KNOWLEDGE-AIDED DESIGN SYSTEM FOR INTELLIGENT BUILDING DESIGN

YONG-SEONG KIM
Department of Architecture, Kookmin University
Chongnung-dong, Songbuk-ku, Seoul, 136-702, Korea

Abstract. In the age of information technology, architectural design problems become increasingly complex, the finding of optimal solutions has become more difficult and obscure. Computer-aided design techniques have been applied to solve these ill-structured design problems; however, most of these applications have been used for graphical automation. Design improvement in quality has not been achieved using traditional computer programs. To handle the critical design decision problems, design systems need to be structured based on theoretical problem solving models. This would enable the design system to handle the problem solving design knowledge as well as the various technological aspects and geometrical representations. A theoretical model, knowledge-aided design, is proposed. Knowledge-aided design is a conceptual and theoretical model based on fundamental principles of design. It provides a problem-solving environment and a procedure for knowledge-based computer-aided architectural design based on cognitive science and artificial intelligence techniques. As a partial implementation of the theoretical model, the development of knowledge-aided design system for intelligent building design is described.

1. Introduction

Current building projects become more complex in function and extensive in scale, the architectural design methods to design complex function buildings such as intelligent buildings need to be more sophisticated. Architects should handle complicated and extensive design problems to create more advanced building products. Architects also need to communicate and control the huge information and design data among large number of project teams.

The knowledge-aided problem solving design tools can be considered a possible way to relieve the architect from the tedious and time-consuming tasks. This would permit the architect to devote his efforts to the complex and obscure design problems. The knowledge-aided design tool could increase the productivity of architects in creating design solutions. To structure such a knowledge-aided design tool, we need a theory based on fundamental principles of design. In this paper, a theoretical framework of knowledge-aided architectural design method and implementation for intelligent building design is described.

2. Knowledge-aided design

Knowledge-aided design incorporates human cognitive processes to build a problem-solving model and theoretical framework. Then design system using knowledge-aided design is structured with components of design and the scheme of integration into a unified design process. The primary objective of the knowledge-aided design is to externalize and mimic the cognitive structure of the designers, so the system can be used in natural and convenient ways.

Architectural design is essentially an ill-structured multidimensional parallel process of creating space. None of the existing design theories explain or represent design processes and problem solving without several exceptions. Because intuition, a major factor of design, cannot be clearly defined or scientifically formulated, the proposed theoretical framework in this paper needs to have flexibility in its application to design practice and must include the consideration of intuition.

From the viewpoint of the theory of human problem-solving (Newell and Simon, 1972), and theory of information processing (Kim, 1994; Akin, 1986), architectural design is defined as a problem-solving process of creating physical environment that achieves design goals while satisfying many design constraints. The design problem-solving process can be represented as the state transition from initial state to intermediate states and then to final solution state through the searching process or the human designer can be represented as following these steps: 1. Design problems begin with the initial state, 2. Design problems process and advance through intermediate states which are represented by symbolic structures, 3. Design processors transform and change the states into other states, 4. Design processors utilize many search strategies and reasoning techniques to reach a solution state, 5. A final solution state can be produced. Using the knowledge-aided design method, the problem-solving model, problem-solving design knowledge, search strategies in design, and knowledge representation of design, are integrated into the design process.

3. Design Process

The problem-solving model begins with a design goal and need. A solution cannot exist without a problem; and a problem cannot exist without pressure or need (Kim, 1993; Archer, 1984). Architectural design involves a number of constraints groups. So, design problems become multidimensional and need highly interactive processes to solve problems. The design of a building includes a large number of different participants in design process such as clients, architects, contractors, mechanical consultants, electrical consultants, structural consultants, public and various kinds of officials, and so on. The phases of a typical architectural each participants of the project team and those generators of

design constraints create internal and external constraints (Kim, 1993; Archer, 1984). The designer seeks the solution to satisfy each goal and constraint in the course of the design procedure using various problem-solving methods in his brain.

A typical architectural project can be broken down into several standard and well-defined phases. The designer's normal responsibilities are clearly established at each step. The five major phases of a typical project are : 1. Conceptual Design and Programming, 2. Schematic Design, 3. Design Development, 4. Construction Documentation, and 5. Construction Supervision.

The constraints of the design procedure can be divided into the following five groups in each phase:

1. Economic: Budget. Efficiency, Operating Cost, Construction,
2. Sociological: Psychological, Spatial, Perceptual, Cultural,
3. Environmental: ecology, Topography, Geology
4. Functional: Space Program, Standard Plan and Detail, Circulation, Structural, Environmental Control System, Materials:
5. Aesthetic: Symbolic concepts, Scale, Proportion, Rhythm, Light, Color, Perception.

The role of knowledge-aided design is to consider and solve design problems and design constraints in each phase of design process using its mechanism.

4. Framework of Design Procedure

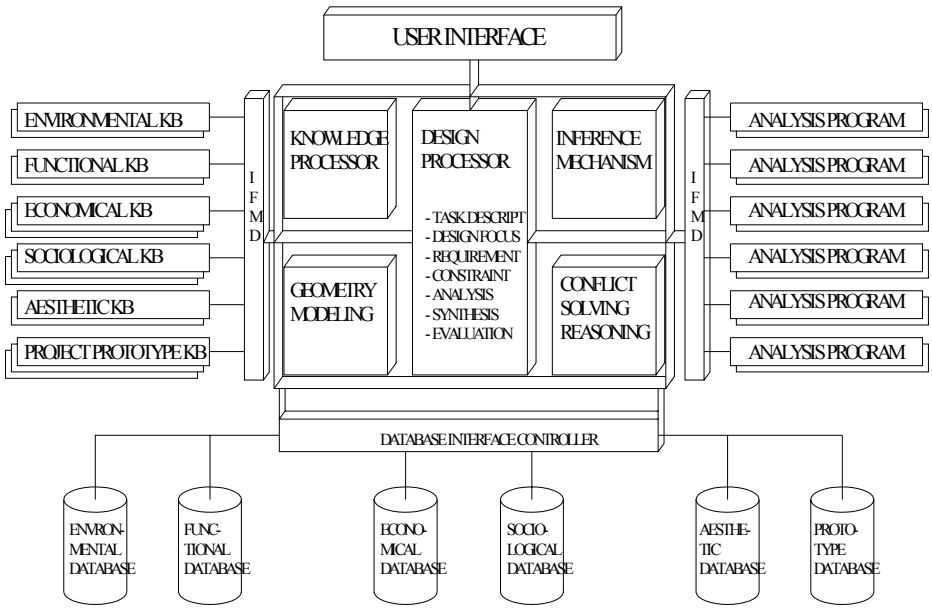
The design system incorporates the theoretical framework and problem-solving model of knowledge-aided design. The system consists of seven major components: user interface, knowledge-aided design controller, project database, geometry modeling system, knowledge bases, databases, and analysis programs.

User interface: The user interface provides the designer to design a building and control the system's alternative generation and design transition.

Knowledge-aided design controller: The controller is made of four subcomponents: design processor, knowledge processor, inference mechanism, and conflict-solving reasoning. The design processor is responsible to advance the design state and achieve a solution state. The design processing can follow two routes-one is automatic processing and the other one is designer driven processing. In the designer driven processing, design begins with the designer's sketch and the system responds to the designer whenever he asks for assistance. In the automatic processing, the system begins from given data such as location, building type, number of occupants, etc. Then, the system generates design alternatives using its knowledge and data. The design processor subcomponents have problem-solving strategies and three modules: analysis module, synthesis module, and evaluation module. It decides design tasks and solving strategies based on the designer's priority and given design state. Then the design

generation begins with analysis of design goals and constraints. It sends a message of task and goal descriptions to knowledge processor considers the task descriptions to knowledge processor subcomponent to select knowledge sources. The knowledge processor considers the task description, design focus, requirement of the task, and constraints. Then the knowledge processor subcomponent select the knowledge sources and passes the list of knowledge sources to the inference mechanism subcomponent.

Figure 1. Knowledge-aided design system.



The inference mechanism subcomponent receives message of task description and solving strategies from the design processor and the list of knowledge sources from the knowledge processor. It processes reasoning through broad search like forward and backward and narrow search like generate-and-test, hill-climbing, backtracking, constraint satisfaction, analogical reasoning, induction, and deduction. It processes the reasoning and sends the result to the design processor. Then the evaluation module of the design processor keeps the results of all subtasks such as energy efficient design, economic design, and ecological design. After completion of all subtasks, it sends a message to user and conflict-solving processor changes the objects in the

project database and the geometry modeling system and then determines the next task and design goal to achieve.

Project database: the object-oriented project database consists of the objects and the relationships between them. All the objects represent geometric and nongeometric attributes and properties of the building. The paradigm of object-based representation provides the base for powerful reasoning like a human designer, because designers process design reasoning using the physical objects like wall and window not the numerical coordinates and numbers.

Geometry modeling: The composite object-oriented geometry modeling system provides sophisticated facilities for decomposition, prototyping, deformation, and composition in representing physical objects and descriptions for them.

Knowledge bases and databases: The system has five major knowledge bases and databases. Each knowledge base and database has many knowledge sources and lower level databases. It has economic knowledge base and database, sociological knowledge base and database, environmental knowledge base and database, functional knowledge base and database, and aesthetic knowledge base and database. Knowledge sources consist of descriptive and procedural knowledge, and can be represented by production rules.

5. Implementation for Intelligent Building Design

5.1. KNOWLEDGE BASE FOR INTELLIGENT BUILDING

The knowledge bases of the knowledge-aided design system consist of five knowledge bases. Knowledge bases for intelligent building are included in the functional knowledge base. The knowledge bases can be composed as following.

1. Planning knowledge base
   - 1-1. Flexible planning knowledge base
   - 1-2. Lifecycle planning knowledge base
   - 1-3. Ergonomics planning knowledge base
   - 1-4. Amenity planning knowledge base
2. Communication System knowledge base
3. Office Automation knowledge base
4. Building Automation knowledge base
   - 4-1. Building management knowledge base
   - 4-2. Security system knowledge base
   - 4-3. Energy Conservation knowledge base

5.2. STRUCTURE OF THE SYSTEM

The knowledge base for Energy conservation has been structured and implemented. The system consists of six components: 1. User interface, 2. Geometry modeling system, 3. Knowledge base, 4. Inference mechanism, 5. Context, 6. Design controller. The system is integrated with energy analysis. The system includes three databases, all of which are integrated in a Lisp environment and utilized by an object-oriented programming paradigm. The system is implemented on Symbolic Lisp Machine.

User interfaces: The user interface module provides an interface between the user and the system

Geometry modeling system: The system is build upon the concept of composite oriented system. The concept of a composite object oriented system is to utilize structural template which describe process can create composite objects and those composite objects are part of a class inheritance network. The ability to make modified versions of a template by making a new subclass that inherits the properties of the super class is the advantages of creating composite object classes.

Knowledge base: The knowledge bade is a component containing the expert's domain specific knowledge and expertise which can provide energy efficient design. The knowledge base is a collection of structures, objects, production rules, and information. The rules represent the relationships between certain antecedent and consequences. The intermixing of rules that include objects and relationships with rules that represent heuristic knowledge can handle the complexity of the knowledge base. The knowledge base contains two main parts: 1. design strategies for energy conservation for intelligent building design and 2. evaluation of the building efficiency.

Inference mechanism: Inference mechanism carries out reasoning tasks and makes the system act like an expert. It manipulates the context using the knowledge to use the pattern matcher and can manipulate the patterns on the right hand side. Two reasoning tasks can be utilized: forward chaining and backward chaining

Context: The context is the system's current memory to store temporary assertions and it contain short-term dynamic data as problem-solving state information. The data in context relates syntactic conventions of facts.

Designs controller: This module control the transformation of the state progress. It contains problems solving model that is a conceptual framework to provide the reasoning process and to focus attention on the next knowledge application process.

Energy analysis program: This program is based on a variable-base degree-hour energy analysis method. It can calculate: 1. winter heat gains. 2, heating degree hours and annualized loads, 3. internal gains, 4. cooling degree

hours and annualized loads, 5. annual fuel and energy consumption by category. Later, an hour-by-hour energy model will be added.

Database: The system uses three databases for information. The weather database contains sample weather data. The wall material database contains wall material descriptions to create schemas.

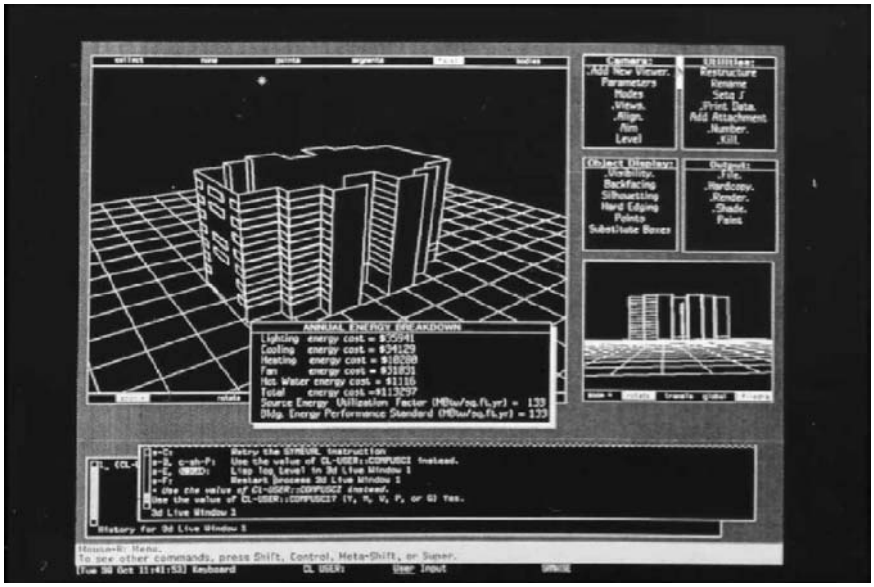


Figure 2. User interface of design system.

5.3. DESIGN PROCEDURE

In schematic design architect will sketch the floor plan or mass of building. He can use top-down design approach or bottom-up design approach or mixed design approach using the digitizer mouse. The system provides general design strategies based on given climate and site condition. The system evaluates the design using the energy analysis program and provides suggestion based on the output of energy analysis.

In design development architect will select or define the wall material, and then select a composite wall assembly from the wall material. Then, the designer defines the thermal zones of the building and properties of thermal zones. The system can evaluate design using the energy simulation method.

6. Conclusions

Externally representing the designer's cognitive design process and problem-solving techniques is not an easy task. However, to structure an intelligent design tool and problem-solving model for knowledge-aided design

system and to become a real design tool, the task is fundamental. To solve ill-structured and multi-dimensional architectural design problem, designers' cognitive problem-solving processes and more efficient knowledge representation schemes need to be studied. The current model of design system has only the rudiments of a fully operational design system. The most significant area remaining to be developed is the extension of the knowledge base to give more precise design advice and recommendations.

Acknowledgements

This paper was supported in part by NON DIRECTED FUND, Korea Research Foundation.

References

Akin, O.: 1986, *Psychology of Architecture*, Pion Limited, London.

Archer, L.O.: 1984, Systematic Method for Designers, *in* Cross, N. (ed), *Development in Design Methodology*; John Wiley & Sons, New York, pp.57-82.

Kim, Y.: 1993, A Study on Development of Knowledge-Aided Design System, *Design Research* (12), pp95-119

Kim, Y.: 1994, Computer-Aided Architectural Design System, *Design Research* (13), pp89-96

Lawson, B.: 1980, *How Designers Think*, Architectural Press, London.

Newell, A. and Simon, H.A.: 1972, *Human Problem Solving*, Prentice Hall, Englewood Cliffs.

Shin, D.O.: 1997, *Planning and Design Guide for Intelligent Buildings*, Kimoondang, Seoul

Simon, H.A.: 1984, The Structure of Ill-Structured Problems, *in* Cross, N. (ed), *Development in Design Methodology*; John Wiley & Sons, New York, pp.145-166.