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Integrated building design decision support with fuzzy logic

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Abstract

In building design, design decision is an essential part to be accomplished for the execution of the actual design process. Therefore in recent times, design decision support systems have received much attention for the importance of need for optimal decisions. A conceptual integrated decision support system for building design considering technical and functional aspects of building design was described earlier. Considering that systematic approach, this work further describes novel fuzzy logic approach for the implementation of an integrated building design decision support system in a unified form considering multidisciplinary building design information including also their interrelationship in design.

1. Introduction

Considering the advancements in building technology together with the modern technologies, building design requires more comprehensive attention than that ever required before. Building design involves multi-dimensional aspects to be considered with conflicting criteria. As result of this, many types of expertise are required for optimal solutions. Therefore during the design, the building information should be thoroughly considered and used especially by the appropriate people most relevant. Such considerations should have flexibility to accommodate the probable emerging demands even in the course of the execution of the project. In this respect building design is also dynamic process. Such demands may naturally occur due to various reasons like new technological possibilities, new technical or financial limitations imposed and so on. In such cases, the modifications and/or additions to the existing project should be reflected to the related bodies or individuals in a well-coordinated way so that concerted actions can be taken for the efficient execution course of the project. Considering all these aspects together with technical and functional limitations and/or impositions, modern building design decision is a formidable task to the designer. To provide the designer with technical and functional furtherance by means of design decision support systems that use the possibilities of modern technologies is virtually imperative for the intended tasks. One modern approach is the application of artificial intelligence (AI) methodologies for intelligent management of the building design information. Hence, the work describes the AI-based building design decision support using fuzzy logic technology. The organization of the paper is as follows. Section II describes fuzzy logic in brief for completeness of the paper. Section III describes fuzzy associative memory (FAM) and its fuzzy logic implementation as integrated building decision support for optimal design decision that is followed by conclusions.

2. Integrated building design decision support with fuzzy logic

The purpose of integrated building design decision support is to provide designer with a tool for effective and efficient decisions. For this goal designer should be assisted with the modern technological tools. The utilization of artificial intelligence methodologies in architecture for computer enhanced building design is recognized and research outcomes on this issue appeared in the literature. Among the methodologies evolutionary algorithms like genetic algorithms, feed-forward neural networks and fuzzy logic can be referred. The fuzzy logic is especially important in architecture since it can handle the linguistic information. It can effectively be used in design reasoning [1], for instance.

The conceptualized integrated building design decision support is systematically described before [2]. In this work fuzzy logic approach is used essentially for knowledge representation, as the architectural information includes technical e.g., engineering related data and functional e.g., linguistic constraints so that the information management even in subtle dimensions should be carried out. Before describing the method of intelligent design decision support, a brief description of the fuzzy logic and its particular implementation fuzzy associative memory (FAM) are appropriate here, as this new AI technology is not widely applied yet in Architecture.

2. 1. Fuzzy Logic in Brief

Fuzzy set theory was introduced through Zadeh [3]. With fuzzy sets, a numerical value is classified into one or more linguistic labels. These labels may be discrete as well as continuous and they are coined as membership functions that represent the numerical strength of linguistic labels for the domain of classification. Since the membership functions can overlap, this results in multi-value representation of the knowledge. An input value intersects with one or more membership functions of the input classification and therefore it is attached to several linguistic labels.

A fuzzy set **A** on the universe X is a set defined by a membership function μ_A representing a mapping

$$\mu_A : X \rightarrow \{0,1\}$$

where the value $\mu_A(x)$ for the fuzzy set **A** is called the membership value of $x \in X$. The membership value can be interpreted as the degree of x belonging to the fuzzy set **A**. A typical membership function might be as shown in Fig.1.

Before entering a fuzzy system, the information at hand is fuzzified. This is done by an input classification, matching the input value against a chosen set of linguistic labels. These labels partly overlap as shown in Fig.1, so that a numerical value can be classified into more than one label, each with an associated member value. Inference is carried out with evaluating fuzzy production rules where the propagation of the fuzziness is linear with respect to arithmetic operations. Logical combinations are performed in a systematic way with certain rules known as norms. The extension of the intersection and union of two classical sets to the intersection and union of two fuzzy sets is not uniquely defined. However, intersection and union operations for fuzzy sets should be able to be

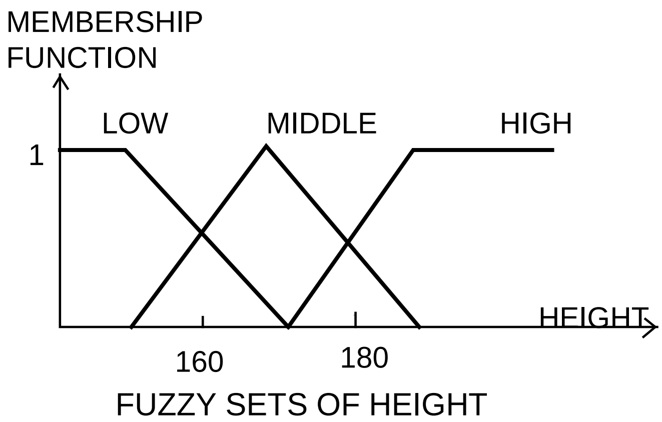

Figure 1: Representation of fuzzy sets of heights

subjected to the intersection and union of classical sets. Zadeh [3] proposed to use the following definitions

$$\mu_{A \cup B} = \min(\mu_A(x), \mu_B(x))$$

$$\mu_{A \cap B} = \max(\mu_A(x), \mu_B(x))$$

If we restrict $\mu_A(x)$ and $\mu_B(x)$ to values {0,1}, then these operators reduce to the intersection and union as defined for classical sets. Since one linguistic value can be attached to several numerical values in the context it is considered, more than one rule might be triggered producing several answers. This multiple answer can be combined to reach an optimal decision or a decision region. This is illustrated in Fig.2.

2.2. Fuzzy Associative Memory

Fuzzy associative memory (FAM) is a transformation described by Kosko [4]. It maps a fuzzy set to another fuzzy set. In general the FAM system includes a bank of different FAM associations. Each association corresponds to a different sequence of considerations that are expressed in numerical form by means of fuzzy logic. Therefore, the numerical data express the membership values connected to the associations. The associations are ordered systematically in a matrix form so that the numerical data constitute a matrix called FAM matrix. The FAM matrices are separated and they are accessed in parallel

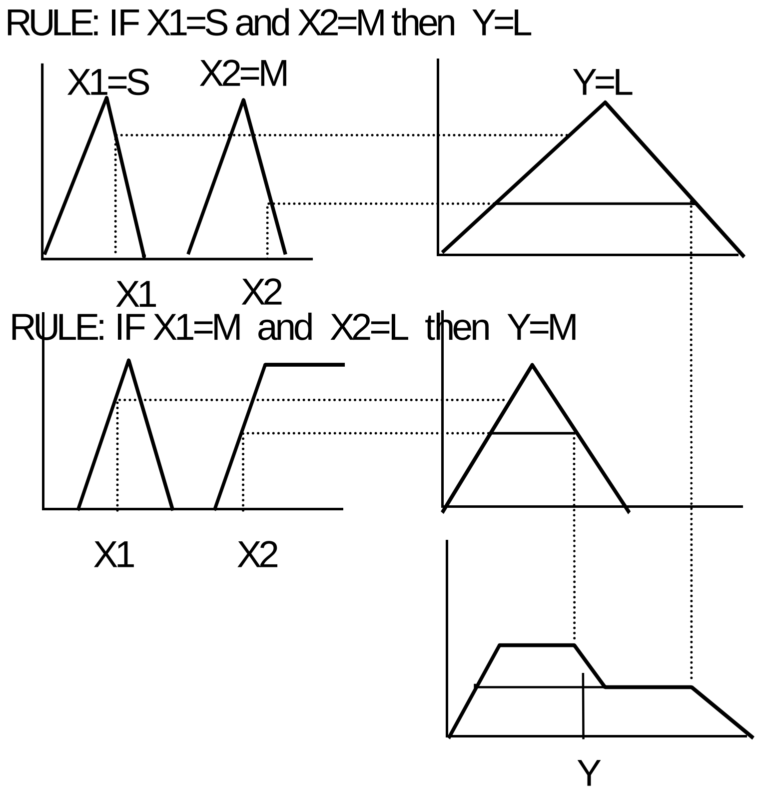

Figure 2: Fuzzy inference

For a given pair of bipolar row fuzzy vectors (X, Y), the outer-product correlation matrix is defined by

$$M = X^T Y$$

similarly, we define fuzzy Hebb matrix by the minimum of the membership values a_i and b_j, an encoding scheme is given by

$$m_{ij} = \min(a_i, b_j)$$

Accordingly, the fuzzy outer-product in matrix notation

$$M = A^T \text{ o } B$$

Due to the similary of this equation to correlation matrix in the statistical theory, the matrix M is called correlation-minimum encoding. If we use A in place of B in the above equation the matrix M becomes fuzzy auto-correlation matrix.

3. Fuzzy approach using FAM

As the building design involves many disciplines in one way or other, it is a multidisciplinary process. This is schematically shown by the conceptual scheme in Fig.3 where different experts from different fields contribute to the design decision.

The fuzzy implementation of this concept is shown in Fig.4 where functional requirements and technical requirements are used as input to a FAM bank to generate alternative design solutions that can satisfy the input requirements.

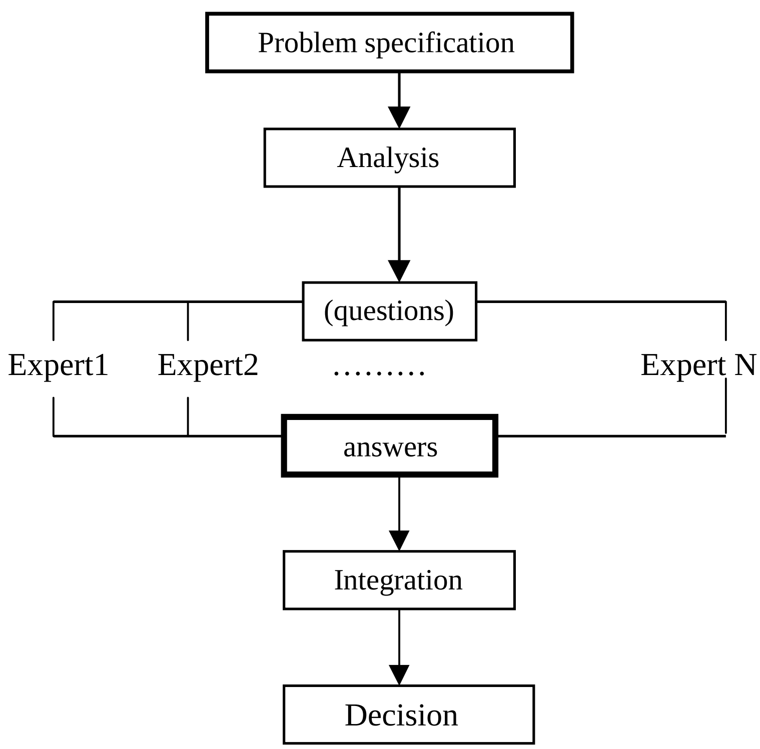

Figure 3: Multidisciplinary decision process [2]

Here, the functional requirements of concern are derived from the functional criteria and the technical constraints of concern are established from the technical criteria. For this problem, the appropriate FAM matrices are established from the data subject to building design in consideration. That is, for the building design we consider several alternatives with essential points suitable for the intended use of the design. The decision support system provides the graded alternatives for the design with fuzzy decision making so that the designer eventually should make use of for his or her final decision. In this structure, the fuzzy associative memory (FAM) is used for knowledge representation. Generic set of FAM rules having been established, any architectural new information in the form of a fuzzy vector **A** is fed to each FAM rule. Suppose we are given a functional requirement fuzzy vector **A**. Then this vector is fed to each FAM yielding the $\mathbf{P_i}$ fuzzy vector outcomes as components computed from

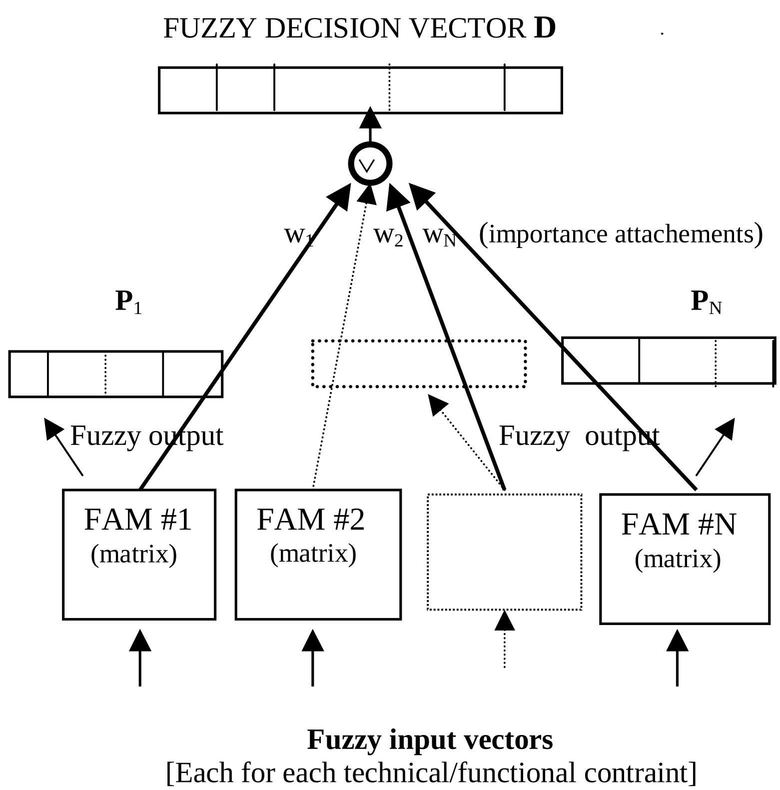

Figure 4: FAM approach for building design decision support system

$$\mathbf{P}_i = \mathbf{P}_{AoM}(p_j) = \max_{i=1}^{n} [\min(a_i, M_{ij})]$$

Hence, each FAM rule is fired in parallel but to a different degree so that each rule generates an *m*-dimensional output fuzzy vector $\mathbf{P}_i$. Basically, this means each FAM rule gives a best design alternatives in a graded form by the membership values. However, since we have several constraints in the form of technical and/or functional requirements, we have to combine all FAM outputs in a constructive way for the optimal decision. The solution to this problem is the fuzzy union of all outcomes so that the union of these output fuzzy vectors $\mathbf{P}_i$ creates the *m*-dimensional fuzzy vector **D** that provides the design information with the membership values as its components. Among others, there are three important features of the FAM approach in building design, here to mention.

- The fuzzy vector $\mathbf{P}_i$ **,** can be further weighted before executing the fuzzy union of the outcomes, to attach different importance to the constraints directed by technical and/or functional requirements. This is important because constraints are generally of different importance and this should be considered in a decision support system.

-The functional requirements and the technical requirements can be considered separately as well as jointly, by forming the fuzzy input vector accordingly. This is important since the building design information is a multi-disciplinary information. This implies that the decision support system should use the cross information for appropriate processing of given information

- The membership values in the fuzzy output vector **D** provide the graded design decision suggestion for a building design conforming to the given data and constraints in a unified form i.e., it handles the outcomes from technical requirements and functional requirements or both, consistently. Namely, in fuzzy notation, it performs

$$\mu_D = \left(\bigwedge_{i=1}^{n} \mu_{fri}\right) \wedge \left(\bigwedge_{i=1}^{n} \mu_{tci}\right)$$

where μ_{fri} is the membership value for functional requirements and μ_{tci} is the membership value for technical requirements. The highest membership value of **D** indicates the most appropriate design. However, since such a decision is totally dependent on the integrity and soundness of the knowledge elicitated from experts and represented in FAMs and also on the importance attachments to the FAM outputs, the designer should be the final decision-maker deciding among the favorite decision outcomes suggested by the fuzzy design decision support system.

4. CONCLUSIONS

Supporting decision making in building design concerns the interaction of many parameters in a wide scope complex environment. In the previous work [2], conceptually, different approaches from architectural and decision support viewpoints have been integrated into one general framework for building design decision support system that forms a consistent basis for working on generic system architectures for building design. Using this generic structure, the realization of a decision support system using a modern approach with artificial intelligence is described. It uses basically fuzzy logic especially for knowledge representation and this is accomplished by means of fuzzy associative memory (FAM). Since FAM can accommodate any number of design information in the form of two dimensional matrix, the complex building design information from different disciplines can easily be represented by FAM. The particular convenient feature of FAM is that, information from different disciplines can be categorized and can be applied to an appropriate FAM. This means that the input information to a FAM can be multi-disciplinary as well as mono-disciplinary. Additionally, depending on the volume of information, the number of FAMs can be increased without any limit to handle any volume of information, and the outputs of the FAMs inherently are combined so that for complex building design the consistent outcome is introduced to designer for his decision making. In building design sciences so far various modules have already been developed. For example, systems for architectural design, systems for physical computations, cost calculation programs, construction dimensioning and so on. Integrating all these modules in a decision support system where the modules are jointly and consistently considered, is very desirable since such support systems are not mature enough. In this respect, the fuzzy logic approach presented using FAM is a novel and an effective as well as efficient method for the demanded and anticipated decision support system using emerging AI technologies for complex building design.

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