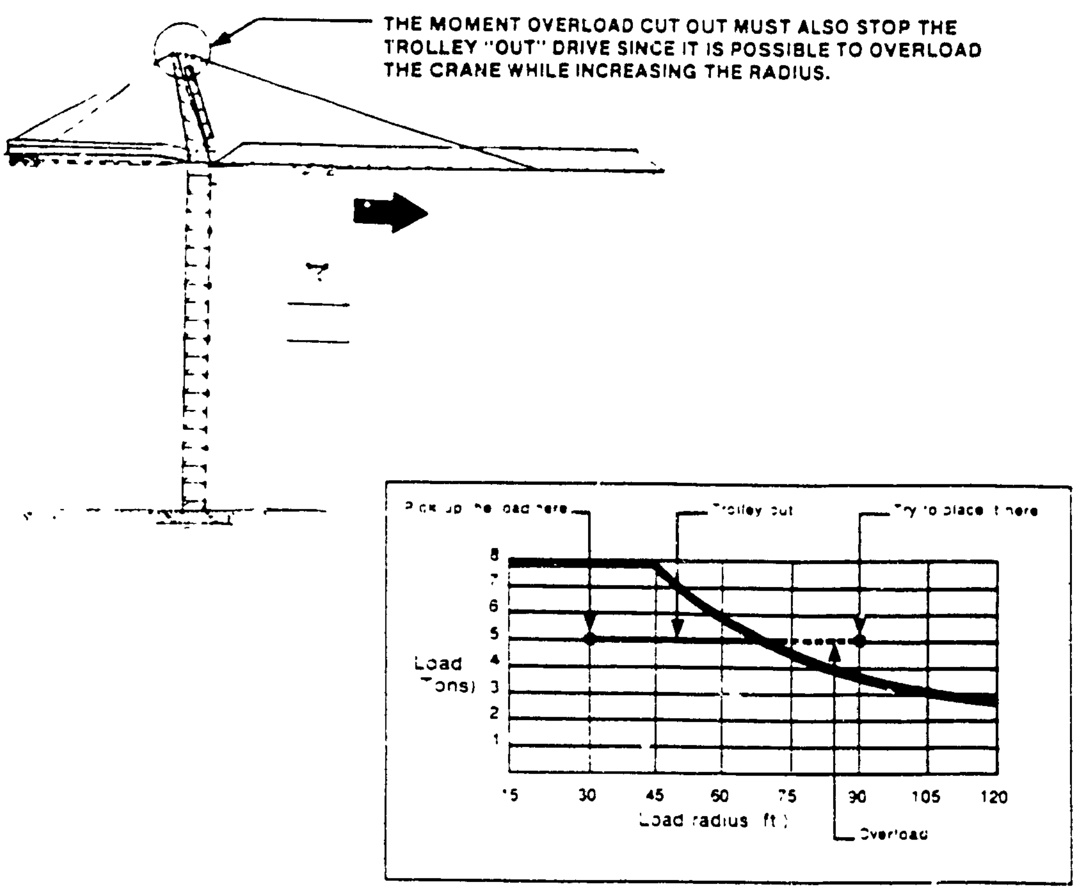
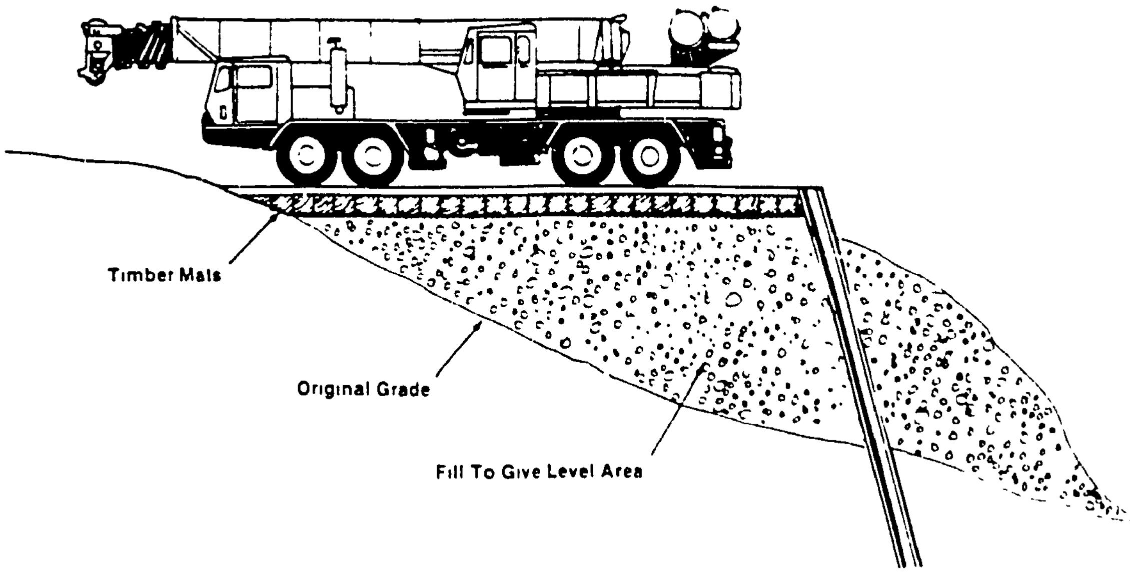


Figure 19 Tower Crane's Load Chart



IN CASES WHERE OPERATION ON SLOPES CANNOT BE AVOIDED, THE OPERATING AREA SHOULD BE BUILT UP TO GIVE A LEVEL BASE.

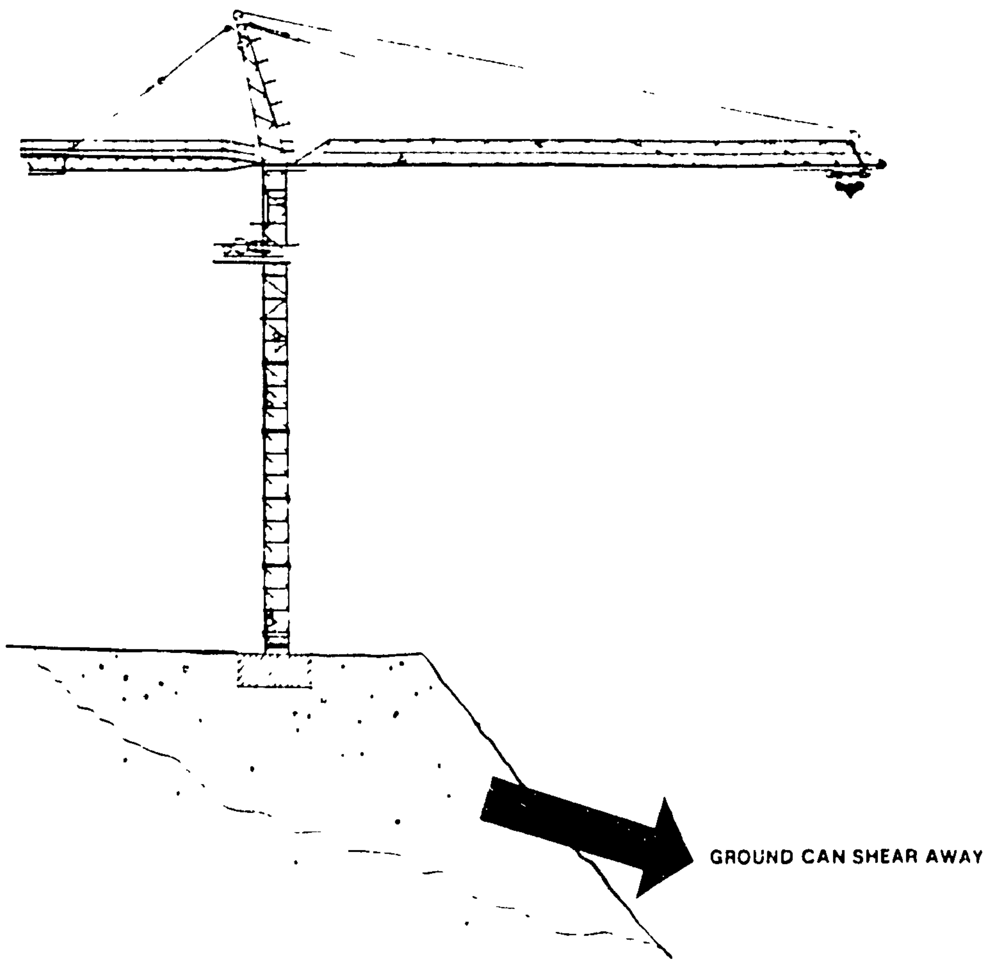


Figure 20 Excavation, Slopes, or Uncompacted Material affect on Crane Selection

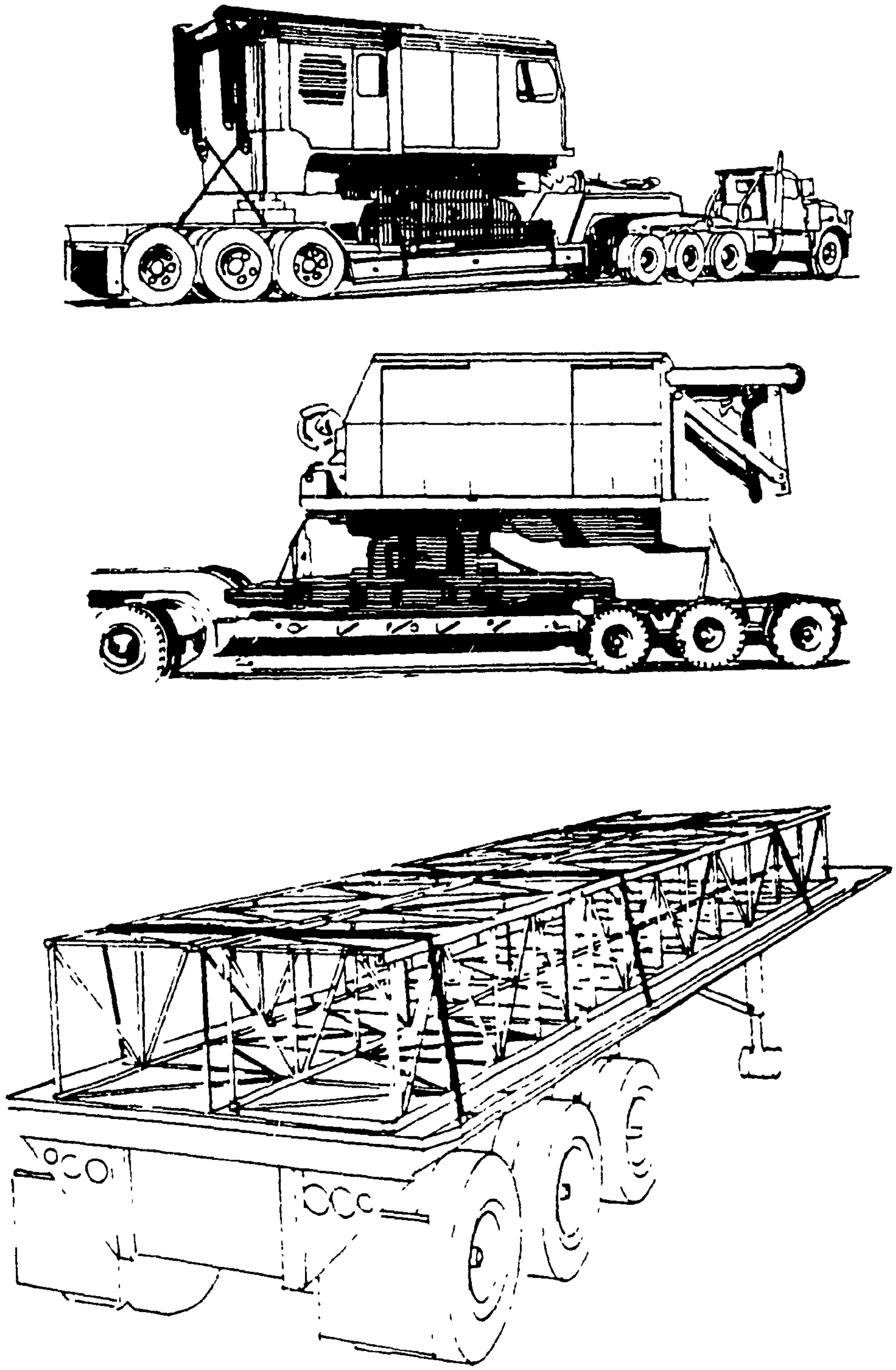


Figure 21 Cranes sections and attachments carried by mobile cranes

APPENDIX B

DEVELOPMENT TOOL FEATURES

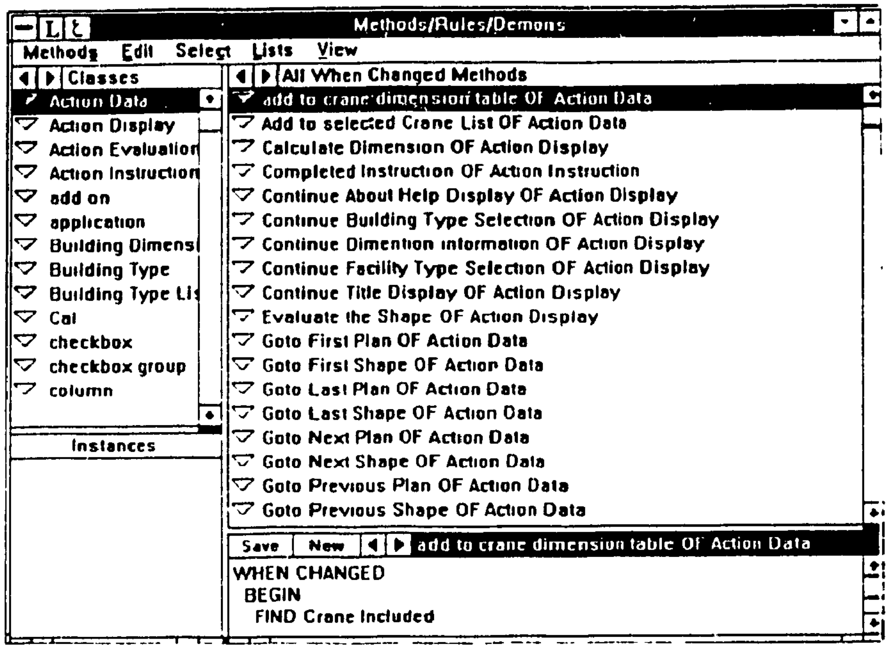


Fig. B.1 A List of Modules When Change Method

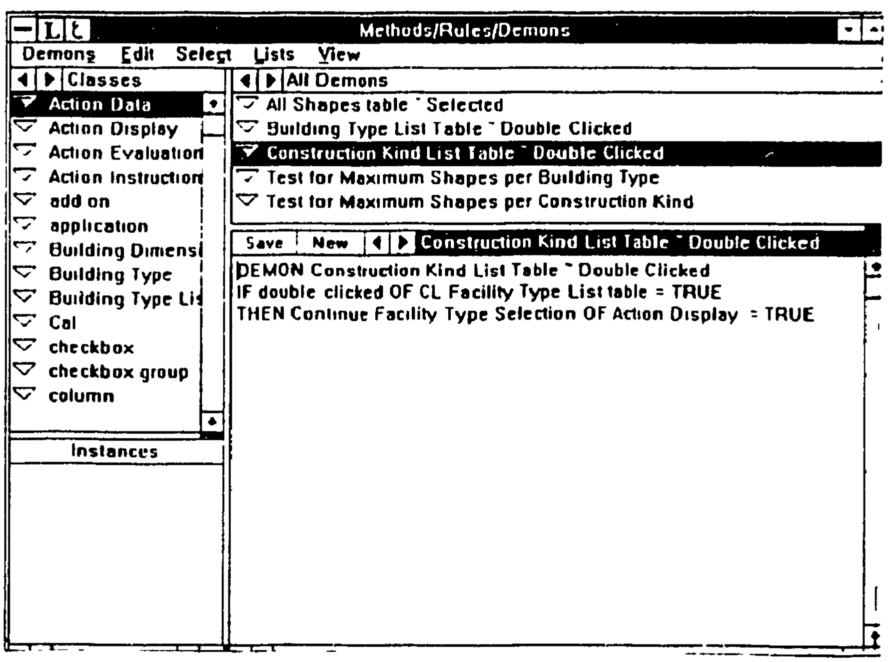
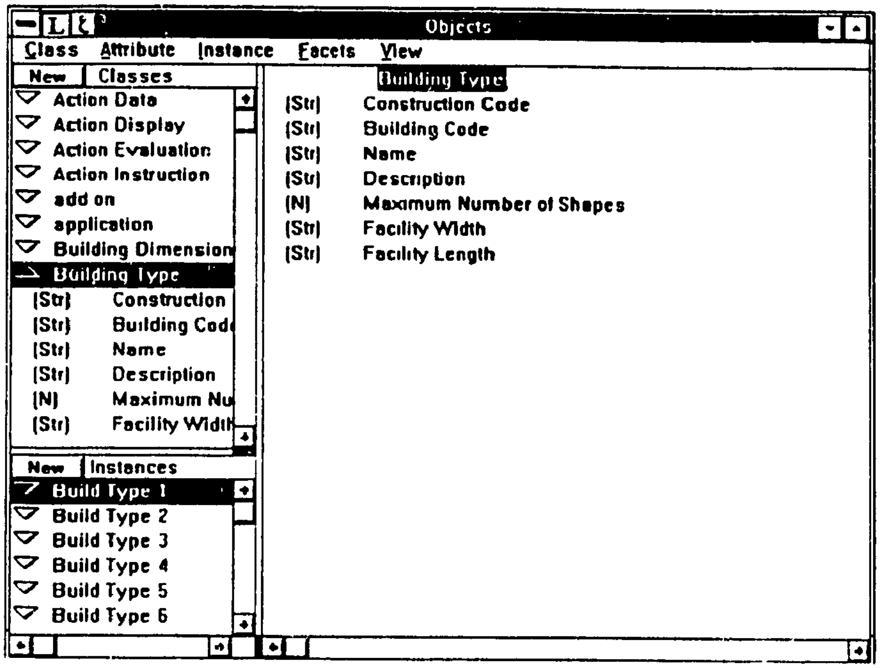


Fig. B.2 A List of Modules' Demons



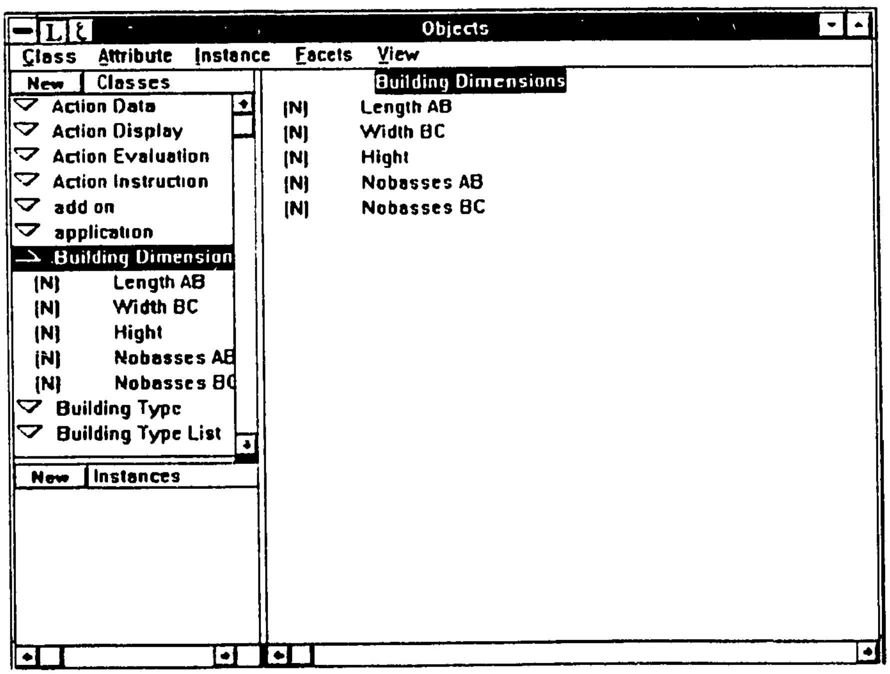


Fig. B.3 Object Editor and Class Creation

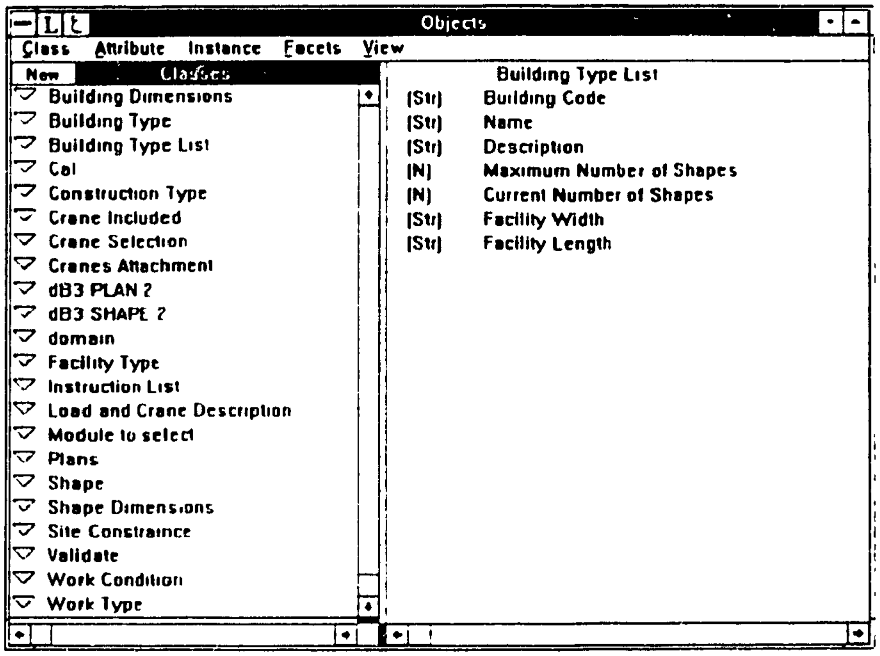


Fig. B.4 A List of Classes from the Class Editor

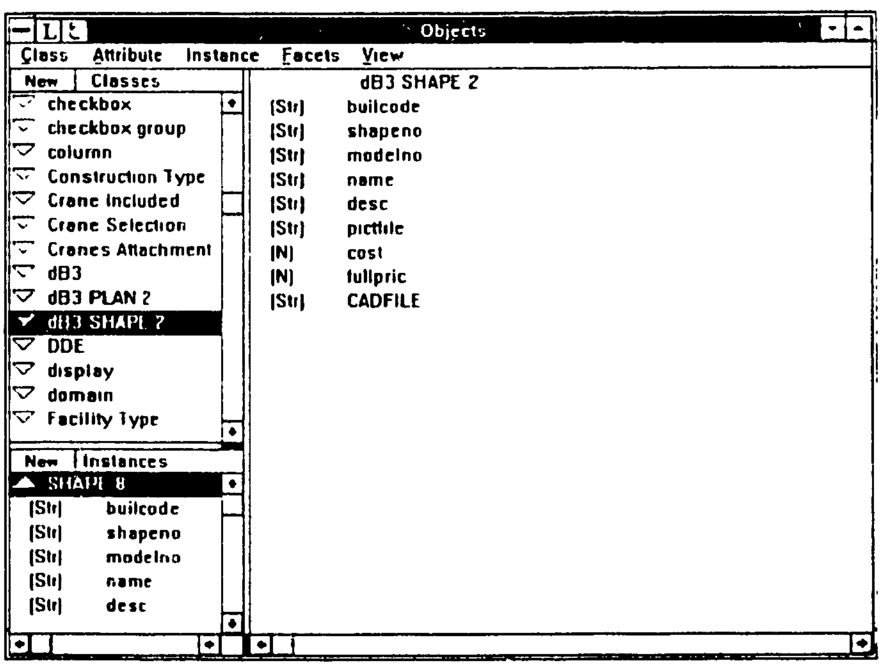


Fig. B.5 The Data-Base Class Attributes from the Class Editor

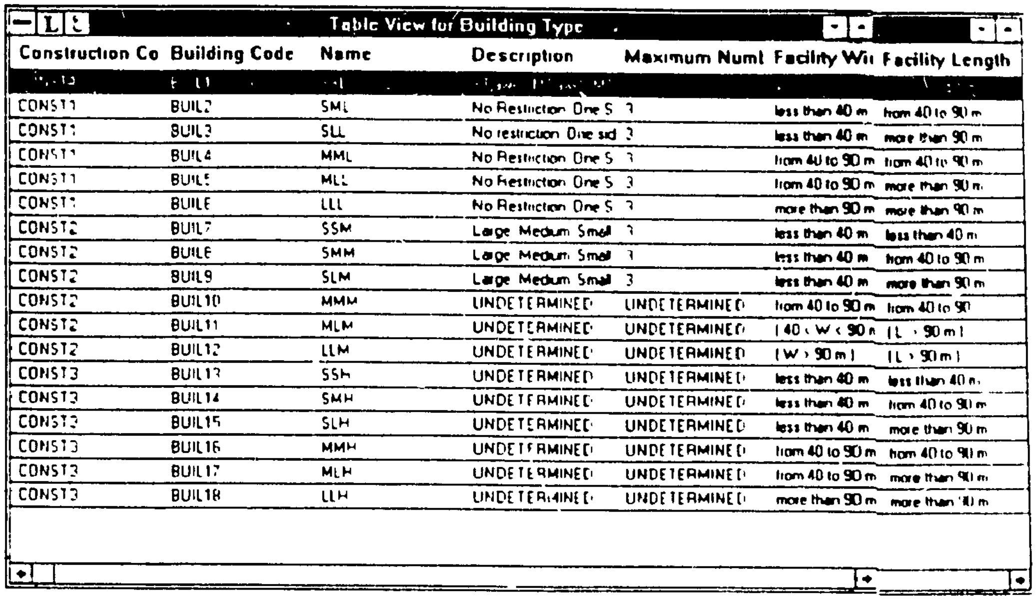


Table View for Building Type

Construction Co	Building Code	Name	Description	Maximum Numl	Facility Wi	Facility Length
[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
CONST1	BUIL2	SML	No Restriction One S	3	less than 40 m	from 40 to 90 m
CONST1	BUIL3	SLL	No restriction One sid	3	less than 40 m	more than 90 m
CONST1	BUIL4	MML	No Restriction One S	3	from 40 to 90 m	from 40 to 90 m
CONST1	BUIL5	MLL	No Restriction One S	3	from 40 to 90 m	more than 90 m
CONST1	BUIL6	LLL	No Restriction One S	3	more than 90 m	more than 90 m
CONST2	BUIL7	SSM	Large Medium Small	3	less than 40 m	less than 40 m
CONST2	BUIL8	SMM	Large Medium Small	3	less than 40 m	from 40 to 90 m
CONST2	BUIL9	SLM	Large Medium Small	3	less than 40 m	more than 90 m
CONST2	BUIL10	MMM	UNDETERMINED	UNDETERMINED	from 40 to 90 m	from 40 to 90
CONST2	BUIL11	MLM	UNDETERMINED	UNDETERMINED	(40 < W < 90 m	(L > 90 m)
CONST2	BUIL12	LLM	UNDETERMINED	UNDETERMINED	(W > 90 m)	(L > 90 m)
CONST3	BUIL13	SSH	UNDETERMINED	UNDETERMINED	less than 40 m	less than 40 m
CONST3	BUIL14	SMH	UNDETERMINED	UNDETERMINED	less than 40 m	from 40 to 90 m
CONST3	BUIL15	SLH	UNDETERMINED	UNDETERMINED	less than 40 m	more than 90 m
CONST3	BUIL16	MMH	UNDETERMINED	UNDETERMINED	from 40 to 90 m	from 40 to 90 m
CONST3	BUIL17	MLH	UNDETERMINED	UNDETERMINED	from 40 to 90 m	more than 90 m
CONST3	BUIL18	LLH	UNDETERMINED	UNDETERMINED	more than 90 m	more than 90 m

Fig. B.6 Class Instance Table

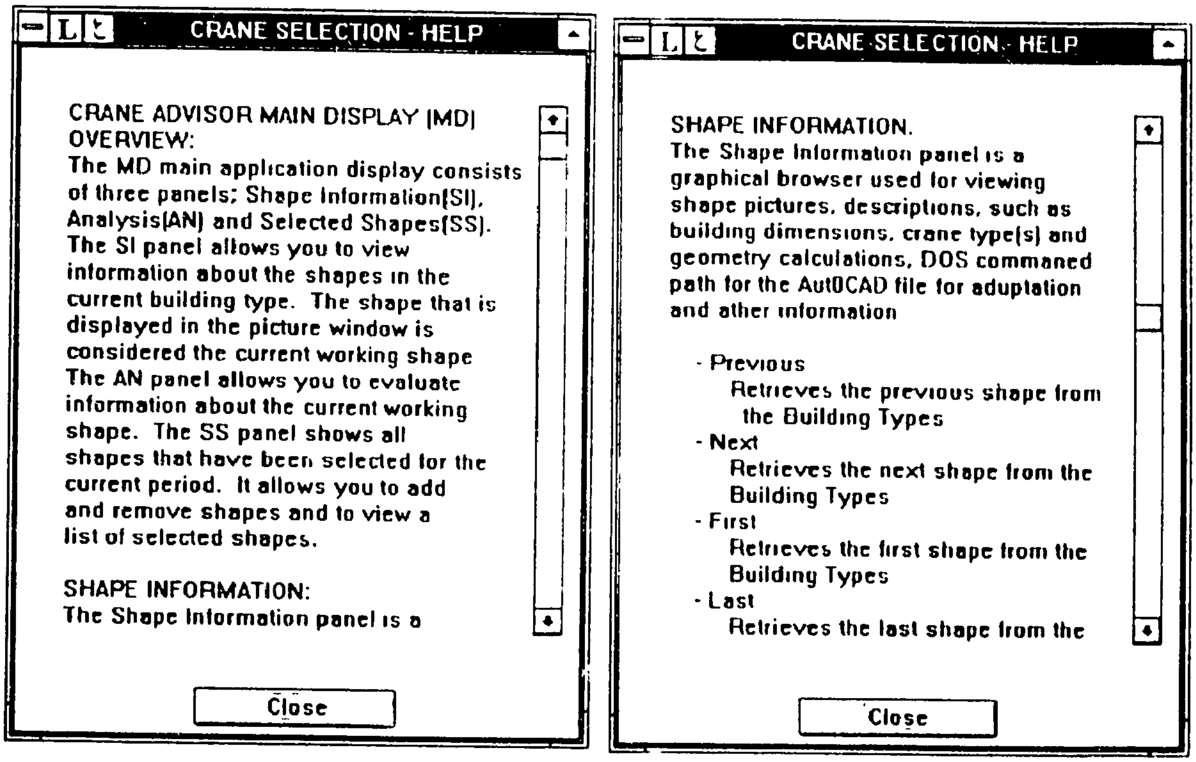
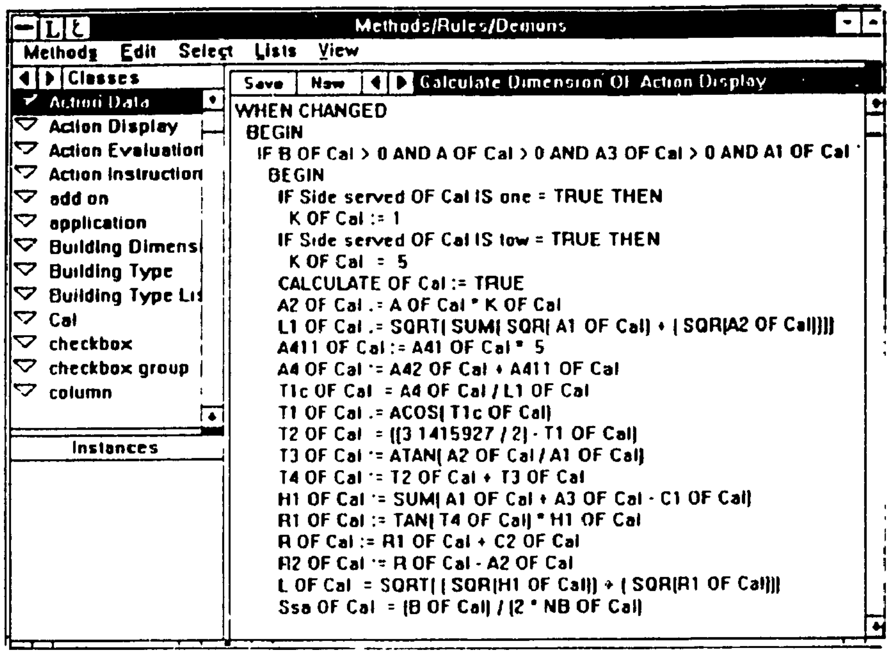


Fig. B.7 Crane Advisors' Help Displays



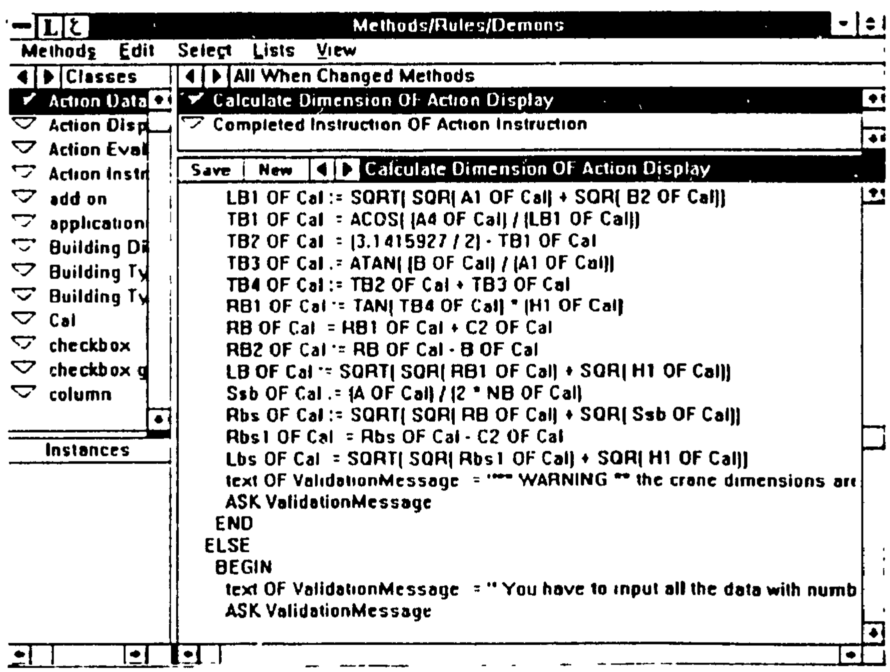
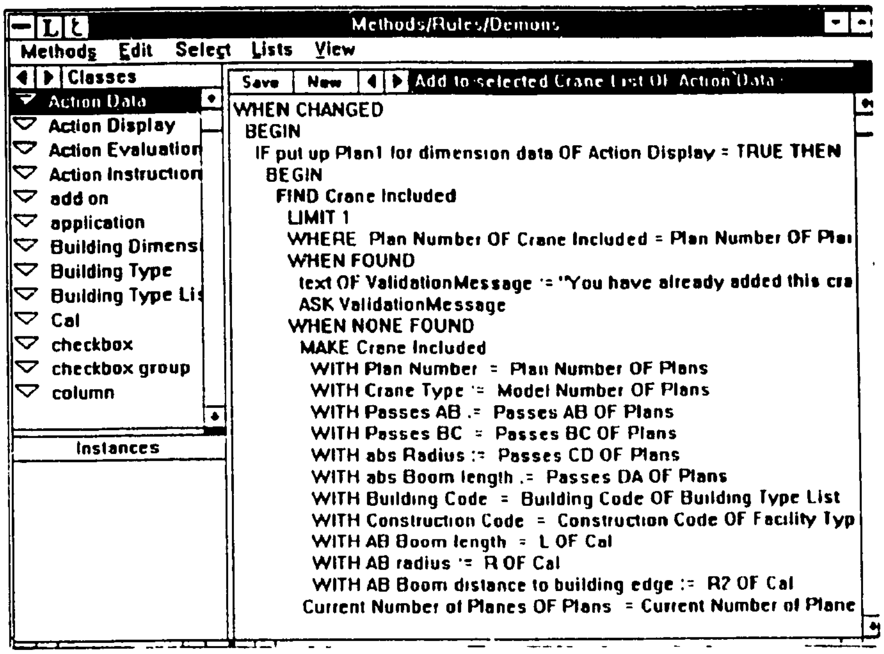


Fig. B.8 The When Change Method that Controls the Cranes Geometry Calculations



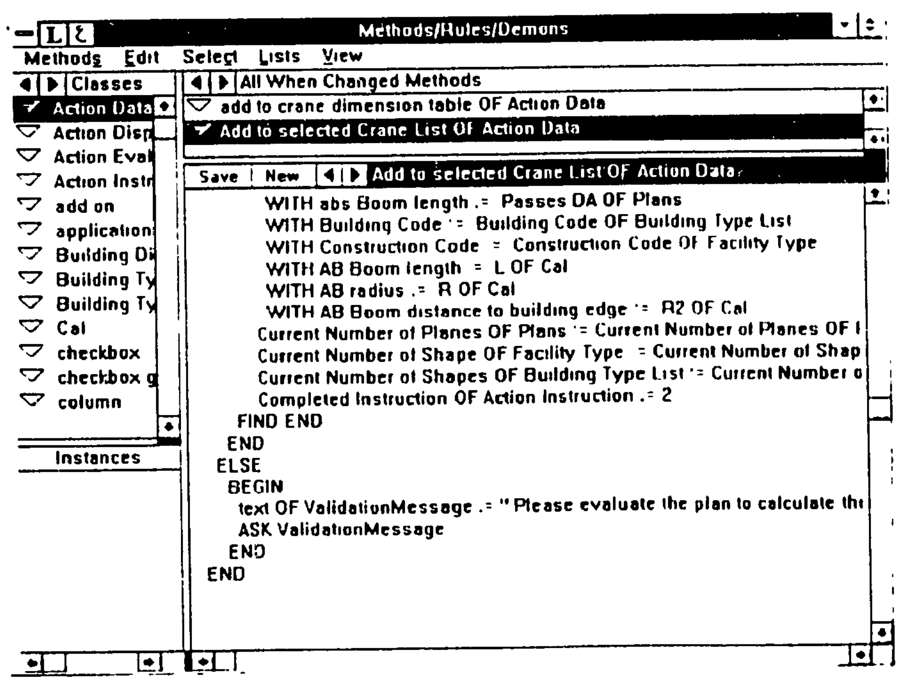
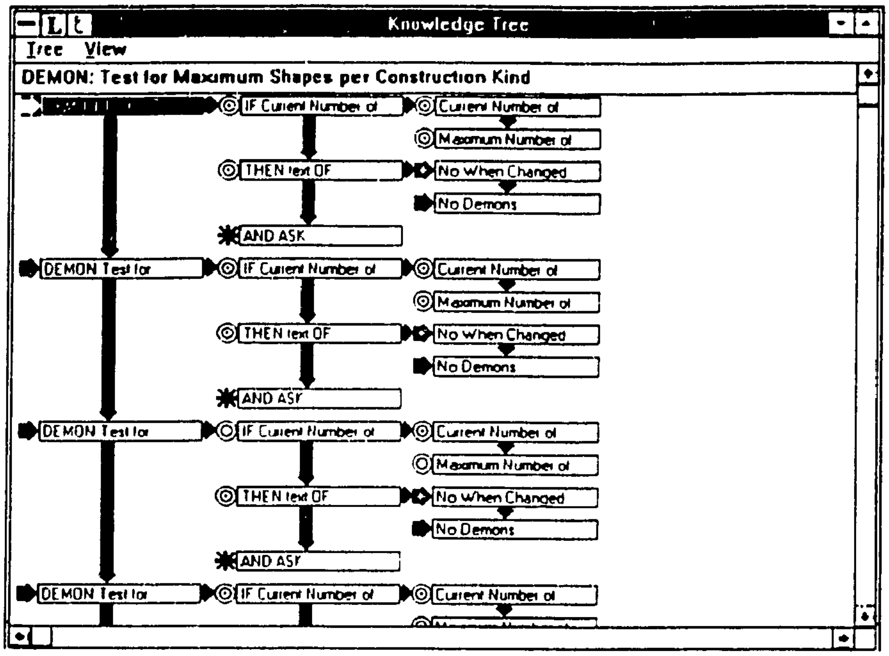


Fig. B.9 The When Change Method that Controls the Data-Base System Manipulations



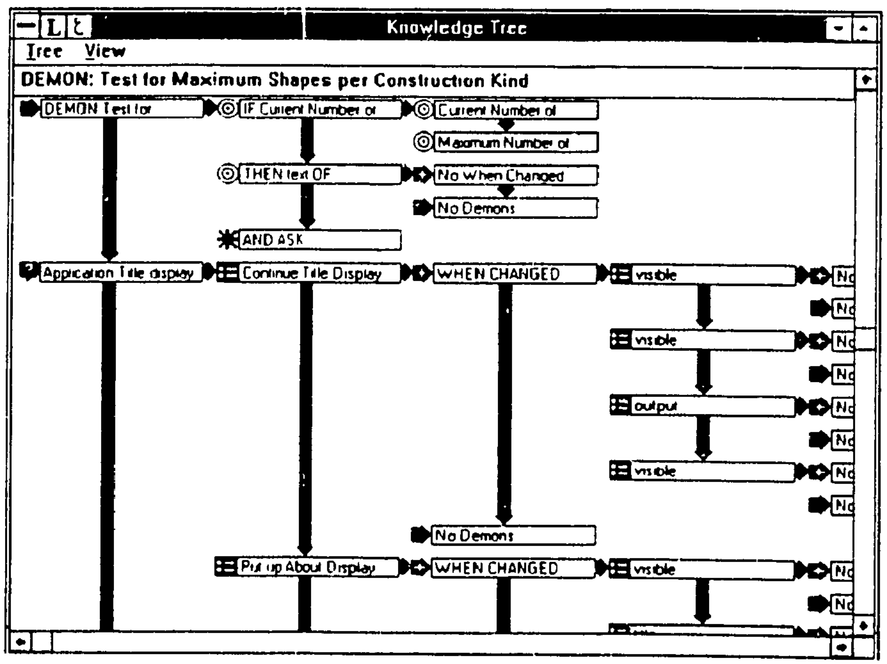
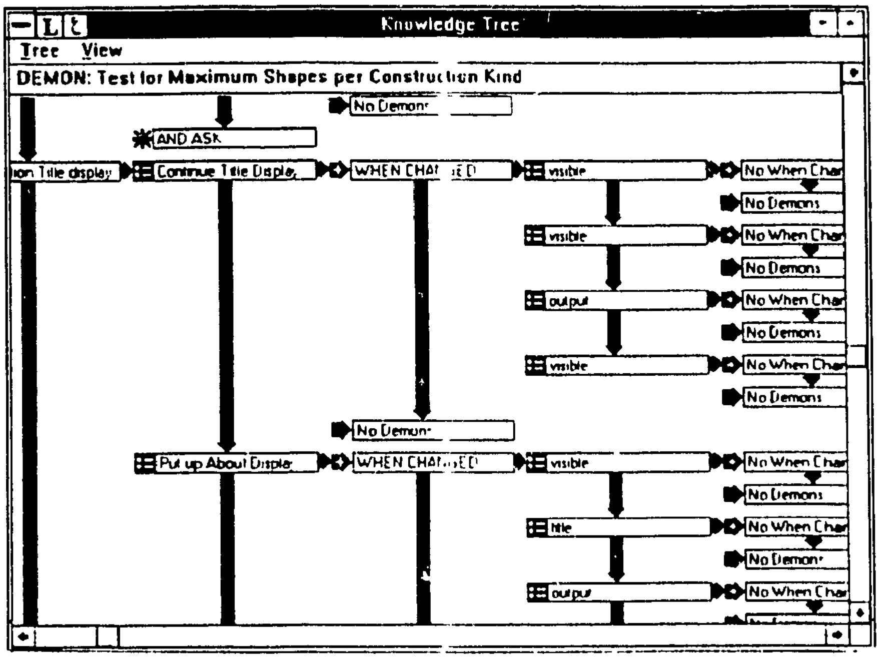
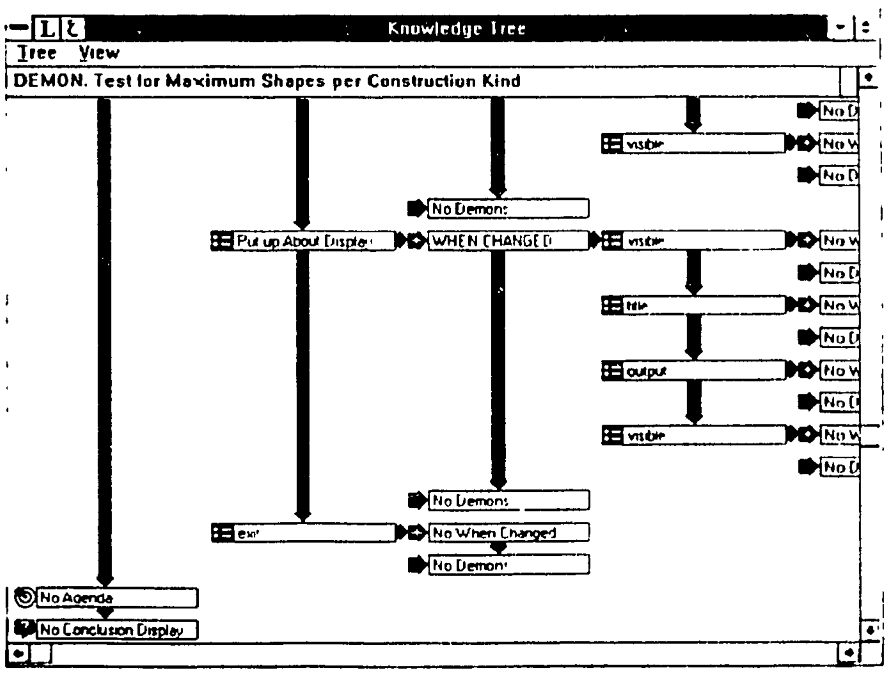


Fig. B.10 System Knowledge Tree





Continue Fig. B.10 System Knowledge Tree

APPENDIX C

FLOWCHART REPRESENTATION OF THE KNOWLEDGE BASED FOR CRANE SELECTION

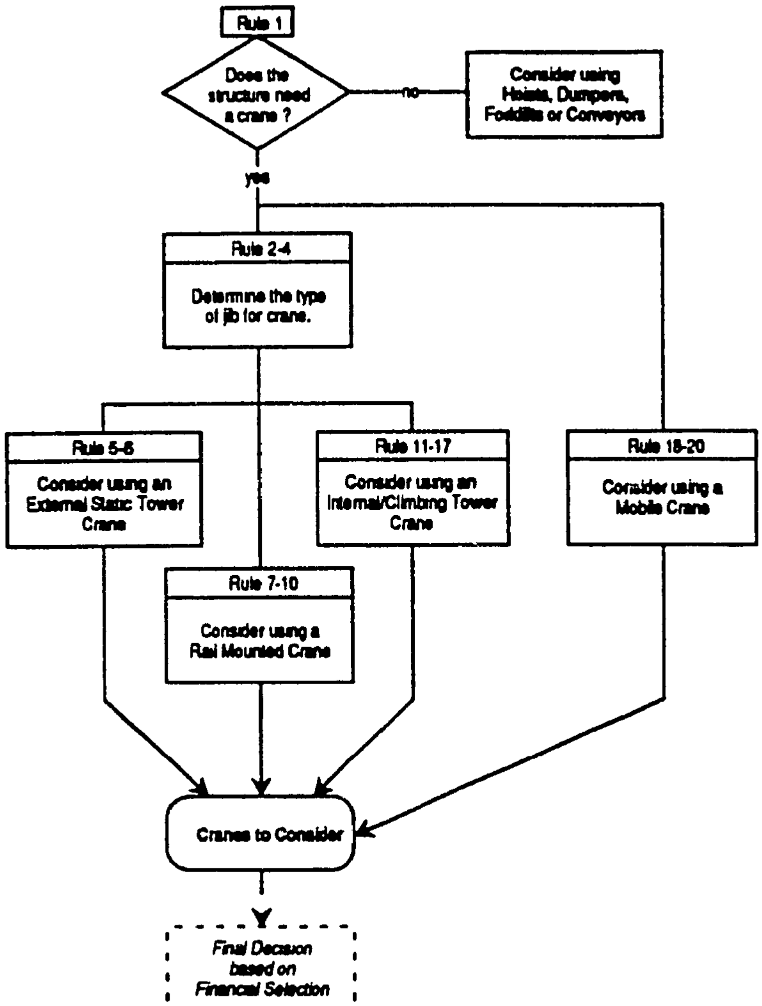


Figure 1. General overview of "Selection of Cranes" Knowledge Base.

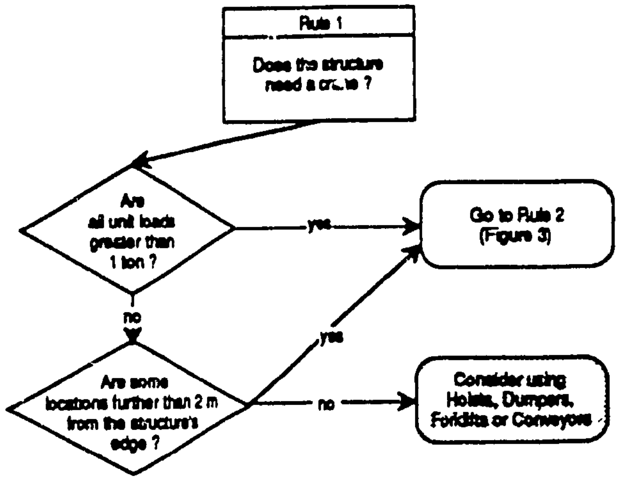


Figure 2. Flowchart for "Does the structure need a Crane" Rule.

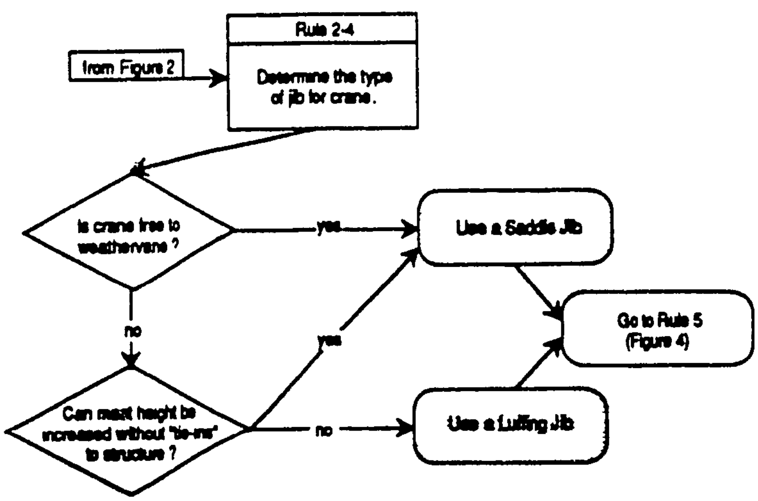


Figure 3. Flowchart for "Determine the type of jib for External Static and Internal Tower Crane" Rule.

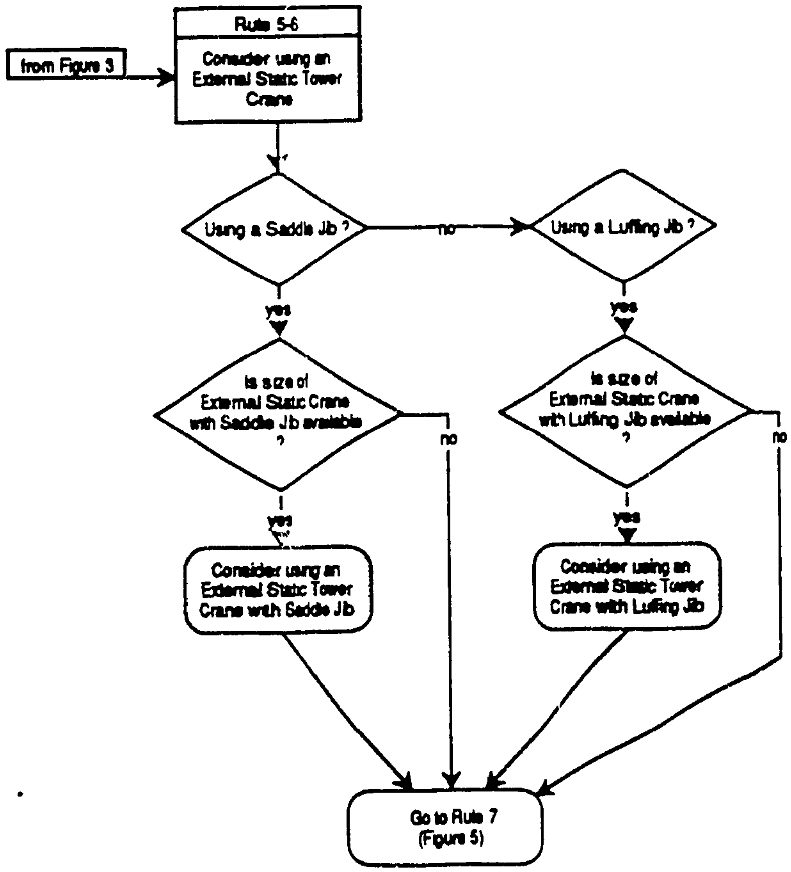


Figure 4. Flowchart for "Consider using an External Tower Crane" Rule.

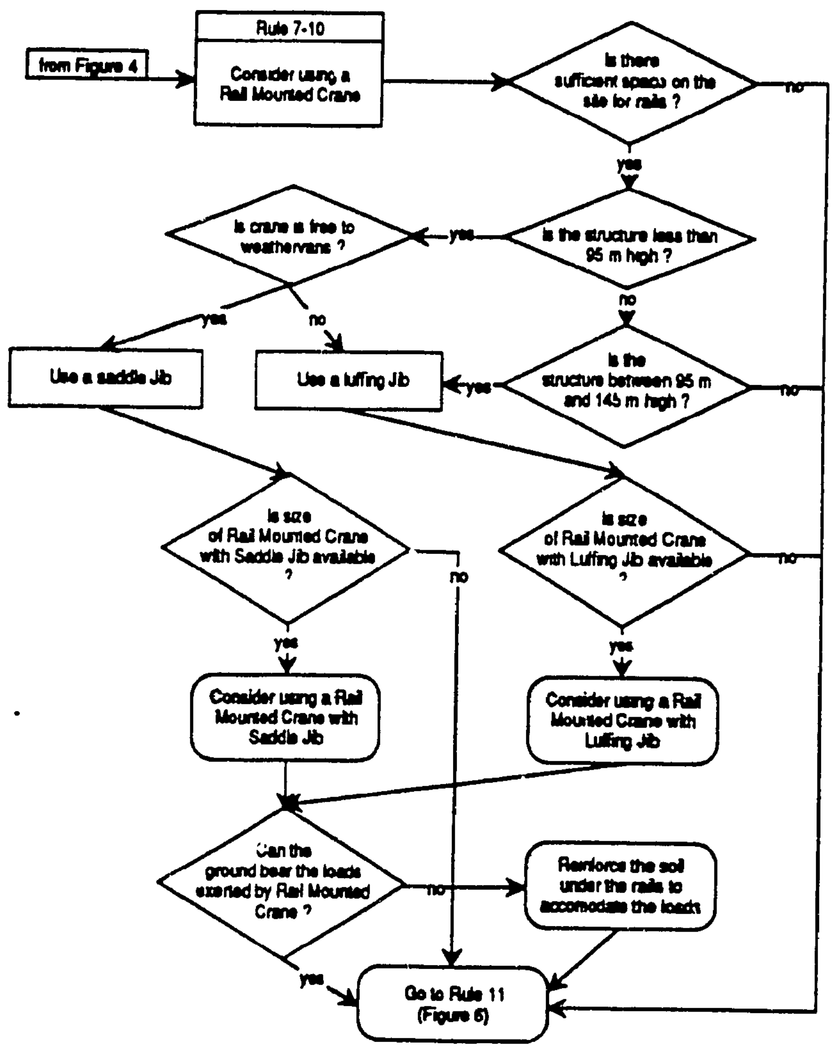


Figure 5. Flowchart for "Consider using Rail Mounted Crane" Rule.

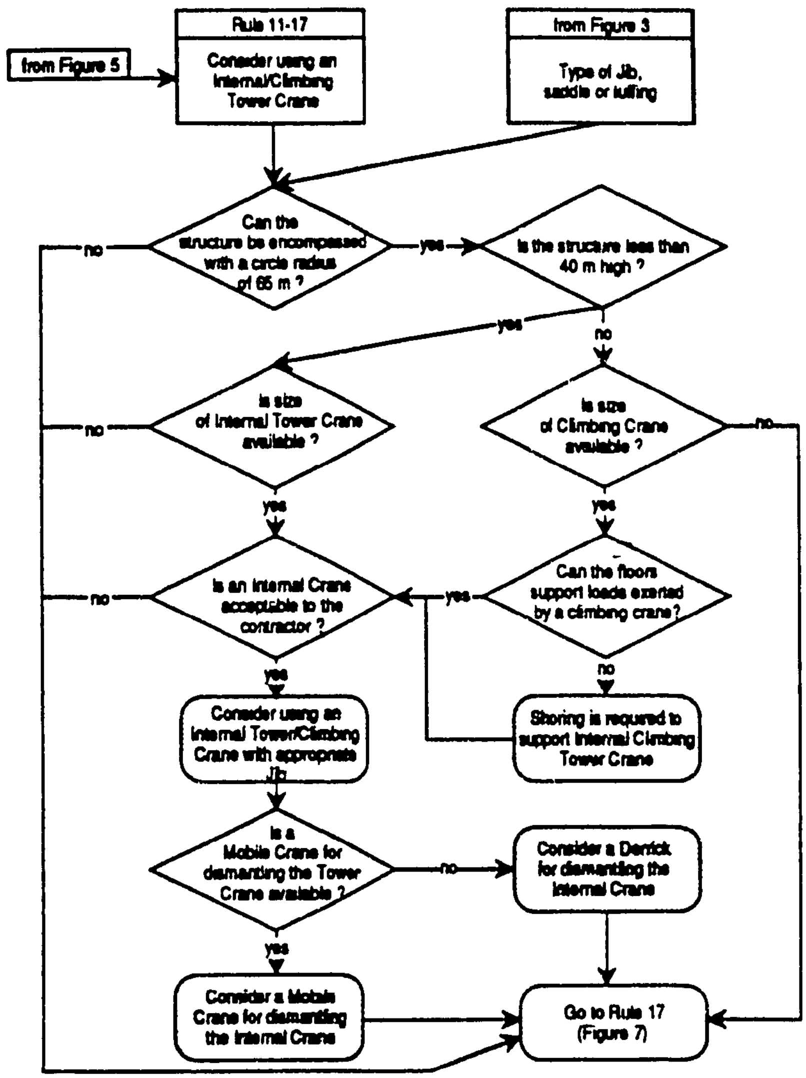


Figure 6. Flowchart for "Consider using an Internal/Climbing Tower Crane" Rule.

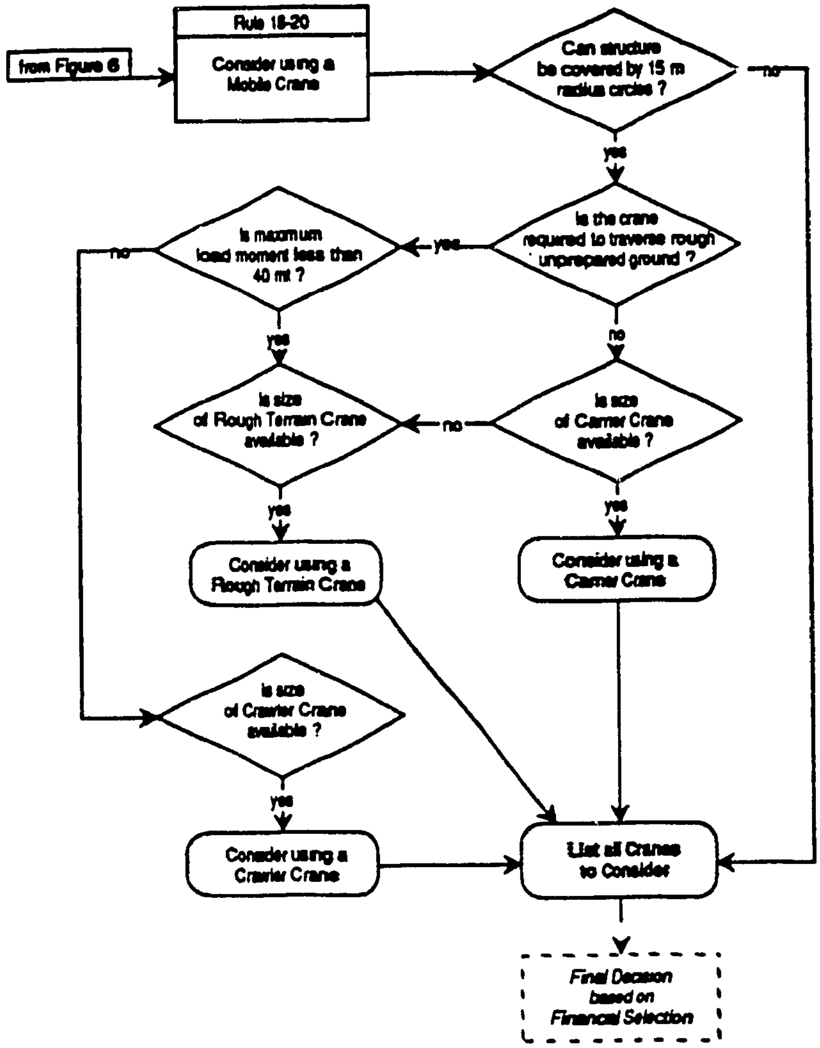


Figure 7. Flowchart for "Consider using a Mobile Crane" Rule.

APPENDIX D

KBES MODULE'S FEATURES

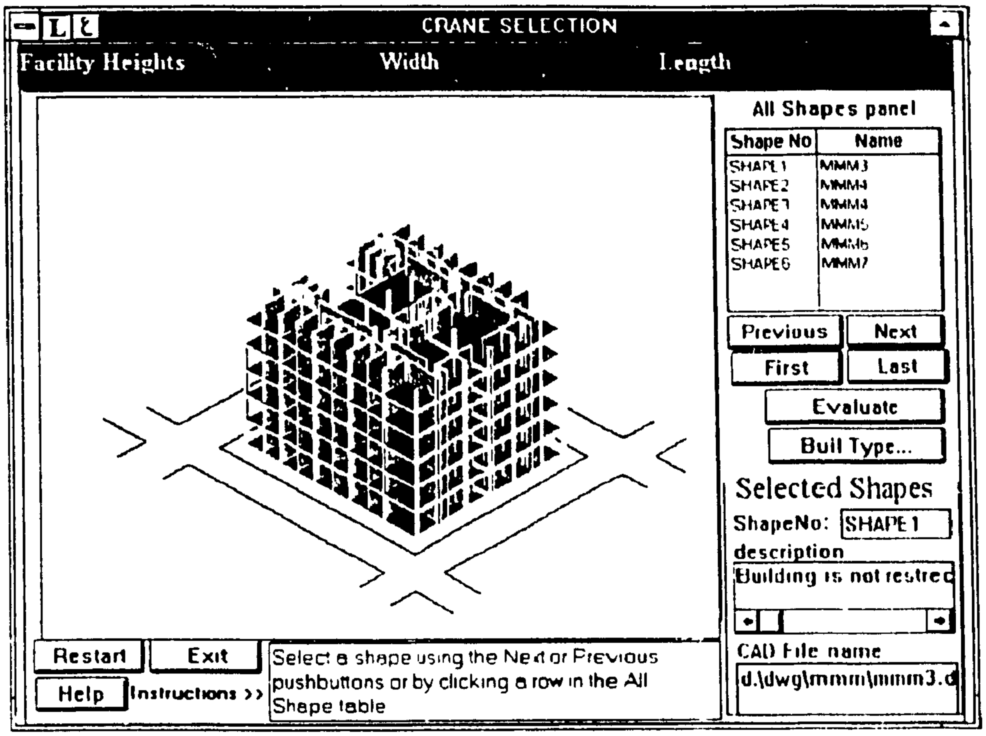
APPENDIX C THE KBES MODULES' FEATURES

This part of the thesis describes the process of the crane selection followed by the KBES module. Selecting the **CONTINUE** option from the title display as was shown in chapter (6), the user is asked to select the building's vertical dimensions in a display called **Building Height Display**, and the other horizontal dimensions in a display called **building width and length display**. In this appendix, facility from the group of mid-height, mid-length, and mid-width is selected. This action is followed by activating the **Main Display**.

I. Module Main Display

The **MAIN DISPLAY** as shown in Fig. (D. 2) provides the user with information on the selected case based on the user's responses to questions posed by the system. In the top of the screen the type of the facility is displayed. The user can activate other options or make changes to his/her previous responses by choosing the command back to building types presented with the push potion called **(BACK-type)**. **ALL SHAPES PANEL** contain the list of other scenarios demonstrating the physical aspects that are inherited in the crane selection process such as: shape of the building, site constraints, adjacent buildings, etc. those considered as the most critical factors affecting the crane selection. This information is available in the database to be retrieved by the user, by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**). Doing so the user will be provided with different scenarios related to other site constraints, as shown in Fig. (D. 2, a, b, c, d, e, and f). Along with the three dimension view of the building the display provides other useful data such as detail description of the selected building, other factors affecting crane selection, terrain conditions, and a path represent the address of an AutoCAD drawing for the user to call if needed.

(a)



(b)

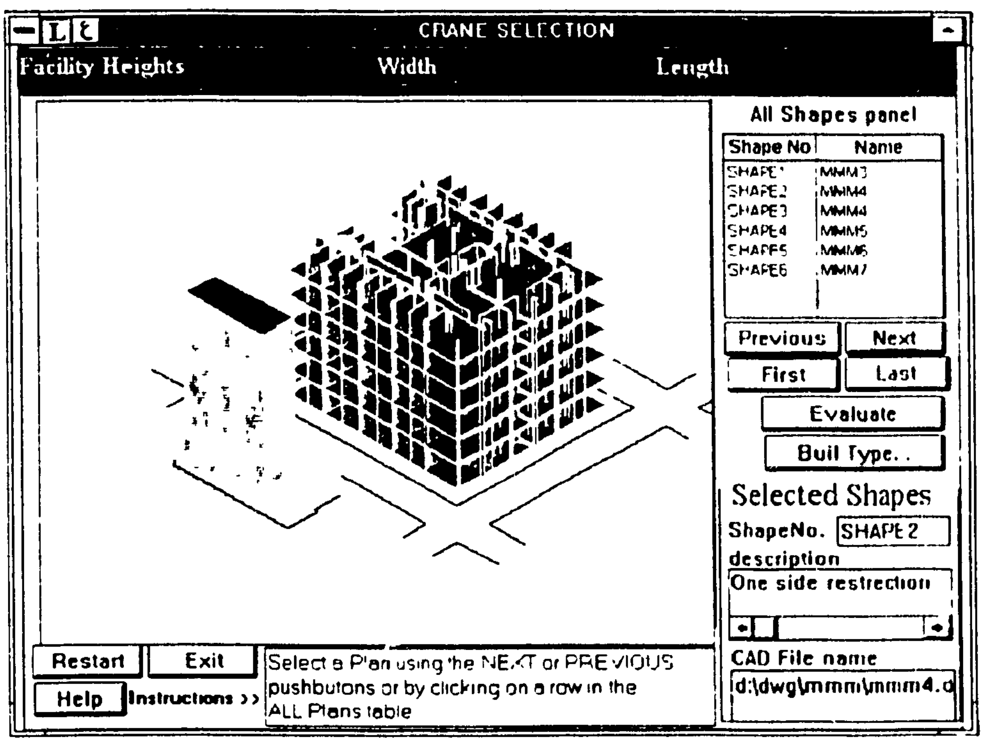
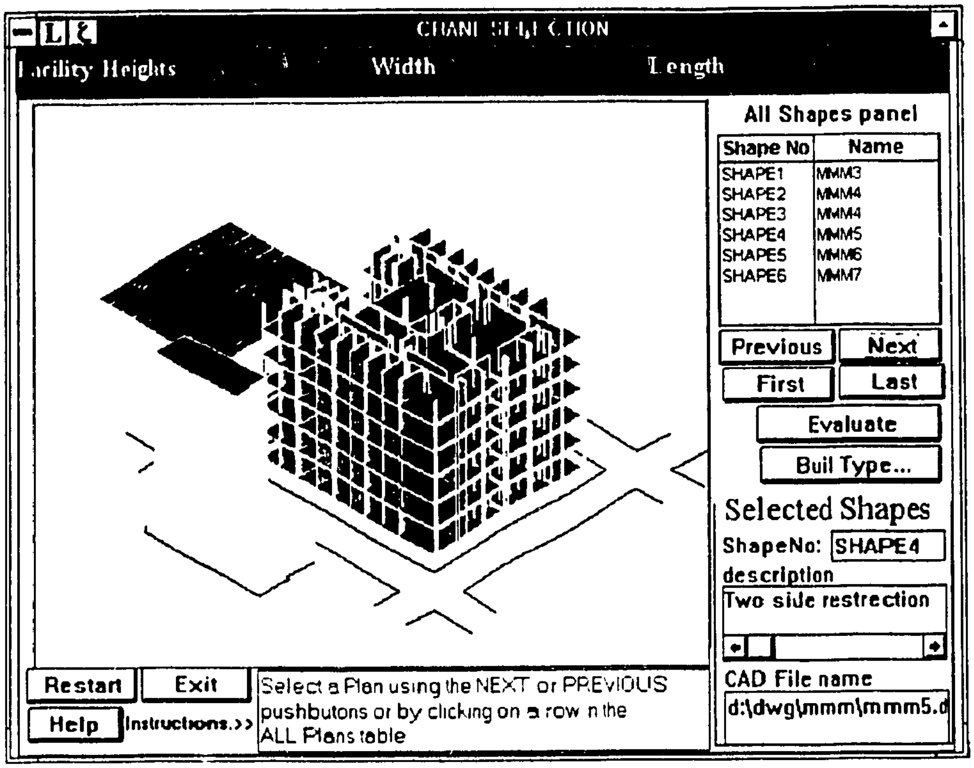
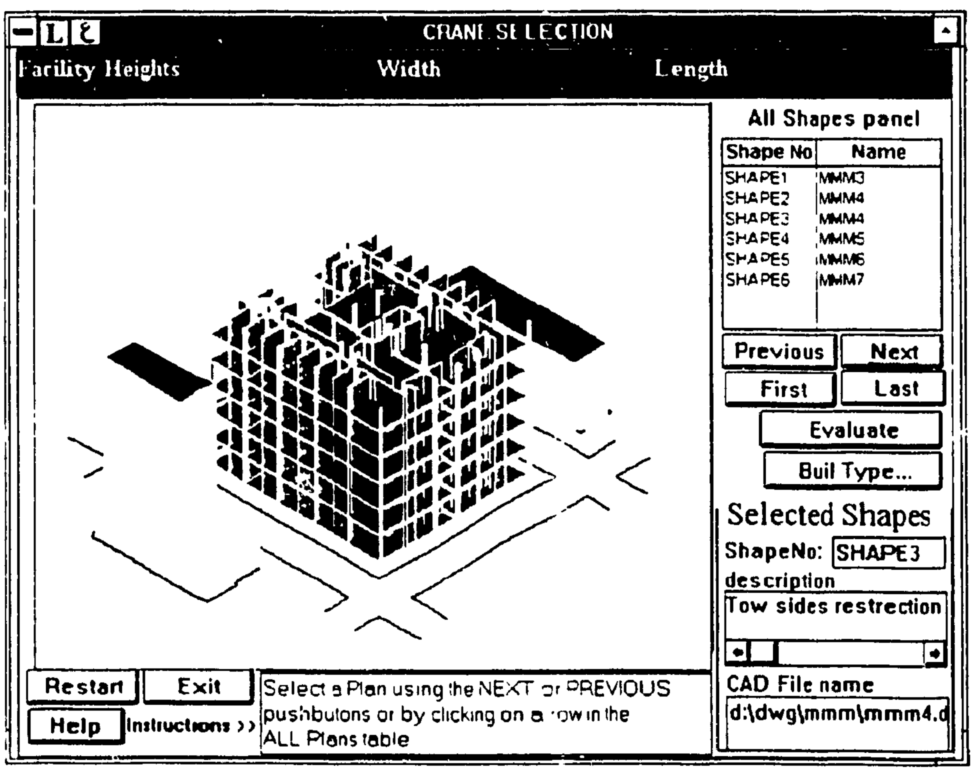


Fig. D. 2 KBES Module's 3D Display

(c)

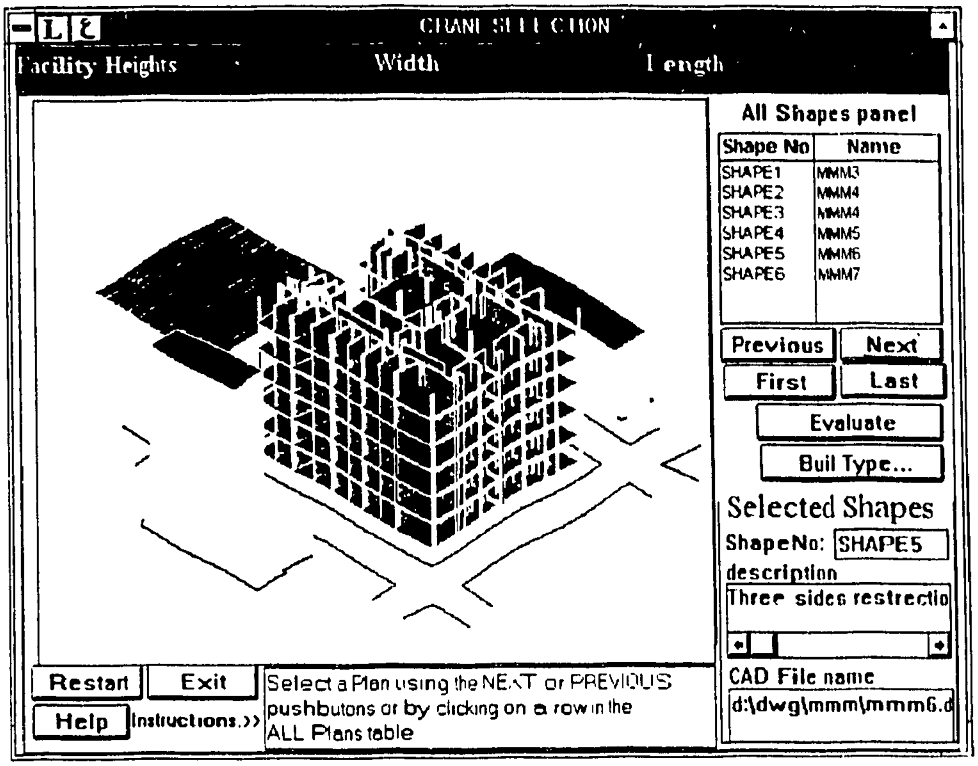


(d)

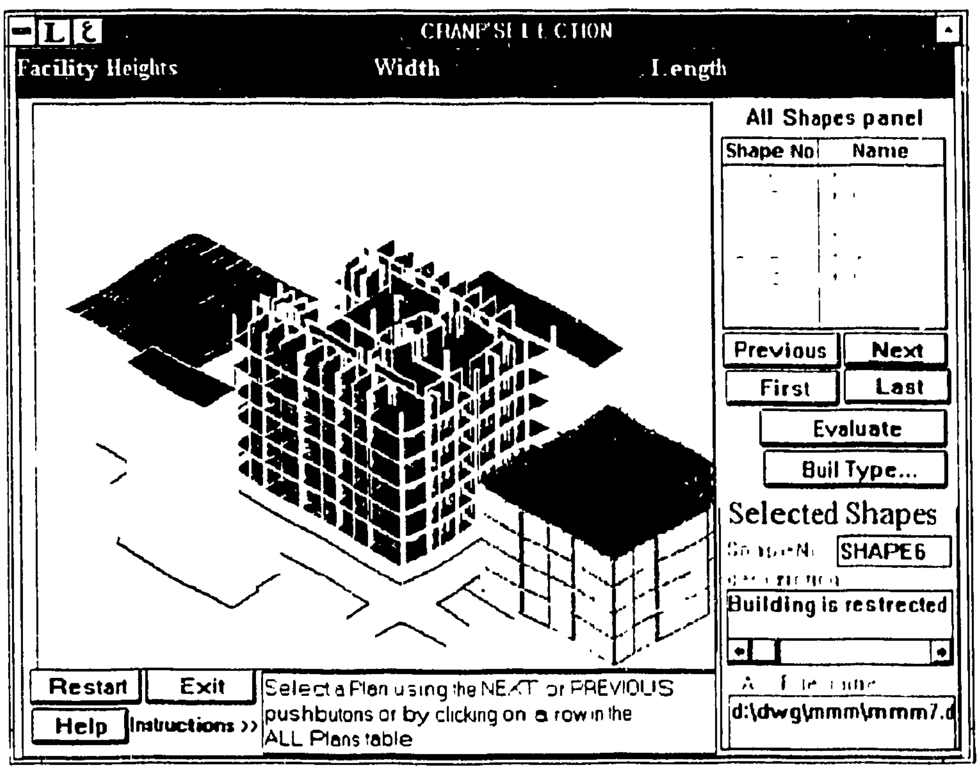


"Continue" Fig. D. 2 KBES Module's 3D Display

(e)



(f)



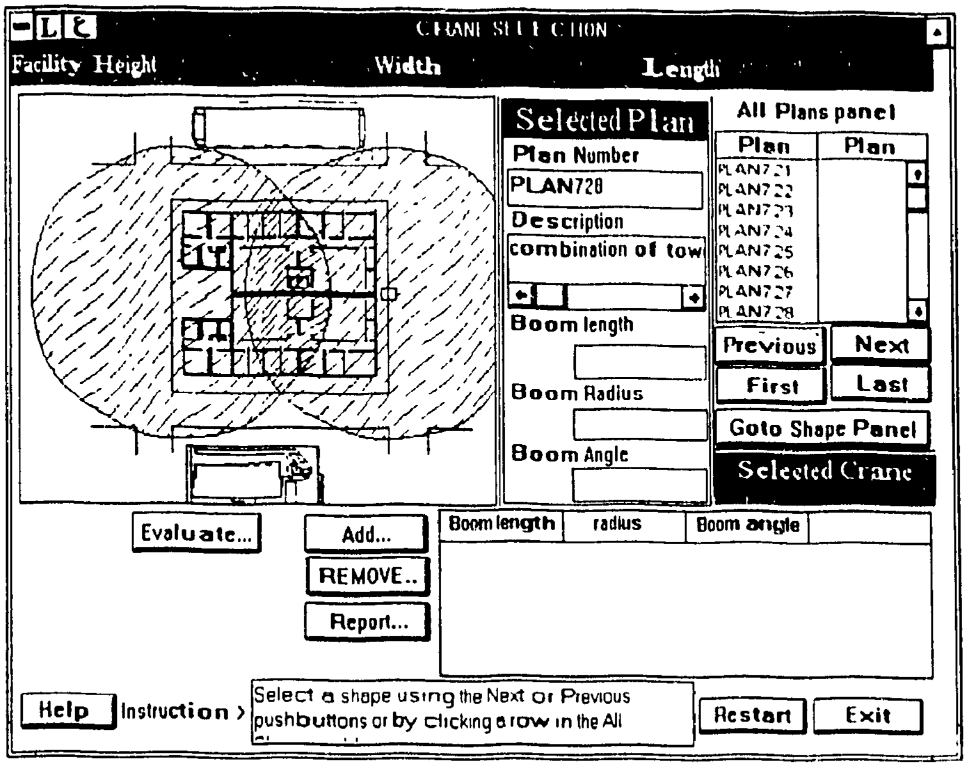
"Continue" Fig. D. 2 KBES Module's 3D Display

II. Plans display

Plan view as shown in Fig. (D. 3) provides the user with information on the selected case based on the user's responses to questions posed by the system in the previous displays. In the picture box the plan view of the selected building from the **Main Display** is presented along with the crane(s) location(s), and the working range of the selected crane as suggested by the system. Geometry calculations of the selected crane such as: cranes distance from the building, boom length, boom radius, boom angle to ground, boom offset to the age of the building, and boom head clearance for a mobile crane(s), and boom length, and boom head clearance of the tower crane(s) are also presented. Such calculation are provided as a default data which is reliable for a largest building dimension in this group, but it may be over-estimated, although feasible, for a smaller size facility. **ALL PLANS PANEL** contain the list of other scenarios containing presentation of different plan views with location of the crane(s) and material to be handled available in the database to be retrieved by the user. The user can activate other options or make changes to his/her previous responses by double clicking on the appropriate row in the list or using the systems commands (**NEXT**, **PREVIOUS**, **LAST**, and **FIRST**). Other information regarding the crane selection, erection, and dismantling on site is also provided as shown in Fig. (D. 3, a, b, c, d, e, and f). Each scenario becomes a new case, it may be selected to be used for further investigation, implemented, as a possible solution for the crane selection. The user can brows through the system's different solutions, and may select one or more of them by using **ADD** command to generate a list of the feasible alternatives.

The system also provides the user with access to the geometry calculation module by clicking on the CALCULATE option, which activates the geometry calculations module.

(a)



(b)

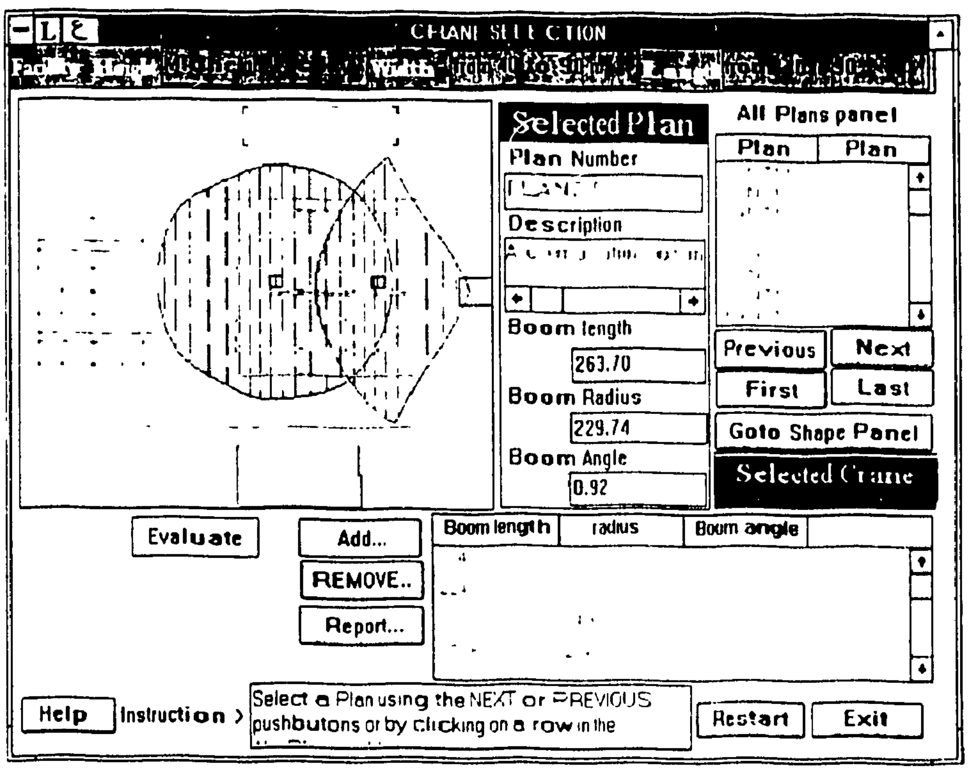
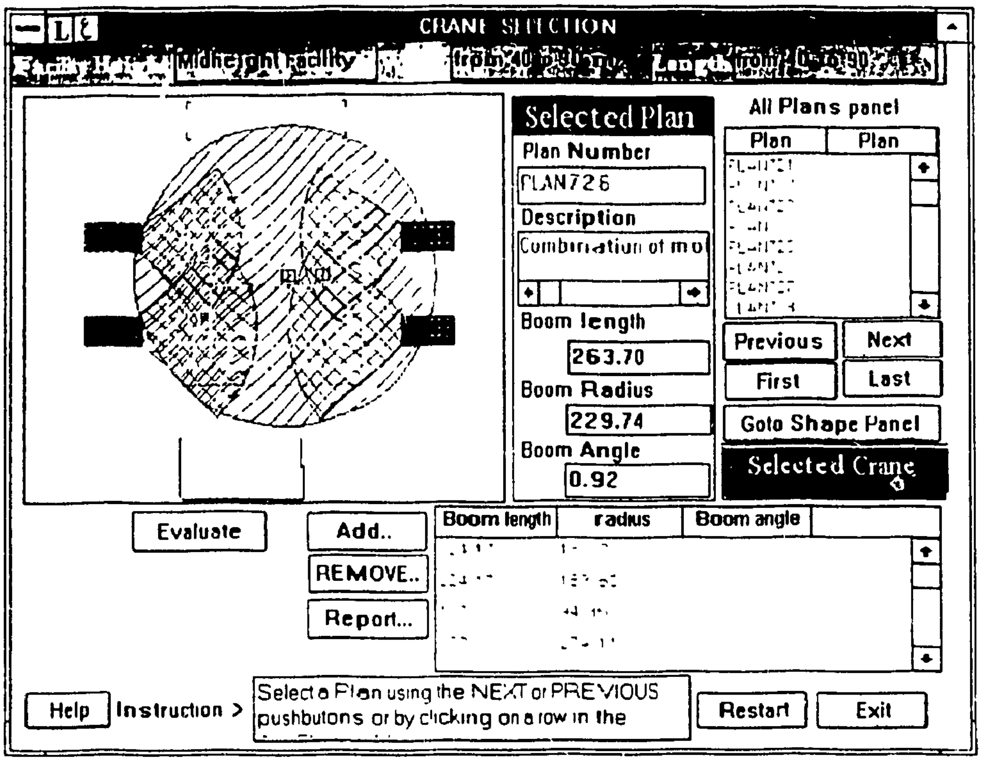


Fig. D. 3 KBES Module's 2D Display

(c)



(d)

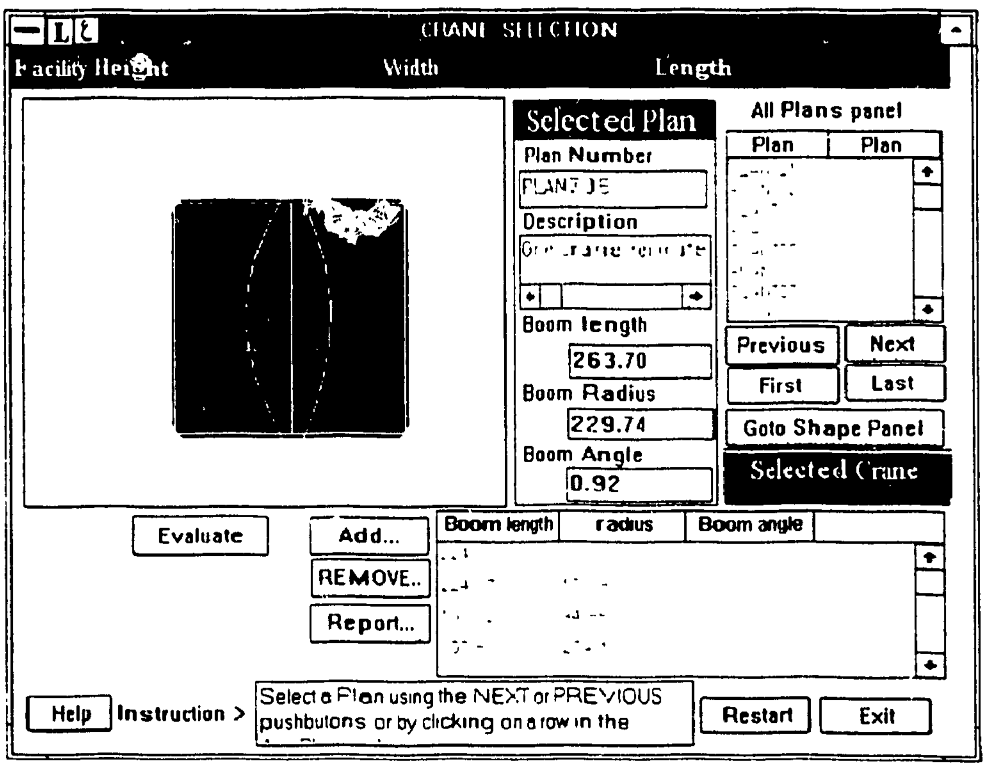
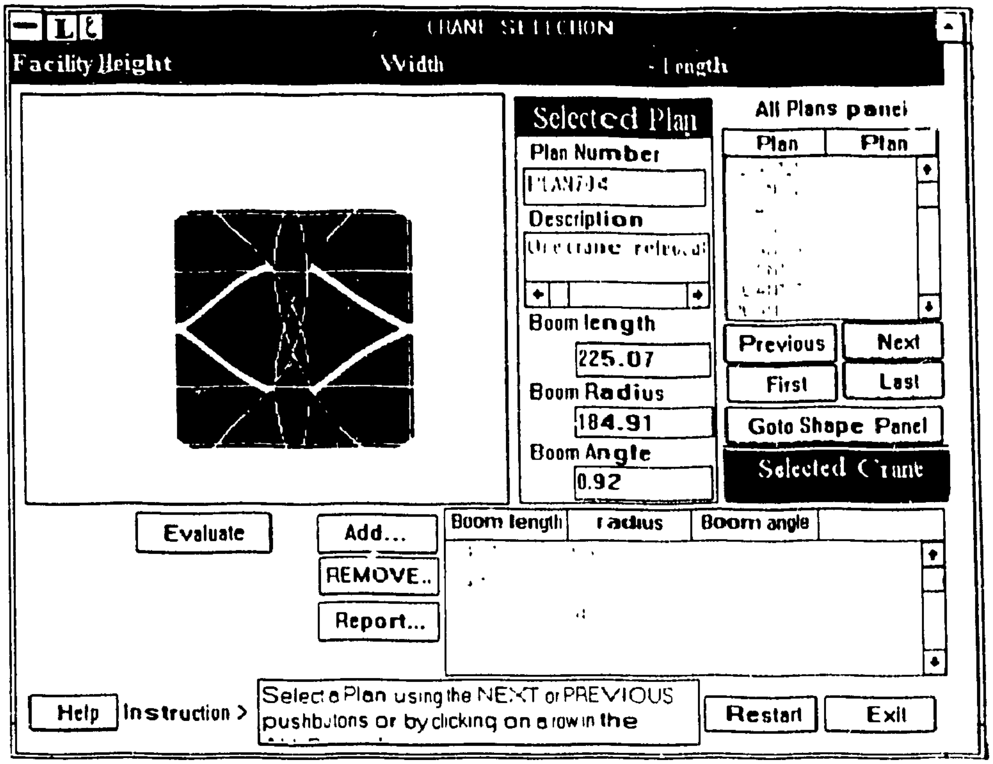


Fig. D. 3 "Continue" KBES Module's 2D Display

(e)



(f)

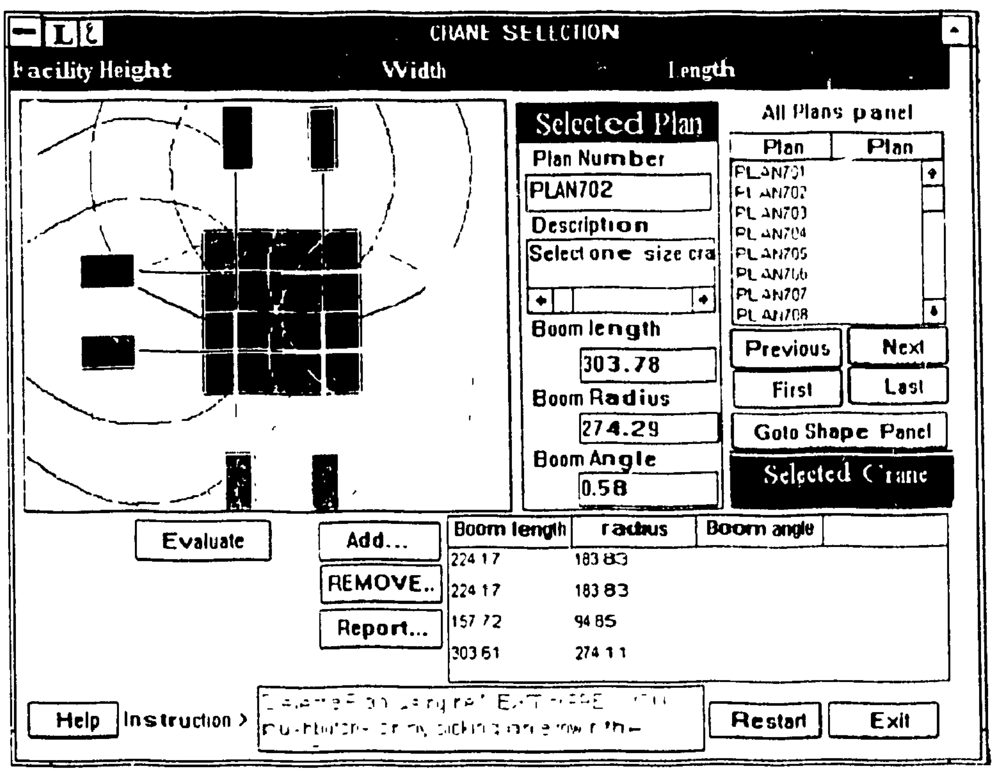


Fig. D. 3 "Continue" KBES Module's 2D Display

APPENDIX E

OWNING AND OPERATING EQUIPMENT COST VARIABLES INVOLVED IN THE COST CALCULATIONS USED IN THE (ECEA) MODULE

Appendix E Operating and Owning Cost Variables involved in the ECEA modules' Cost Calculations

The set of construction equipments cost items involved in estimating their owning and operating costs using the ECEA are classified into three main grogs, the Consequential cost, the Owning costs, and Operating costs, as follow:

1. Consequential costs

The consequential costs are widely recognized, but often overlooked. However because of their influence on the equipment accounting system, they must be considered in any model that seeks to reflect reality (Vorster 1987, Vorster 1990). The equipment breakdown cost calculation implemented in ECEA are based on the methodologies proposed by Cox 1971 and Vorster 1987. It involves time to reassign resources on the deteriorated equipment, and the time to replace it with another temporarily equipment to simulate the characteristic of the job where the underlined equipment is operating. As an option the breakdown cost is considered empirically as 4% of the total operating hours per year.

2. Owning Costs

2.1. Interest Charges

Equipment purchased with loaned funds or on an instalment purchase plan will have interest charges that are considered ownership expenses. A simple procedure for handling interest charges is to average them over the economic life of the equipment using the following formula:

Interest charge per year = Total interest to be paid / Economic life in years

An alternate approach yielding approximately the same charge utilizes the average unpaid principal (AUP) that is converted to an annual or hourly interest charge as follow (James 1989):

$$AUP = \frac{n + 1}{2n} x P$$

Where: **P** = purchase price less down payment

n = economic life in years

Interest charge per year = **(AUP) * i**

where: **i** = interest rate on the loan.

2.2. Taxes

Firms who own, or decide to own equipment, eventually proceed their purchase with a mix of debt and equity capital, the taxes computation are carried only on the tax detectable involves the equipment, excluding the prospective revenues and their corresponding taxable income on the equipment, in order to minimize the uncertainty of predicting them in the equipment cash flow. Thus the after tax cash flow is estimated on the following basis:

The equipment revenue is omitted from the cash flow calculation because it will be poured in the total firm revenue, and to avoid the uncertainty in predicting them.

The tax detectable amount is calculated on the basis of interest payments and depreciation deductions, and subtracted from the cost cash flow.

2.3. Depreciation

Depreciation is the facility to deduct certain amount of money from the capital investment as a cost that reduce the taxable income, hence reducing the tax payment. For the purpose of this work, depreciation is used to estimate the book value or as a resale value of an equipment, alternatively a user input value may be used. The resale value is mainly governed by the law of supply and demand, and according to the operating condition of the equipment, hours of usage. Estimated salvage value depends on the approach to estimate the future resale value of the equipment. Different types of depreciation methods are used by owners to depreciate their equipment, these include the followings:

2.3.1. Straight-Line Method (SL):

This method assume that an annual amount of depreciation $\mathbf{D_m}$ for any year m is a constant value, thus the book value $\mathbf{BV_m}$ decreases at a uniform rate over the useful life of the equipment.

Depreciation rate $\mathbf{R_m = 1/N}$

Annual depreciation amount $\mathbf{D_m = R_m (P\text{-}F) = (P\text{-}F)/N}$

Book value at year m $\mathbf{BV_m = P\text{-}m\ D_m}$

(P-F) is the depreciation value.

From this equation we can calculate the hourly depreciation of an equipment if one knows the number of hours the equipment works per year (Nunnally 1977, & 1980).

2.3.2. Sum-of-the year digit method:

This method provides relatively high depreciation allowances in the early years and lower allowances through the rest of the equipment useful life, and it is computed as follows:

$\mathbf{D_m}$ = Factor time depreciable value

$D_m = R_m \times (P\text{-}F)$

Sum of Year Digits (SOY) = $1 + 2 + 3 + \ldots + n = n \times (n+1) / 2$

The depreciation rate $R_m = (N - (m-1)) / SOY$

The annual depreciation D_m for the m^{th} year is:

$D_m = R_m (P\text{-}F) = (N - (m-1)) \times (P\text{-}F) / SOY$

The book value BV_m at the end of year **m** is:

$BV_m = P - m\, D_m$

$BV_m = P - (P\text{-}F) (m (n - m/2 + 1/2) / SOY$

D_m = Year Digit x Annual to be Depreciated / Sum of Year Digits

2.3.3. Declining-balance method

It is the nearest computed method to the actual loss in market value verses time, in which the value range from **1.25** to **2** times the current book value, giving that the book value can't exceed the salvage value (Nunnally 1977, White 1989, and Nunnally 1980).

R = Depreciation Rate for the Declining Balance Method

= 1.125 / N , 1.50/N , 1.75/N , 2.00/N

D_m the allowable depreciation for any year m and depreciation rate R

$D_m = R\ \ P (1-R)^{m-1}$ or $D_m\ (BV_m - 1)\ R$

The Book Value of any year **m** is

$BV_m = P (1-R)^m$

Where BV_m is greater than or equal **F** (the salvage value)

3. Operating Cost

Operating costs are costs usually occurred only when the equipment is being used (Peruifoy, 1985; Nunnally, 1980).

3.1 Maintenance Direct Costs.

Included in this group are mechanics employee-hours, parts, replacement assemblies, maintenance expandable (such as solvents and welding supplies), and any contract maintenance work.Thais costs could be evaluated in terms of a multipliers of the current replacement cost.(e.g 10 % to 27 % of currant replacement cost per year (James 1989).

3.2 Maintenance Overhead

Including in this category are maintenance supervisory personnel, shops, equipment used in maintenance (air compressors, lubricators, welding machinist) and all small maintenance tools. another costs could be included in this category like fuel, shop expendable, and a charge of tool use and loss, lubrication, minor maintenance and repair cost, down-time, obsolescence, service, special items (Peruifoy 1985, Nunnally 1980, and James 1989).

3.3 Maintenance and Repair

Factors affecting this cost are type of equipment, the service to which it is assigned and the care which it receives. That is why, we could consider the annual cost of maintenance and repair as a percentage of the annual cost of depreciation but with accurate data could be expressed independently (e.g. maintenance cost and repair for power shovel varies from **80-120%** of the annual cost of depreciation with the use of the same equipment of rock crashing will be much higher).

3.4 Fuel consumption cost

The hourly cost of fuel is found by multiplying the fuel consumption in gallons per hours by the cost each gallon of fuel (Peruifoy 1985, and Nunnally 1980). The gasoline engine will consume approximately 0.06 gallon of fuel per flywheel hours power per hour **(0.06 fwhp-hr)**. The diesel engine will consume approximately 0.04 gallon of fuel per flywheel hours power per hour **(0.04 fwhp-hr)** (Peruifoy 1985).

Since the equipment really work continuously at full load it is necessary to convert fuel load consumption to consumption under the expected condition (Nunnally 1980). These factors are engine factors and time factors (Peruifoy 1985, and Nunnally 1980).

3.5 Lubricating, Filters, Oil:

Under average conditions lubricating oil is changed every 100 to 125 hours. Oil filters are changed with the oil; air and other filters changed as recommended by the manufacturer. For any items changed on the basis of hours of use the for determining hourly cost is (James 1989).

Hourly cost = Replacement cost / Hours between replacement

the quantity of lubricating oil used by engine will vary with the size of the engine, the capacity of crank case, the condition of piston rings and number of hours between oil changes. The quantity of oil required is estimated by the formula (Nunnally 1980).

$$Q = \frac{hp \times F \times 0.006\ lb/hp/hr}{7.4\ lb/gal} + \frac{C}{T}$$

Where **Q** is quantity consumed in gal/hr

hp is the rated hours power of engine

C is the capacity of crank shaft in gal

F is the operating factor

T is the number of hours between changes

To maintain this there is a need for service, service cost represent the cost of hydraulic fluids, grease, as well as labour required. These costs are related to equipment size and severity of operating conditions. Rough estimate of service cost may be made based on the equipment fuel cost (**from 20-50% of fuel cost**) (Nunnally 1980).

3.6 Down-time Cost

Down-time is the time that the machine is not working (equipment breakdown). In order to compensate for the equipment down-time it is necessary to have an extra equipment available at the job site or on call to maintain the plant production rate (Nunnally 1980).

On the anther hand productivity is a measure of the ability of equipment to produce at its normal rate. The down-time (breakdown) decreases the production, increasing its cost, for example, if the equipment has a down-time of 5%, it will increase the operating cost with 10%. (Peruifoy 1985).

3.7 Obsolescence Cost

The increasing of the productivity by replacing the old machine with a new one is referred to as obsolescence cost. In term of money if a new machine will reduce production cost by **5%**, compared with production cost for an existing machine, the existing machine will suffer a loss in value to **10%**.

During recent years the increase in productivity of construction equipment has averaged about 5% per year. Similar to the down-time cost, the obsolescence is equal to 10% loss in the production times hours of operation per year time the cost per hour (Peruifoy 1985, Nunnly 1980).

The cost of investment, can be calculated as follows (Peruifoy 1985).

1) If the item of equipment is purchased using company's assets, an interest rate should be charged equal to the rate of return on company investment. Thus, investment cost is computed as the product of an interest rate multiplied by the value of the equipment, then converted to cost per hour

2) Using the average value of the equipment during that year

Average investment = (Initial cost + salvage value)/2

It is common practice to combine the cost of interest, insurance, taxes and storage and to estimate them as a fixed percent of the average value of the equipment. It is usually **10%** interest + **5%** insurance, taxes and storage (Peruifoy 1985).

In recent years, it is exceeded 20% because of the inflation and the interest rate.

Investment cost could be represent into a present worth formula taking in account the deduction of the depreciation, for each year that equipment is used, from its annual earnings (Peruifoy 1985).

Where

$$P_W = \frac{P + \frac{(P-S)}{N} + S}{2}$$

$$= \frac{PN + P - S + SN}{2N}$$

$$= \frac{P(N+1) + S(N-1)}{2N}$$

P_w is the present worth (average value)

P is the total investment cost

S is the salvage value

(P-S)/N is an average value