TOWARDS AN INTERACTIVE INTELLIGENT KNOWLEDGE BASED SYSTEM FOR BUILDING DESIGN

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Abstract

In recent years, attempts have been made to assist designers in performing design tasks through the use of computational methods. A first step toward Computer aided design of buildings must be greater employment of rationality and systems in the field of building design, which traditionally have been more generally associated with artistry and individually.

During the past decade, there has been a general enthusiasm regarding a potential break-through in Computer Aided Design due to the introduction of Artificial Intelligence technologies. The successful development of Knowledge Based Systems (KBS) has been largely responsible for this enthusiasm, given its applicability in the design domain. Knowledge Based Systems are computer systems that advise on or help solve real world problems which would normally require a human expert's interpretation .

This paper approaches Knowledge Based Systems as interactive computerized tools for building design. The concept, structure and implementation of KBS in building design are illustrated. The potential benefits of KBS to assist designers in achieving their goals are presented.

1. Nature of Architectural Design

In a typical architectural design problem, specific functions of a desired building are given; and the architect attempts to generate a structure that fulfills the functional requirements within a framework imposed by constraints such as cost, space and environment. The design process begins with a set of sketches, in which the architect tries to solve the dominating design problems, and evolves upward into working drawings and three dimensional models. During the evolutionary phases of the design process the structural concepts developed in the initial stages are refined, but rarely altered (Kramel and Rogers, 1978).

Architecture is concerned with much more than numerical descriptions of buildings. It is concerned with concepts, ideas, judgment and experience (Gero, 1986). Unlike many areas as disparate as medicine and structural engineering, design, and architectural design in particular, contain no theoretical core or at least no generally accepted theoretical basis. It is, therefore, not surprising that computer aided architectural design has received little attention except from those who have posed a model of the design process (Gero, Radford, Coyne and Akiner, 1985).

The world of design is the thoughts in the heads of designers, plus the skills of designers in externalizing their thoughts. Bijl (Bijl, 1986) characterized design as follows :

(a) Design objects are subject to a diversity of expression. There are different perceptions of things and lack of agreed abstract definitions.
(b) The design process is not problem solving in the orthodox context i.e., from problem statements that reveal solution paths. There are conflicting criteria for validating results and many solutions to any design problem.
(c) Design knowledge: There is no formal, shared knowledge base. Design knowledge relies on integration of overt knowledge and intuitive knowledge and necessarily is made manifest in idiosyncratic design practices.

2. Design as an Information Process Concept

Design, in its broadest sense, is a discipline that formally recognizes our ability to influence the future and our responsibility to do so in the proper way. It is, therefore, a purposeful and conscious specification of the actions that must be taken at the present to attain some desired future conditions (Kalay, 1992). The word design itself is used with at least five different meanings. First, design is often taken to be synonymous with design artifact, that it, the object itself. Design can mean the set of instructions prepared by the designer(such as drawings, specifications, manufacturing instructions and so on) which are used to construct the object. Sometimes when we speak of design we mean the overt activities which designers go through in order to produce the artifact (such as discussions with the clients, preparing sketches and finished drawings, making planning application and so on). Again design occasionally means the overt inner mental process that designers use to envisage the concept. Finally, design can mean all of these rather different things (Lansdown, 1986). This is not surprising since design usually, is a very differentiated process consisting of e.g. problem definition, surveying, searching for alternative ways of actions, estimating and decision making as shown in Figure [1]. Aspects to be considered are manifold, as well as their interdependencies. A decision concerning a specific design component usually has implications for many other components (Groh, 1978).

3. Approaches of Architectural Representation

Every attempt to represent reality is a form abstraction. The only true representation of reality is reality itself. Abstraction requires an agreement on certain conventions. The higher the level of abstraction, the more conventions that must be agreed on. One form of abstraction consistently used in architecture is the model. This includes not only physical models, such as working models and final presentation models, but also geometric or mathematical models.

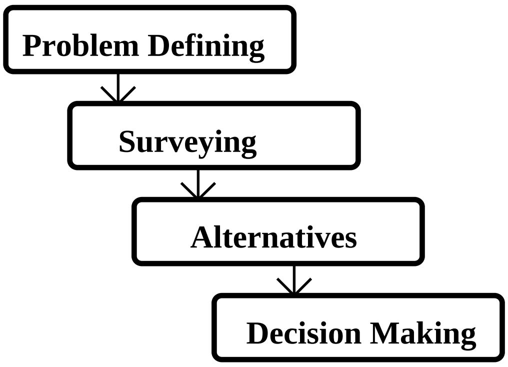

Figure [1] Design Process

These mathematical models are most important for the use of microcomputers in the design process because they allow communication between the physical world and the computer. The use of models in architectural design has a long history. In fact, no successful design process is possible without a model that is common to all participants. Representations of traditional architectural models are plans, sections, elevations, and perspectives. The three dimensional model with all relevant attributes, objects, and functional information is only mentally recorded by the designer. Drawing the projection of the model, that is, its representation, requires coordination and the knowledge of the laws of projection. The real power of computers will only become obvious once a similar body of knowledge and experience resides with the computer (Schmitt, 1988).

4. Design Goals

The conceptual tasks facing any design professionals are the definition of design goals, the creative generation of solutions, and their judicious evaluation to assure their satisfactory response to the defined goals (Kalay, 1992). An intelligent building is a building which is able to provide service corresponding to the actual and future needs of the users within an optimal cost and allowing good conditions for life and work (Filloux and Rubinstien, 1989). The major problem in achieving goals is the interdependence of goals and subgoals. There are different systems that handle goal interaction. The more efficient KBS is explicit, accessible and flexible. It is desirable that the knowledge contained within it is clear and legible (Coyne, 1985).

5. Design Intelligence

The objective of design intelligence is to interpret the world around us and make meaningful decisions toward a design goal. In traditional design the external medium acts as a temporary or permanent storage device for design ideas. We interpret the drawings by looking at and drawing a meaningful conclusions from it. The semantic content is entirely supplied by the designer. Computers and computer programs, on the other hand, cannot simply look at the same external design representations and produce conclusions. In order to do so, they must be equipped with extremely sensitive vision systems and excellent domain knowledge. Both requirements are far from being met (Schmitt, 1988).

6. Creativity in Design Via Computer

It becomes necessary to demystify some of the traditional notions about design and creativity. This not to say intentions are to completely formalized and computerize creativity; this would be a contradiction in terms. But it is necessary to explore design and the processes that lead to new, creative design solutions, as systematically as possible. Only then it will be possible to take advantage of the computer beyond its being a mere drafting tool. Knowing that the following definition of creativity as shown in Table [1] will cause controversy, it will nevertheless be presented as a point of departure for better definitions:

Table [1] Architectural creativity definitions and their representation in computer terms.

No.	Architectural Creativity...	In Computer Terms,......
1	Depends on having a set of precedents in the envisioned domain.	Requires an intelligent data base of existing buildings and building elements with extraordinary indexing capabilities. This condition is close to being met by object oriented databases.
2	Depends on the designer's ability to explain the precedents and their reason for being.	This is related to the capacity of machines to perform abductive inferencing or explanation.
3	Relies on heuristics of finding applicable solutions of the past and adapting them to new design problems.	It is related to heuristic search and inductive reasoning.
4	Relies on the capacity of the designer or an external critic to ask questions	This capability has no equivalent yet. It is related to abductive and inductive reasoning and is almost the inverse of deductive inference.
5	Relies on the idiosyncrasy of individual designers.	This means the necessary building of idiosyncratic machines, or exposure to similar machines with different inductive processes.

Whereas the first three points show that the capability to learn, remember, and apply knowledge are necessary to be creative, the last two items demonstrate the necessity of questioning and individual discovery(Schmitt, 1988).

7. Techniques for Intelligent Computer Aided Building Design

The majority of Computer Aided Design (CAD) systems developed to date are not true design systems. They are in most cases mere draughting or analysis packages lacking the intelligence and creative faculty of the human designer. Due to the recent availability of massive computing power at relatively low cost, opportunities have arisen for building CAD systems with more genuine design abilities. These systems apply techniques drawn from the branch of computer science known as artificial intelligence (AI). The most promising techniques are those of expert system or intelligent knowledge based systems (Pham and Tacgin, 1991).

The general power of computer aided building design (CABD) should be to increase the expressive power of designers, enabling them to manipulate external representations of their own thoughts, relate those thoughts to knowledge of other people, and convey conclusions to other people (Bijl, 1986). CABD has been diversified since the design process encompasses so many decision making steps by architects. However, the segregated design decision making process frequently prevents achievement of effective evaluation of a building's final performance. Thus, Integration of isolated design decision support systems into a CABD is a crucial step toward responsible design (Kim, 1993).

Wang (Wang, 1993) dissertation explored the application of knowledge based system techniques to computational tool development for creative conceptual design. The investigation of engineering design focuses on the perspective of problem solving in a novel situation. A tool was designed to generate justifiable design concept alternatives which can satisfy the system input and functional specifications. Building the tool involved elements of :

- Knowledge representation in conceptual design
- Design process modeling
- Problem solving methodology
- Design creativity
- Domain knowledge application
- Design decision making
- Software engineering

8. Generic Expert System

An expert system is a system that employs human knowledge captured in a computer to solve problems that ordinarily require human expertise. Expert systems can also be used to propagate scarce knowledge resources for improved and consistent results. Expert systems are best known as self contained entities which exist quite separately from other computer aided design systems (Shash and Reffat, 1994). The choice of representation and implementation for an expert system must be based on the type of problem solving involved which typically falls into one or more of the following categories: interpretation; planning; design; teaching; knowledge acquisition / learning and theory information. At the language level there are several main types of representation such as: rule based systems; object oriented systems; logic based systems and mixed representation systems.

The state of the art in expert systems in design is such that while many experiments and prototypes have been built in all the above mentioned presentations, most experience has been gained with the rule based approach. A rule based approach can be viewed as a type of production systems which uses specialized kinds of knowledge structures, reasoning, mechanism and control strategies. The other important components of an expert rule based system are the knowledge acquisition and explanation subsystems. The overall generic architecture of such a system is illustrated in Figure [2] (Kulilowski, 1989). Rule based expert systems facilitate the representation of inferential knowledge in the form of rules and make it amenable to automation (Rosenman, 1990). The efforts of architects should not be to contribute to further developments of the computer and information technologies. These efforts can be best left to specialists. The greater responsibility would be to define the realms and rules of architectural design processes in the context of possibilities offered by these technologies. In this respect a parallel development of the design rule based systems will be a first step towards a fully integrated design information environment (Beheshti, 1989).

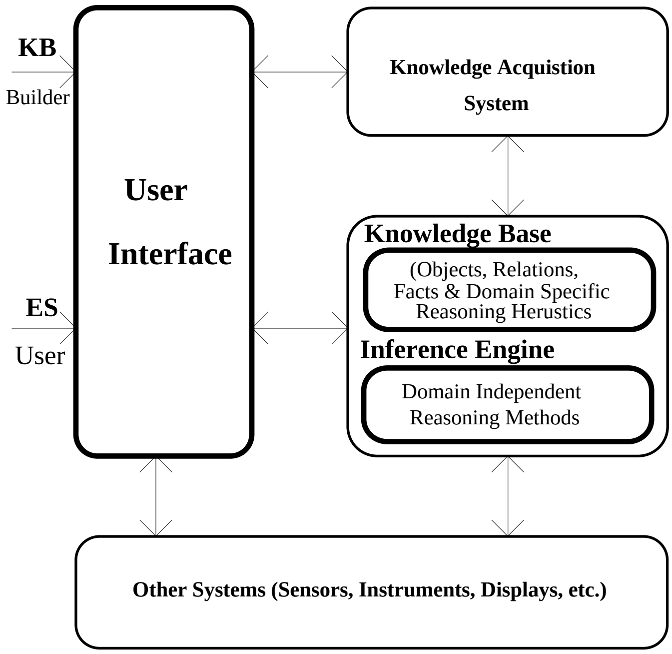

Figure [2] Architecture of a generic expert system

In fact use of stand alone Expert Systems (ES) is sometimes of limited applicability. This may be due to the fact that data required by the ES should be sometimes extracted from databases. Recall that the knowledge stored in the knowledge base of an ES is classified into three categories (Sharaf Eldin, Elkaraksy and Salamah, 1992):

- Declarative knowledge i.e., facts about the domain area of application considered,
- Procedural language i.e., the rules,
- Control language i.e., the strategy for obtaining solutions

9. An Approach of Knowledge Based Systems

In recent years, Knowledge Based Systems (KBS) have become increasingly popular computer software approaches used to solve a wide variety of application problems, in a scientific domain, that are sufficiently complex as to require significant human expertise for their solutions. KBS are more appropriate for use in solving semi structured or unstructured problems, i.e., problems for which a numerical model does not exist. The building design field, like many other multidisiplinary areas is full of ill-structured problems in which social, political, economic and technical consideration are involved. KBS are computer systems that advise on or help solve real world problems which would normally require a human expert's interpretation. Such systems work through problems using a computer model of expert human reasoning. Thus, they are designed to reach the same conclusion that human experts would be expected to reach if faced with a comparable problem (Reffat and Aref, 1994).

The structure of intelligent knowledge based systems generally consists of (Ericson, Ericson and Minoli, 1989): Knowledge Base, Knowledge acquisition module, inference engine, user interface and explanation of results as shown in Figure [2]. The Knowledge Base contains information from human experts in addition to facts provided by the user during interaction with the system. The functions of KBS components are illustrated in Table [2].

Table [2] Functions of Knowledge Based Systems components

No.	KBS component	Functions of KBS component
1.	Knowledge acquisition system	Is a software module that helps in the collection of knowledge for the base from the set of human experts
2.	Inference engine	Deduces knowledge that is not directly contained in the base, Turns the KBS into an interactive system with which the user can interact, Formulates questions and may understand answers provided by the user in a natural language, It is also the mechanism for conveying recommendations to the user
3.	Intelligent user interfaces	Employing an object - oriented environment, Allows efficient interaction with the user.
4.	Explanation part	Provides a description to the user of why the system asked for some information and how the system arrived at a specific conclusion

9.1 Prerequisites for setting up KBS

In setting up a KBS in any domain, four fundamental questions have to be answered (Lansdown and Roast, 1987):

- Is that portion of the domain to be assisted by the KBS appropriate to do this treatment?
- How do we acquire and test the requisite knowledge?
- How do we present the knowledge in a form that the computer can use, and that humans can check?
- How do we formulate the computing side of the system so that the knowledge can be properly brought to bear on the tasks that KBS is designed to perform?

Each of these interdependent questions is important and, therefore, for a useful KBS to be devised, all have to be addressed.

9.2 Framework of an Intelligent KBS

As has been pointed out, stand alone ES are, in certain cases, of limited usefulness. Perhaps the most common case is when the ES, during a consultation session, asks for data which is not readily available to the user. These data may be, however, extracted from some other DataBase (DB) Such a situation necessitates the integration of both ES and DB in a KBS. In fact, a great portion of the data on which decisions are based is historical in nature in and are usually stored in some external DB. In addition to this, DB being a well established technology, will enhance and enrich an ES specially in providing better interface (Sharaf Eldin, Elkaraksy and Salamah, 1992). Another approach of building an intelligent KBS is to create ES using database management system (DBM). The conceptual framework of both approaches is illustrated in Figure [3] (Chen, Sun and Hwang, 1993).

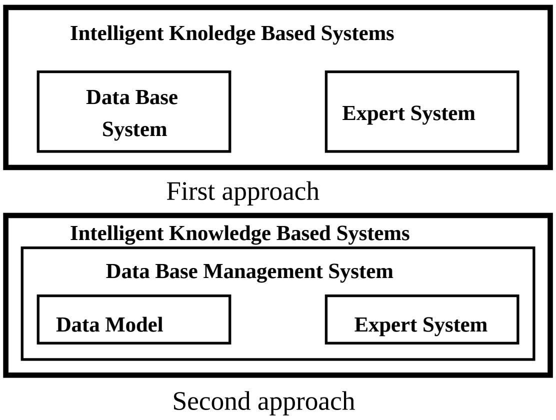

Figure [3] Conceptual framework of the intelligent KBS

The architecture of this intelligent knowledge based system is illustrated in Figure [4]. It contains three parts (a) the knowledge collection, (b) the database management system with a material database and user interface facility, and (c) the expert system shell with the developed knowledge base, an inference engine, and an user interface facility.

10. Knowledge Based Design Systems

Over the last two decades, knowledge based design systems have emerged as a new promising tool to facilitate design. These are founded on formal models of design which are developed using concepts from artificial intelligence, cognitive science, linguistics and operations research. Among the issues concerned in developing these models, two principal ones are:

- The organization and representation of design knowledge; and
- The processes which emulate design as an activity.

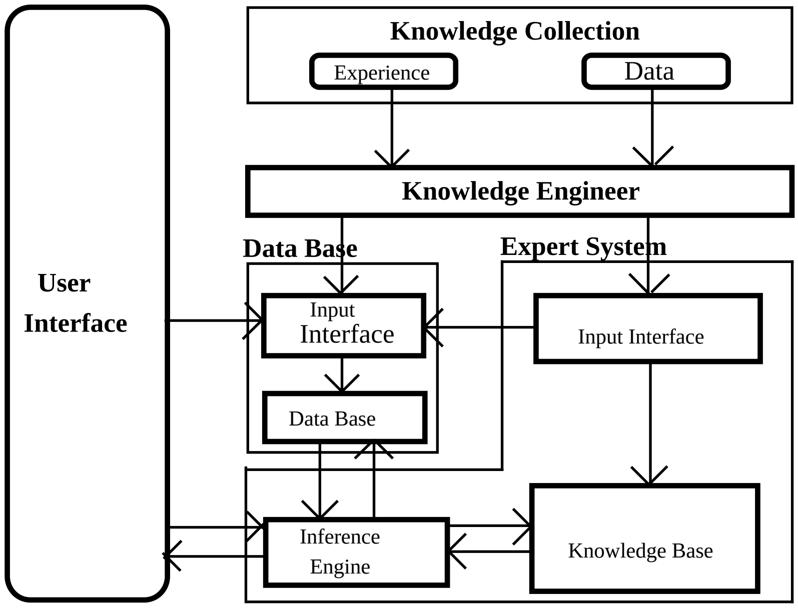

Figure [4] Architecture of the Intelligent Knowledge Based System

Both issues are intimately related: the nature and emphasis of the processes depends on the way design knowledge is structured, while the organization of design knowledge depends on the processes which are deemed most appropriate in characterizing the approach adopted. Although most existing knowledge based design systems organize their knowledge bases to include a library of components representing the artifacts and their components (structure elements) within their corresponding domains, and have carefully tailored processes to support designing based on the various approaches adopted, there are few that address the following issues in an integrated way (Tham and Gero, 1992):

- Provide suggestions as to how design commences or continues,
- provide a mechanism for reasoning between function and structure via behavior,
- Provide a satisfactory representation that comprehensively incorporates and integrates design knowledge to bestow sufficient expressiveness and power which support the above mentioned activities.

Tham and Gero (1992) developed such a system that utilizes design prototypes to produce feasible design within the category of routine design and whose acronym is PROBER (PROtotype BasEd Routine design system).

11. Towards an Interactive IKBS for Building Design

Referring to the Huang and Brandon approach (Huang and Brandon, 1991) to a knowledge based system for the design of a machine tool, each of a building design team is specialized in, and responsible for, one sub problem or aspect toward complete building design according the problem complexity decomposition. One perspective is that of aspects of building design including functions, environment, performance, aesthetic, form, structure, cost and maintenance as illustrated in Figure [5].

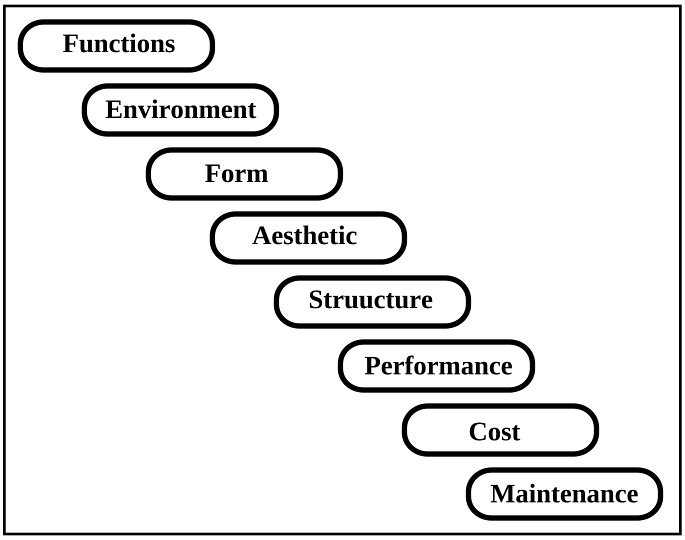

Figure [5] Problem Complexity Decomposition

The process of building design can be generally divided into four main phases: preliminary design, concept design, working design and detailed design. Preliminary design is a preparatory stage which is usually undertaken by human experts. Any decision must entail a stage of requirements processing termed the preliminary design stage. During the initial requirements stage, the design problem is defined, detailed and formulated. With the definition of input requirements, general strategies of problem solving can be recognized. The tasks of the preliminary design are globally represented as a flow chart illustrated in Figure [6]. The effects of two or more requirements, when they appear concurrently, are usually different from those when they are considered individually. Interactions (interdependence and conflicts) are involved.

Preliminary design results in the preparation of a set of design specifications which are well organized and formulated. Conceptual design is simply the interpretation of the feature design, to create overall building design, which consists of generic structures. The conceptual design of building design starts with functional design, process into structural design, and switches between them. Functional design is to transform the requirements into appropriate form functions and arranged in certain patterns. It is feature driven. The generation of functional pattern is usually mixed with the structural design. There are usually several ways of arranging the selected functions and structures into design representation patterns. The output of conceptual design is the release of design representation patterns which are represented symbolically. It is generally required that such a result be displayed on the screen for the user to carry out an intuitive evaluation for later design. However, computer graphics require strictly exact details about the geometry of an object. This is not satisfied at the conceptual level.

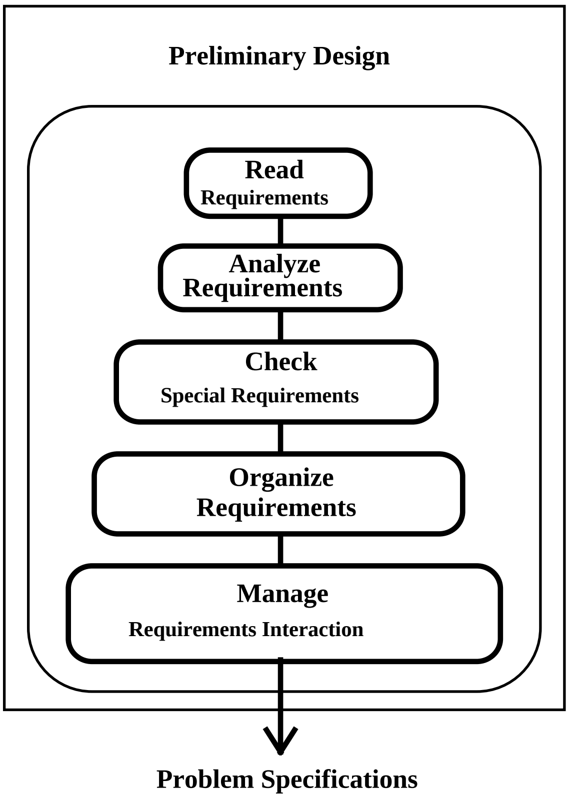

Figure [6] Preliminary Design - Requirements Processing

12. Conclusions

KBS have the potential for providing significant help to designers. However, it is possible to incorporate the potential to accommodate expertise and skills in the domain, if human experts are available. To this end, the general aspects of KBS specially for building design have been discussed on the basis of the literature in this field. Although a cooperative resemblance has been proposed, much challenging work remains for further research. Such an enhanced system will prove to be powerful in building design and in the modeling of the related decision making.

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