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Development of Expert Systems In Structural Engineering

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1.0 Introduction

Computers are increasingly being used in all facets of architecture, engineering, and construction (AEC) industry. Early application centred around the tasks of structural analysis, -later high speed batch mode computations, man-machine interaction with Graphic user Interfaces and logic programming with fifth generation languages took over the scene.

The availability of new computer technology is responsible for initiating significant changes in the AEC industry. For example, the development of Artificial Intelligence (AI) techniques during the 1970's have provided a new set of tools for supporting the analysis and design of structures. AI techniques are being used to develop expert systems which differ from conventional programs in their ability to process non-numerical data and express procedures in more understandable 'English' like rules. This potential of expert systems was initially used to develop an expert system MYCIN (Buchanan and Shortliffe, 1983) for medical diagnosis.The diagnosis and interpretation problems in structural engineering open up possibilities that were not conceivable with conventional programs. The potential impact of expert systems is in providing advice in the areas of design process where conventional computer aids fail.

Engineering process is basically a decision making process. The engineer must be creative, imaginative, using his judgement, intuition and experience. Knowledge-Based Expert System (KBES) are "interactive computer programs incorporating judgement, experience, rules of thumb, intuition and other expertise to provide knowledgable advise about variety of Tasks".

The reasons for using expert systems in structural engineering are the same as for using any type of automation: using less skilled personnel, quicker and more reliable solutions.

Knowledge Based Expert System being developed in the field of structural engineering may be broadly categorised as systems dealing with :

- Design of structures dealing with either one or more of the following tasks :

  a) layout or configuration design
  b) structural design conforming to particular standards or practices
  c) design detailing

- Assessment of strengh of structures and recommendations on strengthening/repair
- Modelling of structures for analysis (say, analysis by using the finite element method)
- Construction Management

The salient features of the above mentioned types of KBESs have been brought out in the lecture notes through a brief description of a few typical systems developed. Development of expert systems for engineering applications can be facilitated by efficient data base management techniques and other software tools. It may be noted here that engineering data bases consist of both graphical and textual data which are interrelated.

In order to improve the productivity of the construction industry as a whole it is necessary to have an integrated approach in the development of computer software spanning the area of Architecture, Engineering, and Construction. Efforts are being made to develop knowledge based systems for structural engineering to meet this need.

To start with the basic architecture and components of a typical expert system are presented.

2.0 Main Components Of A Typical KBES

A schematic of the basic architecture of a typical KBES is given in Fig. 1. (Aravind et. al 1988)

The main components of a typical KBES consist of the following :

- Knowledge base
- Context
- Inference Mechanism
- User Interface Module
- Explanation facility
- Knowledge Acquisition Module

3. Steps In Expert System Development

The six main stages of building of an expert system may be stated as follows:

- Initial Problem Assessment
- Establishing a structure
- Prototype Building
- Evaluation, model refinement
- Tests with end users
- System adjustments and end release

3.1 Tools For KBES Development

A broad classification of the tools that may be used in the development of an expert system is given below (which includes examples).

Logic Programming (PROLOG),
Production system Programming (OPS5, EMYCIN),
Object Oriented Programming (Smalltalk, Flavors, C++),
Hybrid language programming (ART, KEE, LOOPS), and
Shells (VP Expert, Insight II, M.1, Deciding Factors).

In addition, for an engineering design database, the system must be able not only to manage effectively the design data, but also model the objects composing the design. Therefore tools are required for management of complex engineering objects in a sharable, relational framework.

4. EXPERT SYSTEMS IN STRUCTURAL ENGINEERING

4.1 Structural Design

The structural design process starts with the definition of need to transmit loads in space to support or foundation subject to cost, geometry and other criteria. The final product of design is a detailed specification of structural configuration capable of transmitting these loads at appropriate levels of safety and serviceability. The design process (Fenves 1981) may be viewed as a sequence of three distinct steps namely preliminary design, analysis, and detailed design. Both preliminary design and detailed design belong to class of ill-structured problems as they require engineering heuristics and different problem solving strategies at different levels of design, hence they are more amenable to the use of expert system. Two early developments in this area are briefly discussed below.

4.1.1 *HI-RISE* (Maher Fenves 1986) is an expert system for preliminary design of high rise residential and commercial buildings which are rectangular in shape.

HI-RISE configures and evaluates several alternative structural systems for a given three-dimensional grid. The expertise in HI-RISE is derived primarily from a book on preliminary structural design (Maher and Zhao 1986) containing approximate analysis techniques and applicable design heuristics. The knowledge incorporated in HI-RISE is appropriate for buildings between 5 and 50 storeys (Garret and Fenves 1987)

4.1.2 *SPEX* (Standards Processing Expert) (Garret and Fenves 1987) is an ES for component design. SPEX can only design components that are highly constrained either by the requirement of design standards or externally specified constraints. It can design nonprismatic structural components and connections.

4.2 Expert systems for diagnosis

An expert system IRAS (Insurance/Investment Risk Analysis System) has been developed at Stanford University, USA., to assess seismic risk of buildings and structures. Evaluation of the hazard (earthquake) potential, vulnerability of the exposures (buildings and structures) to the hazard and evaluation of the risk of exposures based on their responses to the hazard, constitute the three basic phases of this system.

4.3 Expert systems for analysis

Analysis is a process of determining response of a fully specified structure to its environment. The most highly developed method of the analysis is the finite element method (FEM). There is a need for modelling an increasingly wider range of physical performance phenomena in all stages of system design. The primary functions of the analyst is to model the problem. KBES shows the promise of providing a methodology for such FEM modelling. The expert system for FEM modelling can be viewed as an intelligent pre- processor, in the sense that it acts as a knowledge-based front to the algorithmic programs. An early precursor of analyst expert system is SACON (Bennett and Englemore, 1979).

4.4 Expert systems in construction management

Construction management addresses planning, scheduling, and control of construction activities as well as deciding on legal, behavioral, and other nonphysical elements of the construction process. An application in this area is described below.

4.4.1 *TIME* (Gray and Little 1986) Predicting Time and Cost of Construction During Initial Design. The construction industry is somewhat unique in that the process of design and manufacturing are separated. Generally speaking, the ease of manufacture and assembly of a building is not considered in the design process, because the designer may not have the knowledge needed for consideration. In addition, evaluation of different methods of design requires prompt feedback regarding their time and cost implications. This expert system was developed to help designers evaluate different construction methods, designs, and processes to determine their effects on time and cost of construction.

5. Expert Systems development at SERC

Structural Engineering Research Centre (SERC), Madras has been involved in the development of software for analysis and design of structures. Realising the need for knowledge-based tools in structural engineering, SERC has initiated projects in this direction. The following knowledge-based systems have been developed :

a) EXTASY (EXpert Tower Analysis and design SYstem)
b) KASTLE (Knowledge-based Analysis and Synthesis of Transmission Line towErs)

An expert system on design of cooling towers is being completed. A brief description of these systems is given in the following.

5.1 *EXTASY* (Murlidharan, et.al. 1991a,b) is a system built using some of the knowledge-based programming concepts. To capture heuristics of design experts, KBES methodology was found appropriate. EXTASY's domain of expertise is configuring and design of free-standing steel lattice microwave towers based on the Indian Standard Codes of Practice (IS:800-1984, IS:802-1974). The scope of EXTASY is limited to design of microwave towers. EXTASY has several Knowledge Modules (KMs) which communicate through a Blackboard (Nii, 1986) and are controlled by an Inference Mechanism. The Blackboard of EXTASY is divided into three segments, namely the Coordination segment, the Working segment and the Decision segment. The knowledge base is divided into several levels and these levels provide a methodology for organizing the problem solving activities. These levels are comprised of knowledge modules which perform various tasks in providing a solution to the problem. In EXTASY, knowledge modules are classified as i) Configuration Processor; ii) Analyser; iii) Designer; and iv) Critic. Given a particular design problem EXTASY will generate alternative feasible designs. Also the system will provide the following information about the designs which will be displayed to the designer: i) Profile of the tower indicating the number of changes in the slope of a tower; ii) number of different types of standard sections required; iii) number of joints; and iv) the types and sizes of the bolts adopted. The designer can then finalize his decision based on weight of steel involved, fabrication cost and ease of construction. KASTLE (Raman et. al. 1989) is a similar system where the domain is design of transmission line towers. Both the systems are implemented on IBM PC-AT with MS-DOS. The languages used are PROLOG, FORTRAN and BASIC.

5.2 Cooling Towers

The development of an Expert System for the Design of Natural Draught Hyperboloid Cooling Towers has also been initiated (Pandian and Appa Rao, 1991). The KBES makes use of the results of statistical analysis of the data relating to the geometrical details of different existing cooling towers. Adequate knowledge is also incorporated for thermal design of the tower. Computer programs for analysis and design of cooling tower shell and its foundation, support the KBES to arrive at the preliminary design of the cooling tower. The codal provisions related to the structural design such as wind load distribution on the tower, minimum thickness and reinforcement details have been incorporated in the knowledge base. Graphic routines have also been integrated with the KBES to visualize the geometry of the tower, the plots of stress resultants and reinforcement details. The KBES will give the quantity of concrete and steel for the finalized design. The KBES is built around the VP-Expert shell.

6.0 Scope for Future Work

There is considerable scope for developing special purpose software tools such as shells to facilitate development of expert system for structural engineering applications. It is essential to develop efficient DBMS techniques to deal with graphical and textual information. There is considerable scope for research to formalize knowledge sharing between architecture, engineering, and construction activities.

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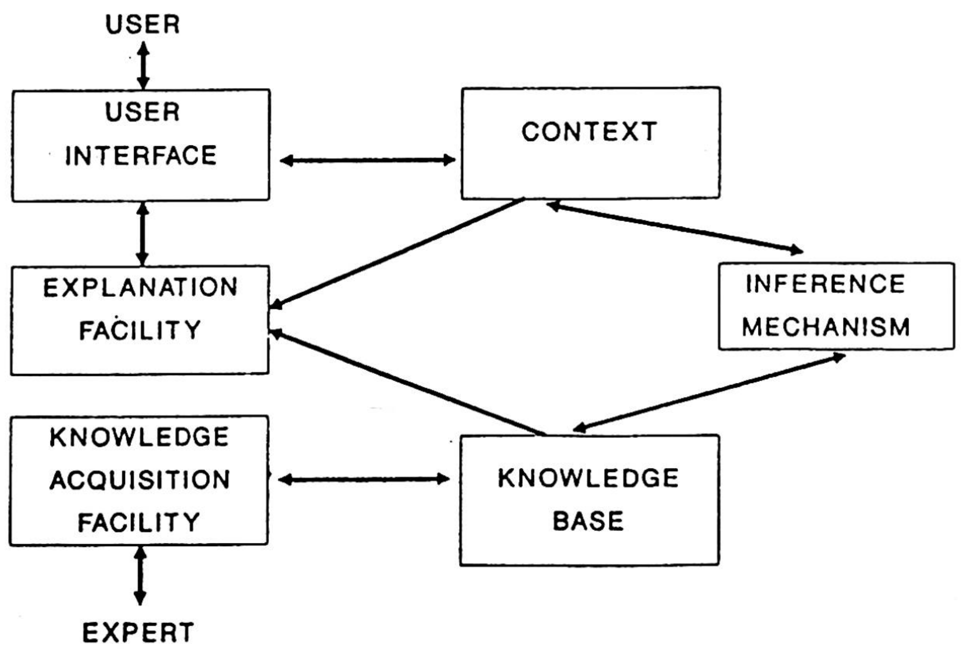

Fig. 1 ARCHITECTURE AND COMPONENTS OF A KNOWLEDGE-BASED EXPERT SYSTEM

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