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AN INTEGRATED SYSTEM FOR IMPROVING LIGHTING DESIGN STRATEGY

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1. Introduction

Lighting and artificial illumination are of critical importance in architectural environmental control. Architectural lighting design is generally considered during the last phase, rather than the beginning, of an architectural design process. The complexity of illumination and lighting requires designers to base their suggestions on visualization. Previous studies on lighting and illumination systems, such as that of Poulin and Fournier (1995) described a system by which users choose colors and apply them on any visible points in a scene. The system uses a simple illumination model, simple materials and simplified light sources, intending to optimize specific functions.When the depiction is completed therefore, color points remain close to the colors specified. The evaluation made by Mahdavi and Pal (1997), based on visualized illumination-oriented simulation, proved that discerning formulaic indices could compress computer output according to a strategy, and preserve only data that is significant in the complex temporal and spatial framework. Costa, Sousa and Ferrera, et al. (1999) adopted optimization to look for solutions for illumination from background geometry. Background materials and the virtual illumination specified by users were used as design targets. The position and lighting direction of desired and undesired illuminating objects are specified in writing. Moeck (2001) derived a structural illumination system limited to standard light sources for overall as well as detailed architectural lighting design. However, there are still no lighting or illumination systems to support designers as alternatives in the early phases of a design development process. Therefore, this research focuses on how to allow users, by way of systematic expert advise, to get professional lighting design solutions. Building up an expertise system requires field know-how and professional experience. How to systemize this is the major issue of this research. A second issue is how to solve the problem of meeting illumination evaluation criteria and automatic layout when there is a difference from the traditional layout of lighting in order to come up with a distinctive alternative.

The research is need-driven, proceeding by acquiring expert illumination knowledge to build up an expert system on architectural artificial illumination design. By integrating lighting in the early phase of a design process, designers are able to use intuitive means to input into the operating system, and obtain relevant suggestions on the attributes of spatial illumination. Therefore, consideration of natural lighting and illumination can be an integral part of the early development of a design project.

2. Review

With the development of artificial intelligence, computers are no longer simple calculating tools but can also have the capacity, like humans, for logical reasoning and decision-making. This is especially true for knowledge-based expert systems, which store in advance the knowledge of which rule is most effective in which circumstances. When circumstances change, the expert system will automatically select and suggest the best rule. The system has the advantage to maintain optimization. The formation of relational knowledge and the production of an inference engine are correspondingly

important and difficult. Expert systems utilize professional knowledge of a certain field to find solutions to all problems within the specific domain and can be used to help solve professional architectural problems (Gero and Maher, 1990).
Object-oriented techniques(OOT), which are highly modularized, reusable, tailorable and possess “inheritance,” have been increasingly emphasized in recent years (Booch, ; Taylor, 1992). Object-oriented techniques originate from programming design. The knowledge structure of human beings is hierarchical; object-oriented techniques are based on a very similar structure. Human knowledge can be expressed in language but there is inevitable ambiguity in human language stemming from different individuals' subjectivity. Fuzzy Theory was developed from attempts to grasp definitions of “fuzziness.” Fuzzy Theory is based on fuzzy sets; the principle lies in embracing the existence of fuzziness. The research target is to handle indeterminedly fuzzy objects and to rigorously quantify the objects, producing data that is accessible for computer processing. (Zimmermann, 1991). Fuzzy Theory is therefore widely applied in artificial intelligence and expert systems as well as in the humanities, in decision-making, decision analysis, multi-purpose evaluation and synthesized evaluation of the human science.

3. Methodology and Conceptual Framework

This research uses object-oriented technique to do object analysis and design for lighting design. The research also integrates fuzzy theory, producing a mechanism to control variations in fuzzy factors and thereby creating an integrated expert system. The development of the system is divided into four phases:

- Preparatory Phase: Confirming purpose of environmental usage and function.
- Preliminary Design: Selection of light sources, selection of illuminatiog device, confirmation of illumination modes, selection of illumination methods and intensity of illumination.
- Detailed design: Layout of lighting device.
- Index-based evaluation: Including modification of illumination, brilliance distribution and glare.

The scope of this research is artificial lighting in office environments. Expert knowledge manipulated via hierarchy searching techniques is the system structure. During initial tests, users are able to use their own design strategies to construct the desired lighting strategies; the simulated results can help users evaluate diversified lighting alternatives.

3.1 Object-Oriented Technique

The key concepts of OOT include:

- Object: An object has its own attributes and behaviors to reflect elements in the real world. Behavior analysis is used to make it abstract. Furthermore, classification is used to define relationships of “inheritance” and “part-of” among classes and sub-classes.
- Class: Class is used to describe a group of objects with similar attributes, common behaviors (operations) and meanings, and common relations with other objects.
- Inheritance: Lower-level classes of objects inherit the attributes, behaviors and meanings of higher-level classes of objects.
- Encapsulation: OOT emphasizes in particular that abstract data objects do not only possess their own attributes and relations: all operations of an object are encapsulated in the object. The attributes of the object can only be accessed or updated through the operations in the object.
- Polymorphism: Whatever the object involved, the same action requires the same terminology.

Using Object-Oriented concepts, the elements of lighting design are treated as different categories and the interrelations between each attribute are analysed to build a comprehensive framework.

3.2 Fuzzy systems

Fuzzy theory enables computers to process the indefinite information of human knowledge and was developed to control elements with fuzzy definitions. The application of fuzzy theory focuses on human experience and on degrees of control over the characteristics of a problem. In this respect, the theory is applicable to the design control and expert experience facets of design behavior and decision-making. Fuzzy expert systems use the integration of rule-based and fuzzy reasoning (Negoita, 1985). Rule-based reasoning is used to make logical judgments and fuzzy reasoning to make intuitive judgments. The inference engine, composed of these two types of reasoning patterns, produces appropriate conclusions or suggestions. Humans in fact depend on the degree of logical judgment in an intuitive judgment to resolve problems. Therefore, fuzzy expert systems chiefly use rule-based reasoning to initiate fuzzy reasoning. [Figure 1]

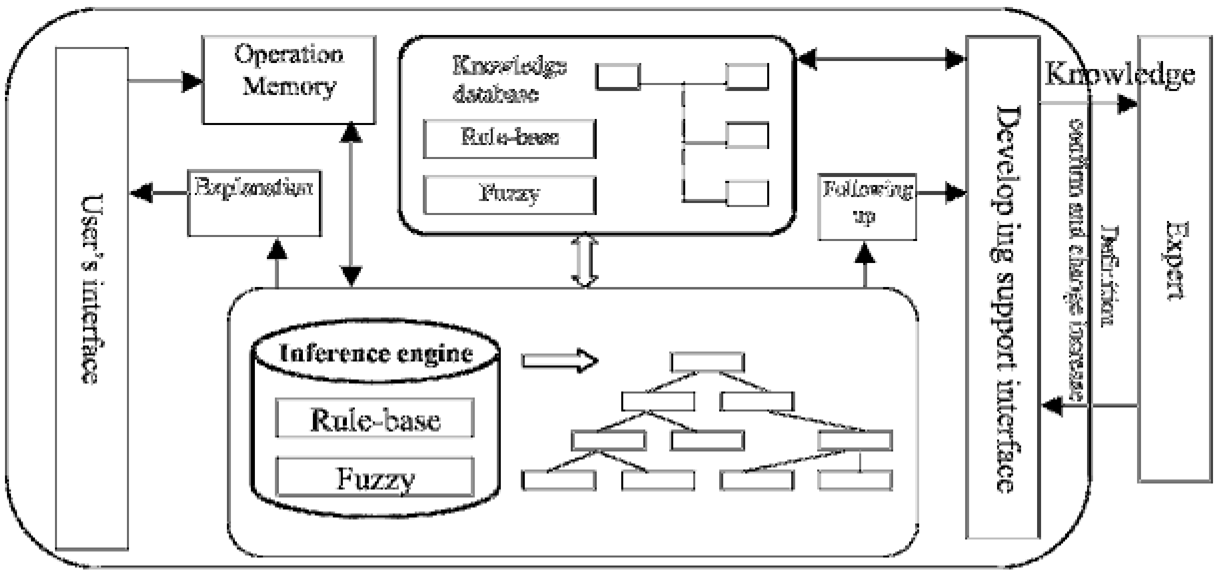

Figure 1. Conceptual framework

4. Discussion and explanations

4.1 Building expert system for artificial lighting design

Traditional lighting design processes depend on control of spatial functions to decide lighting targets and methods and to select light sources the nature and quantity of equipment and the layout. Afterwards, the designer evaluates the lighting target index and decides whether to execute the proposal or to use another. In this system, application of experts' field experience and design principle (IES, 1993; Steffy, 1990) produces changes in the design procedure. Consideration of the lighting design process proceeded in order to meet the goal of a need-driven system. Hence, expert strategies in design decision-making were probed. It is clear that specialized expert knowledge influences the decision-making of designers. Because of that, in addition to considering functional needs, designers want to change the layout of lighting equipment for a more creative design and at the same time need to meet illumination requirements. The system, using evaluation and judgment, based on expert knowledge and experience to design the lighting layout So that architects, with the spatial function under control, can take into account not just envelope design but also the interior system.

The OOT framework effectively integrates fuzzy theory with an expert system, hence it can provide structural expert knowledge through the whole design procedure. It can thus suggest many effective alternatives to lighting designers in the early phase of design. The design principles and hierarchy of expert knowledge of the present are different from those of the past. It is therefore important to establish a rule database. This research proceeds first by selecting the methods for obtaining system knowledge, then by classifying decision-making rules, assembling data relating to different rules, analyzing and generalizing the factors dealt with by rules. The research then expresses knowledge as decision-making trees and establishes a systemized and organized knowledge database.

4.2 Fuzzy operations in application and the results

Rules are generally expressed in the pattern: "if…, then…" The pattern allows expression of experience, knowledge and control strategies. Control rules are developed in four ways: obtained from expert knowledge; set by an operator's control behavior; set by the characteristics of a controlled system, or obtained by self-learning. If knowledge cannot make inference by rules, it can be presented by the inter-connection between knowledge and objects (Lee, Lee and Kuo, 1994). This system adds to the inference engine a fuzzy controller, the basic structure of which has five major parts: fuzzifier, inference engine, database, rule base, and defuzzifier. The fuzzifier transfers input figures via scaling mapping to the fuzzy zone corresponding to the input variable. The input data, by way of a fuzzification function, is then transformed into the appropriate linguistics value for fuzzy inference operations. Inference engine that is the core of the whole fuzzy controller, handles fuzzy reasoning according to the fuzzy rules. The inference operations, with a system of two inputs, one output and only two conditions to describe minimum operations in compound reasoning, lead to attribute relationships of every rule and finally compound two rules for a conclusion.

During the design process, the system can handle diverse forms of layout, differing from traditional fixed lighting layouts. The processing mechanism for evaluation is more efficient at processing visual impressions. Simulations of lighting design and layout allow designers more efficient lighting decision-making. The rule of lighting layout: If the center point of the frame meets the requirement of illumination , the center point is the illumination location.In the system input decision, design must deal with different base sizes. Therefore, conceptually, the emergent subshapes of Liu (1996) is adopted. We provide the size of the environment base, and sub-type recognition produces a closed shape. The system will be able to recognize the area and size it needs to operate on, and remove the hidden parts so as to calculate the exact size [Figure 2] and determine the illumination needed. Through such processing, the system provides a continuous mechanism for calculating change in the layout of lighting device.

East	North	Elevation
1	0	50
2	1	80
1	2	100
2	3	120
3	4	100
1	4	50

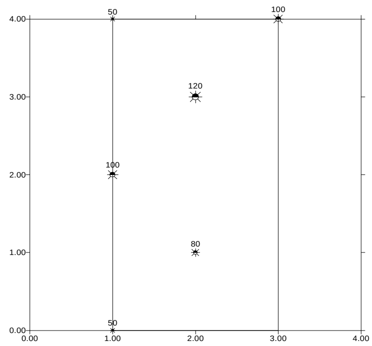

Figure 2. The needed illumination at input point. System transforms designer's illumination concept into a spatial chart

Input the illumination specified for an office space into the system and transform into distribution diagram. Calculation can produce an illumination equivalence chart. [Figure 3].

53	50	87	100	100
67	86	120	110	104
75	100	104	103	100
65	75	80	88	91
53	50	65	75	81

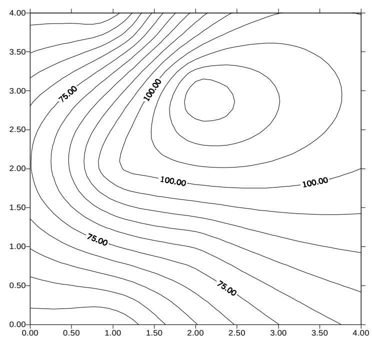

Figure 3. Illumination equivalence chart

4.3 Classification by layout and location

The research's design strategy for layout is to adopt the divisions between standardized forms to find out the points on illumination equivalence lines. By balancing the center point of each pattern with the location and illumination requirement of an actual object (for example, an office desk), the system can find many solutions that meet the illumination and layout requirements [Figure 4]. In addition, research into the density of control forms has discovered an inference engine that has undergone fuzzy control can effectively resolve the problem of errors. Therefore, this expert system not only simulates the location of lighting equipment in just the way an architect does design work, but can also prove that OOT and fuzzy theory are able to stretch the limitations of expert system.

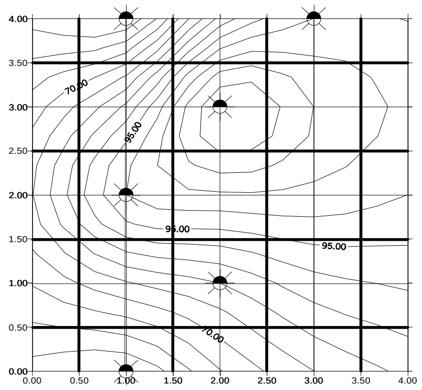

Figure 4. Example of relation between illumination and layout location: If the center point of the frame meets the requirement of illumination , the center point is the illumination location

5. Conclusions and future work

This system can be used to view lighting design from different angles. The research will investigate the applicability of rule-based systems to be adapted to the more complicated architectural lighting layout design. To improve lighting design procedures, it will supply designers with reference material assembled as a professional knowledge database which can be involved in preliminary formula design to produce a simulation that fits with the illuminance and visual situation. This will include using light sources and lighting equipment for all types of display objects, many different viewpoints, and simulations of light and dark scattered throughout the room. Use of professional design procedures proposed by expert systems not only reduces costs but can raise efficiency and time management in architectural planning from the early surveying to the consideration of fine details in the latter phase of a project. Besides, it can raise the diversity of architectural planning and modeling project. The hierarchy of fuzzy control is adopted in consideration of human control strategies. It can be split into three levels: inference, judgment and execution. There is a clear analogy with human thinking.

This research aims, by way of the expert system, to process issues that are generally handled in the latter design phase during the early phases of a design procedure. Secondly, the aim is to help architects, when considering interior space, to quickly control the structure of the whole spatial design by means of an expert system. Third, to breakthrough the limitations on layout set by traditional lighting design, making function and satisfaction of needs a priority and at the same time including creative design, providing new methods and principles for layouts.

The research is mainly to build an expert system for artificial lighting design, which is need-driven and focuses on illumination as a priority. In the selection of lamps, only those lamps meeting the illumination requirements of an office building are considered. Lamps set up in the expert system give effective control of variables. The factors of open windows are not considered in this research. Factors such as the influence of natural light on lighting, the distance from adjacent buildings, the building height and degree of reflection are not fully considered in the system. They could be regarded as the limitation of this research and serve as subjects for follow-up research. In the future, the research will include multiple environmental factors that influence illumination. Future research will also propose an expert system covering artificial lighting and collection of natural lighting.

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