ARCHITECTURAL EXPERT SYSTEMS: DEFINITION, APPLICATION AREAS, AND PRACTICAL EXAMPLES

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ABSTRACT

Knowledge Based Expert Systems (KBES) have emerged as a new tool for decision making in scientific disciplines. From the definition of the term and from previous experiences in geology, computer science, engineering, and medicine, it seems that they could develop into an important tool for architectural design and the building industry. This paper gives a very general overview over existing expert systems and potential application areas in architecture. It then presents in more detail two of the prototype systems that are under development in the Department of Architecture at Carnegie-Mellon University to gain practical experience.

INTRODUCTION

Experience has shown that from introducing a new technology into the design profession (i.e. Computer Aided Drafting) to the point of widespread utilization a time span of at least 10 years is required. In addition, affordable state-of-the-art CAD programs still do not include many of the features that were envisioned 15 or 20 years ago.

Now Knowledge Based Expert Systems are introduced, based on research and techniques developed in disciplines other than architecture. Will it again take 10 years until some practical impact can be felt on the profession? The hypothesis of this paper is that this time the new tool can be used much quicker and more successfully by the design and building industry related professions. This is primarily due to three reasons:

1. The new techniques utilize the same medium - computers - that already exist in many offices.

2. The paradigm shift from problem solving approaches to knowledge driven approaches in

programming could help bridge the gap between the computing and the design environments.

3. The characteristics of the new tool almost designate it to be used in design and performance related issues.

The following definitions try to substantiate these assumptions.

1. EXPERT SYSTEMS - GENERAL

1.1 Definition

Knowledge based expert systems are interactive computer programs incorporating judgement, experience, rules of thumb, intuition, and other expertise to provide knowledgeable advice about a variety of tasks. For specific domain applications, they can reach the level of competence displayed by human experts [8]. This could give them a role as design consultants. The main parts of a Knowledge Based Expert System can be seen in figure 1.

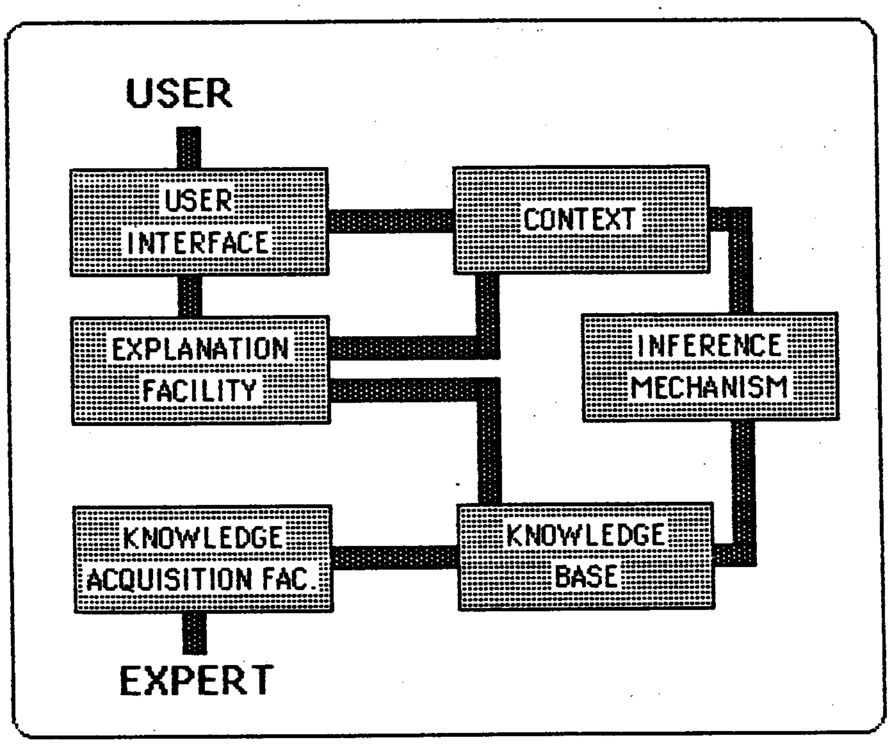

FIG. 1 : SCHEMATIC VIEW OF A KNOWLEDGE BASED EXPERT SYSTEM (KBES)

1.2 EXAMPLES IN OTHER AREAS

Large scale expert systems have been successfully used for the typical derivation tasks of monitoring, interpretation, diagnosis, and design. Examples are "Ventilation Manager", a program monitoring a patient's ventilation therapy, illustrating a monitoring application; "Prospector", a system for identifying geological ore-bearing formations, an example of an interpretation application; "Mycin Puff", a system for diagnosing blood infections and menengitis infections and for recommending drug treatments, illustrating a diagnosis application; "RI" for the configuring of VAX computer systems, illustrating a restricted type of design application.

1.3 Selected Representation and Control Strategies

A number of representation paradigms have been developed to present the knowledge base in Expert Systems. It would be impossible to list them all at this point. The selection of appropriate representation and control strategies for the architectural domain is evolving as a research area. The following strategies are selected because they seem to be relevant to the architectural context after a first evaluation [1,2,4,5,8,9,10,11]

A popular tool is the **production system** which contains production rules. The production rule paradigm assumes the existence of pairs of symbols with a left hand side (LHS) and a right hand side (RHS). The LHS symbols represent the conditions, the RHS symbols represent the appropriate actions. Other important parts of the production system are the inference mechanism and the context. The use of the production rule representation in the software prototype described below was based primarily on software availability. Semantic network representations emphasizing relations, and the schema representation emphasizing object description, are especially interesting in the architectural context and will be explored in the future.

A set of control strategies used in Knowledge Based Expert Systems is specifically applicable for architectural design problems. If all or a large number of facts are given for a design problem, the system can deduce a hypothesis that fits most of the facts by using **Forward Chaining** (data driven approach). For an existing design - i.e. the design hypothesis is given - **Backward Chaining** can be used to check if the hypothesis can be supported (hypothesis or top-down approach). Modified versions of the **Plan-Generate-Test** approach are used if all the possible solutions are of interest. To eliminate solutions of no interest, the search space is pruned during the plan stage by applying constraints.

1.4 Tools for Architectural Expert Systems

There are no special tools to build architectural expert systems at the moment. There are, however, three possibilities to adapt more or less general techniques developed in and for other domains to build architectural expert systems:

1. Expert System Frameworks. These are inference mechanisms with an empty knowledge

base. Examples are EMYCIN [12], Expert Choice [4], or M1 [11].

2. Representation Languages, languages developed for Knowledge Engineering. Examples are OPS5 [5], and SRL [13].

3. General purpose programming languages such as Fortran, Pascal, Lisp, or Prolog. Lisp is used mainly in North America for its symbolic computation capacities, whereas Prolog is preferred in Europe.

For the inexperienced user, Expert System Frameworks are the easiest to start with, but KBES based on general purpose representation or programming languages are more versatile. This observation is based on teaching experiences where OPS5, Prolog, and SRL were used to solve the same design problem.

2. APPLICATIONS OF EXPERT SYSTEMS IN ARCHITECTURAL DESIGN

One of the main advantages of expert systems over conventional deterministic programs is their capacity to offer solutions to ill defined problems by using knowledge driven approaches and to combine quantitative and qualitative methods. Architecture and design are disciplines that can benefit most from this development because rarely is a design problem defined to an extent that only one solution could be expected. This applies particularly to the planning, design, and performance evaluation phases of a building. A few examples for expert systems applications in each of these domains are listed below.

2.1 Planning and Design

In the early planning and design phase a large number of high level decisions must be made. Their validity is often limited by the channel capacity and short term memory of the human brain. A number of expert system building frameworks exist that could support the early planning and design phase. Programs like M1 [11] or Expert Choice are microcomputer examples that allow a relatively quick construction of a knowledge base and provide an inference mechanism. Priorities for certain decision alternatives are derived by calculating eigenvalues and eigenvectors of matrices representing pairwise comparisons of criteria and alternatives [6]. The higher the level of the decisions, the more idiosyncratic the character of the knowledge base will be, displaying the individual experiences and judgements of the decision maker. The process of formalizing symbolic knowledge with the intent of later applying it to a variety of problems is a relatively easy task with expert system building frameworks.

The lower level decisions, often specialized or detailed design decisions, can be supported by general purpose representation languages such as OPS-5, SRL or PROLOG. Applications might be the selection of the structural and mechanical systems, materials and windows, contractors and suppliers. The knowledge bases for these applications will contain hard facts and deep knowledge if the form of proven algorithms, but also user specific knowledge and personal judgement. The value of such systems depends to a high degree on the quality and on the actuality of the knowledge base and the user's capacity to judge the results. Explanation modules are therefore a necessary part of the system.

Generally, knowledge based systems in the planning and preliminary design stage will be of mainly generative character to produce a set of solutions. In the design stage, the character of the expert system will switch towards interpretive and diagnostic approaches.

4.2 Building Performance and Facilities Management

Upon the completion of a building, the facilities management and building performance evaluation processes begin. Both issues are of growing importance, especially building performance evaluation as a multifacetted field. It was shown that any isolated approach to building performance bears little validity with respect to the overall building performance [10]. Thus, knowledge based systems are necessary which:

1. Choose the analysis method or program for a specific evaluation.
2. propose which parameters should be input for a specific evaluation.
3. interpret the results of the evaluation and relate them to previous findings of other simulations.

The levels of measurement, the test procedures, and the evaluation thresholds for performance criteria are interrelated issues which offer an ideal application field for KBES.

Knowledge Based Expert Systems in the Facilities Management and Building Performance areas will have monitoring and diagnostic character. An important by-product of monitoring building diagnostics is the formulation of new rules. The new rules could be added to the knowledge base of the generative systems in the design phase, thus providing an important feedback function that is lacking at the present.

3. PROTOTYPE DEVELOPMENTS: KBEDES1 AND KBEDES2

3.1 KBEDES1

KBEDES1 was developed in early 1985 and consists of three parts:

1. The expert front end - a program that uses rules extracted from "Energy Graphics" [2] as its main knowledge base. The program accepts user input for the design of a residential building and judges whether or not the building in the given form is recommendable for

the specified location and orientation. The program is written in OPS5 and runs on a VAX 11/780.

2. The graphics program DDD. It allows the user to graphically edit the output of the expert system. Once satisfied, this program produces an output file that is used as the input file of the energy analysis program. DDD is written in TURBO PASCAL and runs on the IBM PC/AT.

3. The energy analysis program. The EEDO program was chosen to simulate the energy consumption of the proposed building more exactly. All necessary geometric input for EEDO is automatically generated by using DDD as the graphic front end. EEDO is written in BASIC and is the IBM PC version of the CIRA program developed by the Lawrence Berkeley Laboratory.

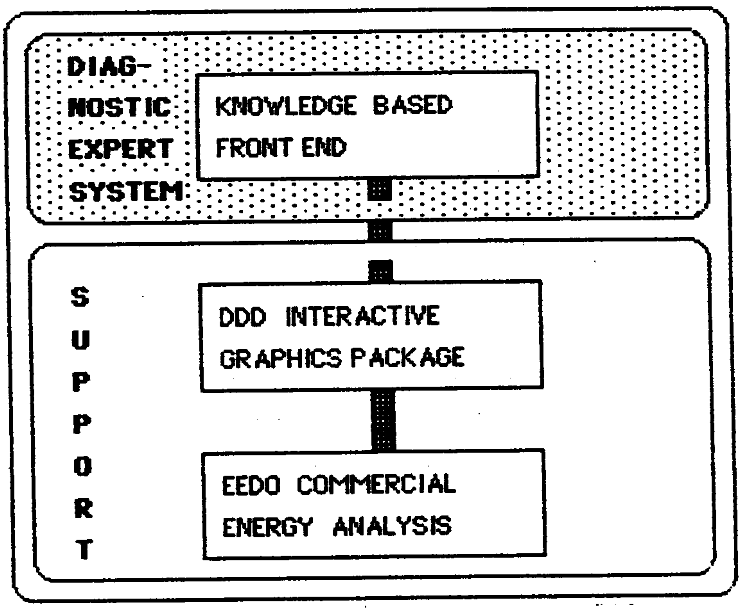

FIG. 2: KBEDES 1

The knowledge based front end is the only KBES component of the system. The user makes high level choices concerning size, orientation, windows, U-values, and number of occupants. The expert front end then determines the quality of the input with respect to passive solar design considerations. Once the expert front end "agrees" that the input follows the guidelines extracted from Energy Graphics, the resulting building can be drafted with DDD and its exact performance is simulated with EEDO.

3.2 KBEDES2

Experiences with KBEDES1 support the assumption that expert systems for restricted domains - such as specific steps in the design process or specific building types - are easier to implement for beginners and yield more satisfactory results than very general systems. Therefore, energy related design considerations for one building type - small office buildings - were chosen for KBEDES2. The "Small Office Design Handbook" by Burt Hill Kosar Rittelmann [3], winner of the Progressive Architecture Applied Research Award in 1985, was selected as the primary knowledge base, i.e., the experiences, rules of thumb, and measured data contained in this book were used to construct the rules for the two expert systems in KBEDES2. To explore the possibility of further integration with other building data or firm-specific experiences stored in commercial databases or spreadsheets, dBase III and LOTUS 1-2-3 were added to the system. Energy simulations are still performed by EEDO but will be replaced by a program better suited for the simulation of office buildings. KBEDES2, then, has six components:

1. One generative expert system containing general design knowledge in form of rules. It is written in OPS5 to run on the VAX 11/780. It is presently rewritten in TOPSI, the IBM PC version of OPS5 in order to be compatible with the other parts of KBEDES2.

2. A GKS (Graphics Kernel System) based graphics package, implemented in C and using the professional graphics board of the IBM AT for highest resolution, featuring two and three dimensional graphic presentation of the building design.

3. A commercial relational database management system, dBase III. It communicates with the other programs via its .DBF files.

4. A commercial spreadsheet program, Lotus 1-2-3. It communicates with the other programs via its TRANSLATE utility (.DBF files for dBase III and .DIF files for the other programs).

5. A diagnostic expert system. Its knowledge base contains rules about small office buildings extracted from the Small Office Design Handbook. It is written in OPS5 and presently rewritten in TOPSI for compatibility reasons.

6. The EEDO energy analysis program, soon to be replaced by an office simulation program.

The new system offers several advantages over the first prototype: one knowledge base includes general design knowledge. A diagnostic knowledge base contains rules compiled for small office buildings. Preparation of data or input is intended to be done through the database or spreadsheet programs. All programs run on one machine and are to a certain degree transportable. Results of energy simulations can be stored in the database, and - if enough evidence for a certain trend is collected - can be added as a new rule to the diagnostic or generative expert system. See figure 3.

The main advantage of KBEDES2 over conventional simulation programs are twofold: first, the generative expert front end prevents the user from choosing and simulating a design that is completely insensitive towards energy considerations - or, if he insists in doing so, he will know the cost of his decision. Second, the generative expert front end offers the possibility to gradually refine and complete the knowledge base by adding more rules, thus personalizing the system.

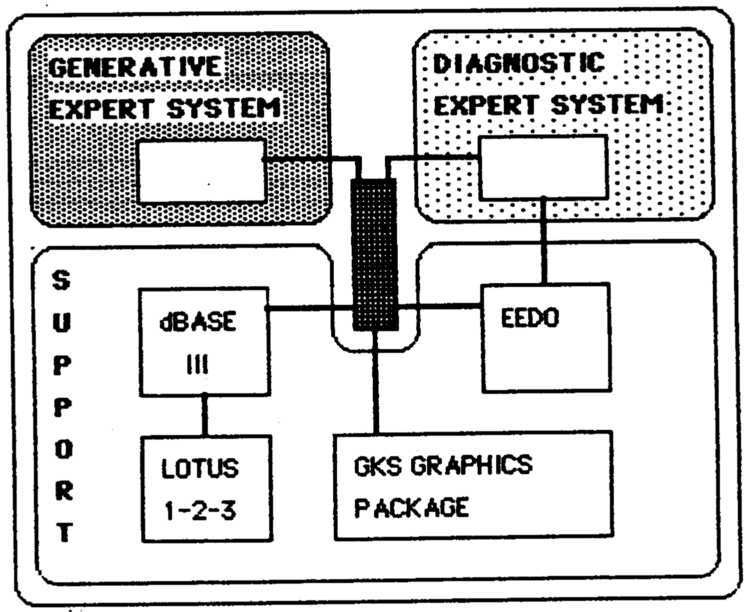

FIG. 3: KBEDES 2

KBEDES2 is not intended to be a complete product but a test vehicle. It has proven most useful in discovering unexpected problems - such as data transfer between commercial and research programs, graphics presentations using data in the working memory of rule based systems, and user's reactions to the new tool. It has also shown that the RAM capacities and execution speed of even the top Personal Computers would need an improvement factor of at least 10 to satisfy an impatient designer's needs.

4. CONCLUSIONS

The limited experiences with KBEDES 1 ans KBEDES 2 support the assumption that the advent of Architectural Expert Systems in combination with advanced computer equipment could bring a paradigm shift in architectural computing in a direction that is closer to the human design process than any previous techniques. The sophistication of the systems could soon reach a level that they adapt to the user rather than the user to the system - which is the present situation and the reason for much of the animosity against the new tool.

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