MANAGING INFORMATION WITH FUZZY REASONING SYSTEM IN DESIGN REASONING AND ISSUE-BASED ARGUMENTATION

Quinsan Cao
Department of Architecture
Virginia Tech.
Blacksburg, VA 24061

Jean-Pierre Protzen
Department of Architecture
University of California at Berkeley
Berkeley, CA 94704

Design by argumentation is a natural character of design process with social participation. Issue-Based Information System (IBIS) is an information representation system based on a structured database. It provides a hierarchically linked database structure to manage design information and facilitate design by argumentation. In this paper, we explore the enhancement of IBIS with FRS (Fuzzy Reasoning System) technology. The FRS adds computationally implemented dynamic links to the database of IBIS. Such dynamic links can represent logic relations and reasoning operations among related issues which allows further clarification of relations among issues in IBS. The enhanced system provides a general framework to manage design information and to assist design reasoning, which in turn will contribute to machine assisted design. The final goal is to formulate a system that can represent design knowledge and assist reasoning in design analysis. The system can help designers in clarifying and understanding design related issues, requirements and evaluating potential design alternatives. To demonstrate the system and its potential use, we reexamine a design experiment presented by Schon and represent the design knowledge and reasoning rules of the architects with our system, FRS-IBIS.

1. Introduction

As the scale of today's design and construction projects expands, and their technological sophistication grows, so does the quantity and complexity of the information upon which the projects depend. The high levels of investments, the scope of committed resources, and the magnitudes of the impact of modern projects demand ever broader participation in architectural design and planning processes, and involve more elaborate discussions, extensive collaboration, and rigorous analyses. The tasks of generating, preserving, organizing, presenting and processing information become momentous and difficult.

It is widely accepted that today's architectural design process is a social activity with expanding participation of many parties (Cuff, 1991). The involved parties are no longer just architects, clients and engineers, but a variety of scientific and technological experts (e.g., health authorities, technical experts, special scientists, etc.), bankers, lawyers, community representatives, environmentalists, government agencies, media and general public.... The list may go on and on. With this wide social participation, designs, especially early phases of designs, are made through meetings of discussion, deliberation and debate. Such process is formalized as design by argumentation. During such process, effective representation of arguments and communication of information are among the most crucial factors for design progress. To meet the challenges, the industrial and academic communities are striving to develop more effective methods and tools.

One approach, which we call the instrumental approach, strives to provide modern computer, communication and information processing technologies to assist the architectural design process. Thus, Computer Aided Design (CAD) and Information Technology (IT), like image data generating, editing, storing, organizing, distributing, processing and representation, are now widely used in architectural design practices. Another approach is pursuing Artificial Intelligence (AI) technology applications for design professionals.

The instrumental approach, despite some impressive progress made, has not overcome all difficulties and leaves many frustrations. CAD, since its introduction into design practice some decades ago, has become a mainstay in most architectural offices. However useful and cost-effective CAD has become, it still leaves many design tasks, particularly in the early stages of a project, unassisted. CAD does not support, for example, the generation, exploration, development, and evaluation of initial design alternatives.

The Artificial Intelligence community strives to fill the gap left by the instrumental approach by attempting to capture the designers' knowledge and their reasoning patterns. What is known as expert system represents one such attempt. Expert systems are most successful in solving problems for which there is a definable goal, a clear set of initial conditions, and the outline of a procedure or a set of rules by which the goal can be reached. These conditions, as Rittel has shown, do not apply to design problems (Rittel, 1972, 1973). The expert system paradigm relies on a universal description that is applicable to all situations in practice, yet design problems "are essentially unique," and extremely context dependent. Design problems do not have "a definitive formulation," that is, what the goal is becomes clear only once the problem is solved. Design problems do not have a specific set of rules by which they get solved.

To overcome the difficulty of establishing and using rigid rules and procedures in design, many explorers turned to a new approach called Case-Based Reasoning (CBR). CBR attempts to directly use historical examples in forming new design rather than extracting rules. Much effort has been aimed to the development of record storing, editing, and distributing tools in order to establish case libraries. However, lacking of effective abstraction, (such as classification and recognition), reconstruction and evaluation schemes, CBR developments essentially remain as building case libraries or archives of historical examples. The case libraries provide little direct help in design for lack of mechanism to identify the relevant essence of the cases and associate it to a design goal, although they might help designers in seeking inspiration and reusable components from the history.

A new design, especially an exceptional one, is not an ensemble of old components made by following a set of rigid rules. For instance, to design a new type of "cash-less bank" that completely relies on electronic transactions, there is little can be learned from traditional bank designs. No case library could have examples of the new type. Moreover, there is little chance to build an expert system to help design, since nobody has ever seen one before not to mention establishing design procedures. Different people may have different ideas and expectations about the new type of bank. It is a great challenge for designers to systematically sort out existing information and knowledge related to the new design and innovatively produce a new design. However, some architects could handle the situation better than others. What is their skill? What is the process? Can it be understood? Similarly, many fundamental questions about design are yet to be answered, such as: What is design? Is design knowledge manageable and communicable? How do knowledge and intelligence contribute in design process?

In seeking answers to these questions, some explorers concentrated on observing designers' design process and analyzing their cognitive patterns. This approach is more directly aimed to address the fundamental questions about design. We call it analytical approach. While the instrumental approach is making admirable progress in providing convenience to designers, the analytical approach is seeking for long range and fundamental breakthrough. According to many explorers' observations of actual design process, such as Schon (1988) and Akin (1993), logic reasoning based on knowledge represented by rules (explicit and implicit) seems to be a fundamental element in the process of design.

1.1 A MODEL OF DESIGN PROCESS – COMPOSITION AND EVALUATION

Design is "a kind of dialectic between the designer's prestructuring of the world and the world as it is seen to be when examined in these terms" (Hillier). Obviously, "prestructuring" and "examine" are two different types of activities. It is like an argumentation involving: suppose I do such and such, then this and that would happen, and then is this acceptable? This line of self argumentation could repeat again and again with different initial assumptions until an acceptable solution is reached. Therefore, we can consider design an iterative process with two different phases alternately playing the dominant role. The two phases are speculative composition (prestructuring) and predictive evaluation (examining), respectively. Although the two phases are not always distinct, the differences and iterative progress of the two types of activities are evident.

In terms of speculative composition, the intelligence propelling such activities is definitely one of the most mysterious part of human brain's aptitude. It is responsible for the most innovative concepts and greatest discoveries. Although little is understood about such process, clearly such process is led by a goal and eventually constructs a form to accommodate the goal. Many attempts have been made to artificially reproduce or substitute such process, such as formulating design problems as finding a solution that fits all constrains or an optimal solution search with given criteria. However, the success of such attempts is severely limited by its linear and deductive approach, while inductive and nonlinear nature is essential in speculation.

Recently becoming more and more widely used evolution programs (such as evolution strategy and genetic algorithm) offer a significant breakthrough from the linear and deductive nature of earlier optimization schemes. It emulates the natural evolution process with selection based on the principle of best fits survive. The speculation (offspring) generating is essentially random. The evolution driven by random mutation over generations is directed by evaluative selection. Such method offers a "soft" connection between the speculations and the goal. Compared to other known methods, this method is more similar to human designers' behavior, a trial-and-error process guided by the evaluation regarding the goal. This method has been successfully used in electronic device layout design where the requirement and thus the evaluation is objective and relatively simple. It is difficult to predict how much such methods would succeed in general design, such as architectural design and planing. One of the most distinctive difference between electronic device layout and architectural design is in the design criteria. In architectural design, design criteria are much more complicated, often subjective and constantly evolving.

In general design process, design goals are often quite complex. It is often a set of many different and even conflict desires and concerns. For architectural design and planning, the situation is more severe due to broad social participation. It is often very difficulty to clarify and understand concerns of different parties, not to mention aggregating them into a single decisive opinion.

To address broad participation in design and planning practice as well as the complexity of design related issues, concerns and knowledge about them, Rittel developed the Issue-based Information System (IBIS) in late sixties with the objective of facilitating argumentative approach of design (Kuntz, 1970). Rittel pointed out that design process with social participation is conducted by argumentation. The system provides a framework to document, clarify and represent design and planning processes. Its hierarchical structure of linked topics, issues, positions, arguments and references provides a natural and convenient form to capture design related information and knowledge.

Due to the complexity of design goals and criteria, design evaluation for selection is also complicated. Rittel studied hierarchical structure of building performance evaluation and developed the concept of Deliberated Performance Evaluation (DPE) (Musso, 1967). The DPE method was further enhanced by Cao and Protzen for general applications and addressing uncertainties (Cao, 1992, Cao and Protzen, 1994). The DPE offers a framework to aggregates complicated design criteria into a single measurement index. However, the tree structure hierarchy and symmetric aggregation limited the use of PDE as a general form to describe design criteria and to represent design analysis and reasoning. To address such limitations, a general hierarchical mapping system based on fuzzy logic theory, Fuzzy Reasoning System (FRS), was developed (Cao, 1994). The FRS offers a more general format to describe design criteria.

1.2 THE NATURE OF DESIGN --- REASONING

As we have seen from above discussion, design process is really an argumentation process: a self dialectic arguing process within a single designer or a group arguing process among participants. Such arguing processes are reasoning processes, self reasoning and group reasoning. The composition and evaluation iterative process can be viewed as a iterative reasoning process of composing an hypothesis (an hypothetical premise) and then derive a conclusion. Schon (1988) observed that architects' design activities are nothing but reasoning with knowledge of "types" and "rules". In such reasoning process, "their patterns of inference were entirely familiar and conventional" and "the logic by which they passed from premises to conclusions was indistinguishable from the logic of everyday discourse." However, Schon also warned us about context relevance of design reasoning and implicit nature of design rules. Realizing the essential nature, argumentation or reasoning, of design process, solving the mysterious puzzle of design problems seems to become hopeful.

Obviously, the value of traditional wisdom about the model of reasoning, logic, is indisputable. There is no doubt that logic is very helpful in sorting and clarifying premises and to draw conclusions without conflicts. Tweed (1994) has demonstrated an example of using IBIS together with traditionally understood general reasoning pattern to design regulatory codes and standards.

However, traditional principle of inference, or logic, is strict and linear. Although it is mathematically perfect in theory, it's application in real life is limited. The "logic of everyday discourse" is not quite the same as the logic in theory. "The logic is linear and the world is nonlinear." In all our lives we are engaged in making guesses and conjectures, and finding evidences to support (not necessarily prove) them. We take reasonable judgments and actions based on reasonably well supported conjectures without worrying about a solid proof.

1.3 PRACTICAL REASONING --- PLAUSIBLE, SHADED AND FUZZY

The non strict logic in "casual" reasoning has been recognized and studied for long time. Some scholar argued that such studies can be traced back to the thoughts of Buddhism and Taoism thousands of years ago (Kosko, 1993). Black (1937) studied the vagueness in logical analysis mathematically with a multivalent logic model, which might be considered the beginning of formal study of such unconventional logic.

Polya (1954) recognized the importance of such practical reasoning in the course of scientific discoveries and named it plausible reasoning, in contrast to the traditional logic reasoning that he called demonstrative reasoning. He pointed out, "We secure our mathematical knowledge by demonstrative reasoning, but we support our conjectures by plausible reasoning … Anything new that we learn about the world involves plausible reasoning, which is the only kind of reasoning for which we care in everyday affairs." Instead of having rigid rules and standards, plausible reasoning has fluid standards. In the effort of uncover and describe such standards, Polya used the concept of shaded inductive inference and, further, used probability theory to describe the inference patterns mathematically. The goal was to describe patterns of inference in which the premises and conclusions are neither absolutely true nor absolutely false, and the rules governing such inference are neither absolutely reliable nor completely unreasonable. In such theory, truth is relative (not absolute) and quantitatively measurable. Although, as Polya admitted himself, the detailed numeric formula of probability theory may not hold strictly and even show conflicts, the key concept that the plausible inference lies between the extreme limits set by demonstrative inferences (traditional logic) is well and sound.

Zadeh developed fuzzy logic and fuzzy set theory in early sixties that can be considered as another mathematical form of describing shaded logic and plausible inference. Compared to probability theory, it seems to have more freedom and flexibility in describing heuristic inferences, since the theory does not have to be associated with random experiments that are essential in probability theory. Recent development on fuzzy reasoning techniques based on fuzzy set and fuzzy logic theories offers a powerful tool to represent heuristic (mostly plausible) inference patterns. This paradigm is powerful in dealing with concepts and rules with uncertainty and vagueness, especially in real life situations where absolute precision has little relevance while a robust representation of relative trend is more valuable.

With the encouragement of Zadeh and Protzen, Cao (1994, 1996) developed Fuzzy Reasoning System (FRS) to describe reasoning process in design analysis. In FRS, design knowledge is represented as fuzzy rules (or functions) describing relations among various issues and their status. Fuzzy logic technique in such framework allows the representation to be more flexible and compact.

In this paper, we explore the enhancement of IBIS with FRS technology. The final goal is to formulate a system that can represent design knowledge and assist reasoning in design analysis. The system is expected to help designers in clarifying and understanding design related issues, requirements and evaluating potential designs. To demonstrate the system and its potential use, we reexamine a design experiment presented by Schon (1988) and represent the design knowledge and reasoning rules of the architects with our system.

2. Issue-based Information System (IBIS)

IBIS offers a natural framework to record information as argumentation (Grant, 1992). It consists of a hierarchical network of essentially four types of nodes: topic, issue, position and argument. The nodes are connected by various types of links. Figure 1 shows the basic structure of IBIS network with all major types of nodes and links.

A topic serves as a starting point and defines the domain of the discussion in terms of its relevance. Issues related to the topic are raised by the participants during the discussion. Positions are taken by participants regarding their opinion about the issues. To justify their opinions, participants often support or object certain positions with various arguments. On the other hand, issues often trigger or introduce other issues in various occasions. To record and represent the information generated in such process, the framework of IBIS shown in Figure 1 is obviously quite natural and convenient. There have been many applications and developments of IBIS, such as IBIS with hypertext programming (Hashim, 1990).

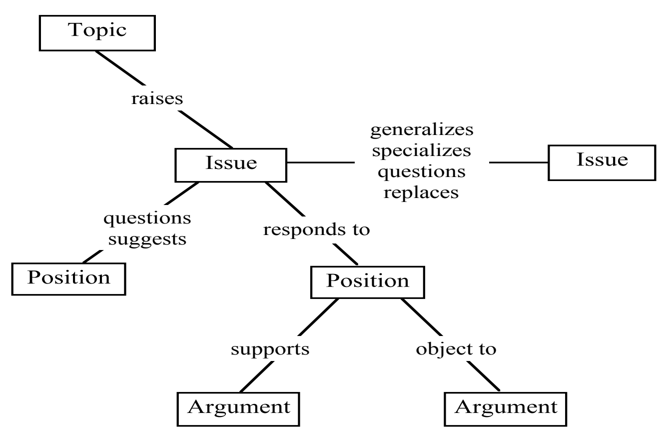


Figure 1. Framework of IBIS with four types of nodes and various types of links for recording argumentation.

Traditional wisdom about general patterns of reasoning has also been used to enhance IBIS to in resolving design and planning problems. Tweed (1994) used the general framework of reasoning (Toulmin, 1984) to further detail IBIS when representing knowledge to design regulations and standards. The general framework of reasoning is illustrated in Figure 2.

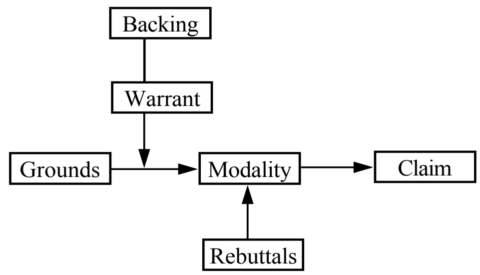


Figure 2. ***A general framework of reasoning, which offers a micro-structure to clarify the link between the position and argument nodes in IBIS.***

This framework can be used to specify the micro-structure between the position and argument nodes in IBIS, where the "claim" represents a position, "grounds" represents the arguments, and "rebuttals" support and modify the applicability of the argument. Obviously, with such a micro-structure, the IBIS representation of knowledge can describe argumentation and reasoning with more clear definition of relations.

On one hand, the detailed micro-structure allows more precise description of the knowledge. On the other hand, the micro-structure also makes the system more strict and rigid. Such rigidity makes the use of the system cumbersome in many practical situations. As we discussed in the introduction, the traditional logic does not support shaded or plausible inferences that are more useful in practice. The paradigm of fuzzy logic and fuzzy reasoning offers an improved mechanism to support shaded and plausible reasoning by quantifying premises, conclusions and rules of inference.

3. Fuzzy Reasoning System (FRS)

The paradigm of fuzzy logic and fuzzy reasoning has gained wide application in information technology, system science and engineering, especially in intelligent systems (Yager and Zadeh, 1993). Using fuzzy reasoning paradigm to represent design knowledge for design analysis is a relatively new exploration, such as treatment of uncertainty in design evaluation using fuzzy logic and fuzzy numbers and functions (Cao and Protzen, 1994), and design analysis system using FRS (Cao, 1996). The main function of such system is to provide a general framework to describe "soft" (fuzzy, shaded or plausible) inference rules, premises and conclusions. One of the most important properties of such fuzzy reasoning is that the limiting extremes of the inferences must agree with traditional logic, while intermediate situations fall in-between the extremes.

The essential concept of the FRS is illustrated in Figure 3 and Figure 4. The FRS consists of Fuzzy Reasoning Charts (FRC) and Fuzzy Reasoning Equations (FRE)

(Cao, 1994). The FRC and FRE are two different forms of representation of a fuzzy reasoning network with nodes and links. Each node corresponds to a fuzzy variable that represents an interested issue and its status. The links represent different types of relations among the issues. With the FREs, the links in the FRCs not only depict relations among issues but also quantitatively describe the relations among their status. With such a system, the reasoning can be implemented quantitatively with a digital computer. It has the capability of representing relations and status that are not quite crisply clear (neither "true" nor "false" but somewhere in between). Figure 3 demonstrates the FRCs describing four fundamental logic relations and Figure 4 demonstrates those describing two typical combinations of them for aggregation. It is obvious that the FREs presented in the figures agree with the traditional logic at the extreme limits, absolutely true (represented with value 1) or false (represented with value 0).

Compared to IBIS, FRS emphasizes on the positions taken on various issues and the interactive relations among these positions. With such relations, changing of the position on one issue is propagated through the network which properly represents (predicts) new positions on other related issues. FRS offers a dynamic format to implement the essence of IBIS.

It is straight forward to see, from Figure 3 and Figure 4 in comparison with Figure 1, that the FRS can be conveniently used to implement and describe IBIS including the micro-structure described in Figure 2. In FRS, topics, issues and arguments are represented by nodes in the network of FRC and corresponding variables in the FRE. The positions taken on each issue are simply represented by the status measurement of the corresponding node or the value of the corresponding fuzzy variable. The links between issues are represented by fuzzy logic functions or fuzzy rule based mappings that specify the relation between the position of linked issues. Compared to the original IBIS, FRS presents the links in more detail with clearer definitions.

For example, the relation between an issue and the issues specializing the original issue in IBIS are defined more clearly in FRS as aspect aggregation or alternative aggregation, shown in Figure 4. Different aggregation functions represent different ways for the positions on the specialized issues to contribute to the position on the general issue. The aspect aggregation, for instance, requires a positive position on every specialized issue (numerically represented by 1.0 or near 1.0) for a positive position on the general issue; a negative position (0.0 or near 0.0) on any specialized issue leads to a negative position on the general issue.

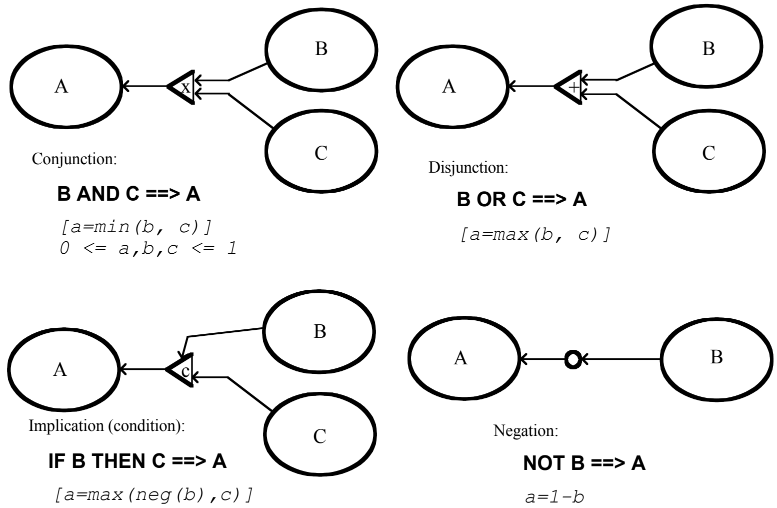
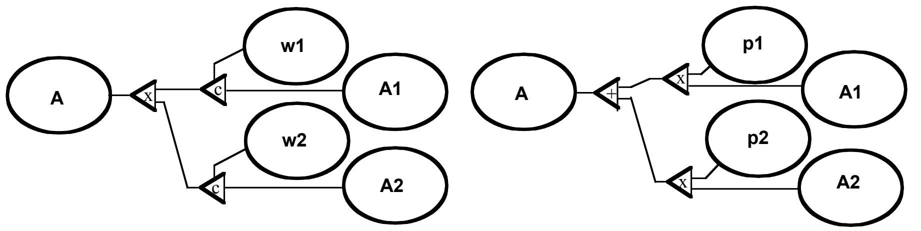


Figure 3. ***Fuzzy Reasoning Charts (FRC) of four basic types of logic relation, with a name of the relation, corresponding logic statement, and associated Fuzzy Reasoning Equations (FRE). The FRE operates on the variables whose values represent the status measurement of their corresponding nodes. An issue in IBIS corresponds to a node (issue) in FRS, and a position suggesting an issue in IBIS corresponds to the status measurement (value) of the node (variable) in FRS. An argument supporting or objecting a position in IBIS corresponds to a node in FRS whose status measurement contributes (directly or through a function, conjunction, disjunction, etc.) to the status measurement of the original issue to which the position regards.***

We have shown in Figure 2 the general reasoning framework depicting an argumentation supporting a position. Such framework can also be conveniently represented by a combination of the four fundamental relations shown in Figure 3. The FRS corresponding to the reasoning pattern of Figure 2 is shown in Figure 5.

In Figure 5, the "backing" that supports the "warrant" to the "claim" is given as an inactive comment that does not affect the network's operation actively. The modality is represented by the function (warrant) AND NOT (rebuttals). Although the construction of FRS corresponding to a reasoning pattern may not be unique, there is little room for ambiguity once an FRS representation is established. In addition to the basic first order logic relations, the FRS network also describes the strength measurements of the nodes, such as grounds, rebuttals and claims. In other words, FRS can describe not only how but also how much.



Aspect aggregation: All important (w_i) aspects (A_i).

(IF w1 THEN A1) AND (IF w2 THEN A2) ==> A

[a=min(max(neg(w1),a1),max(neg(w2),a2))]

Alternative aggregation: Any preferred (p_i) alternatives (A_i).

(p1 AND A1) OR (p2 AND A2) ==> A

[a=max(min(p1,a1),min(p2,a2))]

Figure 4. ***Fuzzy Reasoning Charts (FRC), corresponding logic statements and associated Fuzzy Reasoning Equations (FRE) of two typical types of aggregation, aspects and alternatives. When an issue specializes into several issues in the framework of IBIS, the status measurements of these issues aggregate to the status measurement of the original issue in the framework of FRS.***

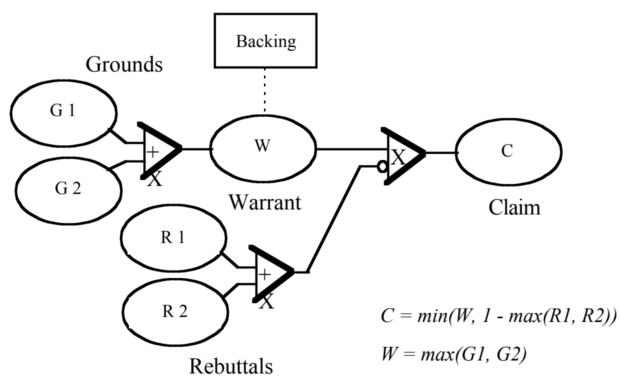


Figure 5. ***FRS representation of general reasoning pattern with FRC and corresponding FREs. All elements are represented by active nodes except the "backing" that is given as an inactive comment.***

With the new paradigm of FRS-IBIS, different designers' design knowledge can be represented separately or collectively. Representation of subjective preference and context dependence can be accommodated either by separated networks or collective network with conditioned connections. The fuzzy variables, fuzzy rules and fuzzy logic functions allow complex relations to be described in a compact form that is suitable for computer processing. In addition to the fuzzy reasoning patterns shown in Figure 3, 4 and 5, fuzzy rule based general mappings can be used to describe more general and complicated relations if necessary. Above all, the FRS-IBIS is not only a compact, graphical and digitally implementable representation of design information, argumentation and knowledge, it is also a very flexible and thus dynamic media. Since the design problems is a dynamically varying problem with its definition being evolved and modified during the whole problem solving and resolving process, a flexible and dynamic media for information management during such process is critically important. The net work of FRS-IBIS system is conveniently modifiable during such dynamic evolving process to properly reflect the changes of problem definition, argumentation knowledge, and solution.

4. Representation of Architects' Reasoning Patterns

As an example to demonstrate the use of the FRS-IBIS system to represent design knowledge, in this section we reexamine an experiment of design exercise reported by Schon (1988). In the experiment, invited designers were presented with a drawing shown in Figure 6. They were told that the drawing represents the "footprint" of a generic design of suburban branch library. Their task was to analyze the entrance locations and provide guidelines for entrance location selection. Each participant was asked to independently describe his opinion and the reasoning supporting it.

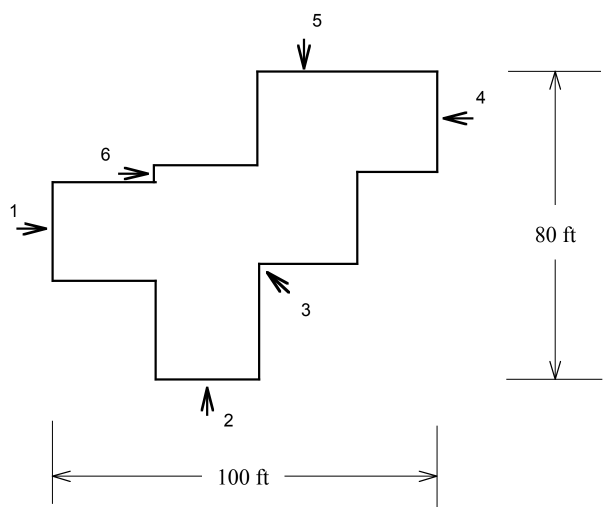


Figure 6. "Footprint" of a building with six generic alternatives of entrance positions.

A practicing architect's, Henry's, description can be represented in the framework of IBIS shown in Figure 7. Regarding the topic of good entrance position, he raises two issues, workability and interesting (features). Each issue further specializes into more issues. The issue of workability specializes into three issues: (1) spatial order of reading rooms and stacks, (2) clarity of entrance from street, and (3) efficient traffic control of materials with narrow end entrances. The positions and supporting arguments are: narrow end entrances offer series internal order and clarity of street entrance as well as efficient traffic control and therefore works fine. The issue of easy traffic control is conditional, depending on the location of the library. It is only important if the library is in a city center, otherwise the issue is negligible. The other issue, beside workability, interesting (features) can be replaced by the issue of poetic attraction. The position and arguments are entrances coming from middle of the form are rather poetic. However, as Henry said, "Poetry is only for poets."

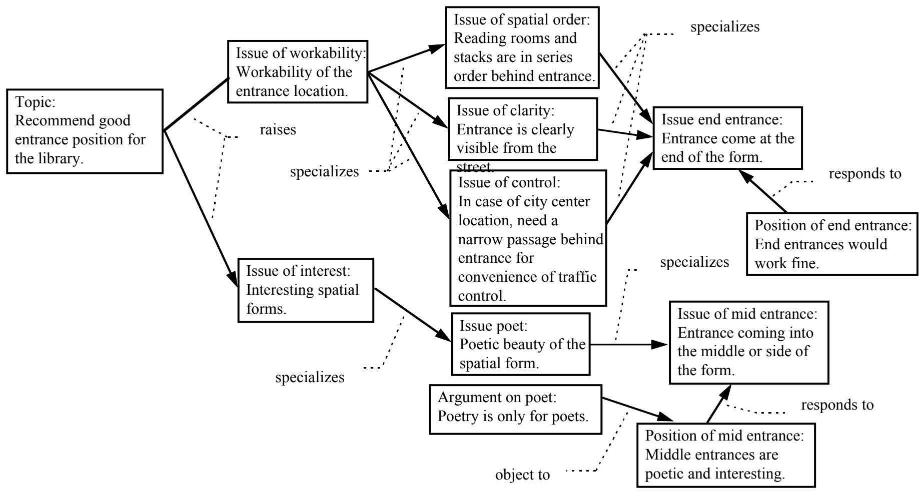


Figure 7. ***An architect's analytic arguments about entrance location design of a county library represented in the framework of IBIS.***

In the above discussion about Henry's analysis, we follow the structure of IBIS starting from a topic to issues and sub-issues, as well as the positions taken on various issues and the arguments supporting the positions. This IBIS representation can be further clarified in the framework of FRS as shown in Figure 8. Here, all issues in IBIS are represented by nodes or variables in FRS. Positions are represented by the values of the variables or status measurements of the nodes. Arguments are represented by functions that link nodes to nodes. Figure 8 shows the FRC of the corresponding IBIS in Figure 7, while FREs that can be constructed based on basic FREs such as those shown in Figure 3, 4 and 5 are omitted for brevity. Compared to the IBIS, FRS carries more detail of design reasoning information. It is more definitive and, therefore, requires more clear specification for the designers. In the reinterpretation of this particular example, we took the freedom of assuming that Henry implied all specialized issues' positive positions are necessary for a positive position on the issue of workability and thus form a component aggregation relation.

Henry grouped the entrance alternatives shown in Figure 6 into two groups. The first group consists end entrances, number 1, 2, 4 and 5, that "come in at the end." The other group consists of middle or side entrances, number 3 and 6, that "coming in the middle of the form." Supported by the given reasoning and arguments, he concludes, as one would find by checking each entrance alternative with the FRS shown in Figure 8, that the entrance number 3 and 6 are more difficult, although poetic. He recommends the other alternatives, number 1, 2, 4 and 5.

To further clarify Henry's reasoning, Henry could specify his criteria regarding the classification of end, middle and side entrances. The specified criteria can be described in FRS. If the criteria can be clarified down to objectively measurable parameters, then the evaluation can be conducted automatically with the FRS in a computing and measuring machine.

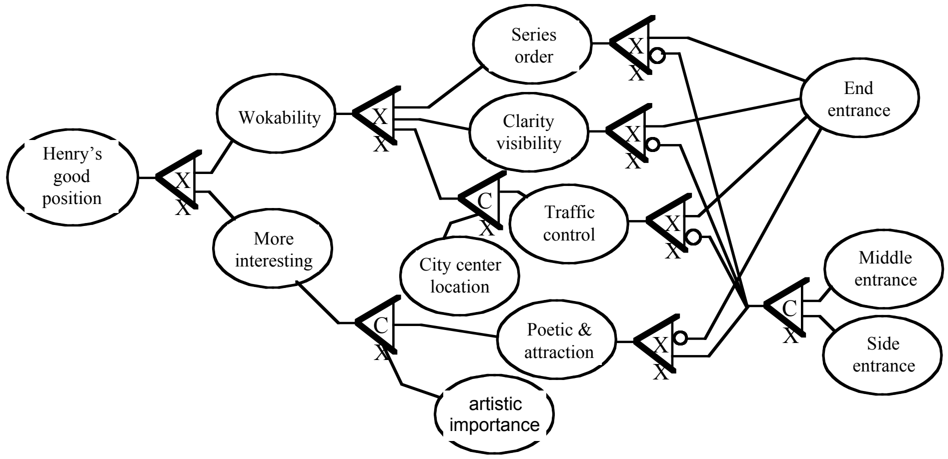


Figure 8. FRC representation of Henry's reasoning and analysis for good choices of entrance position. Examining each alternative of entrance positions through the network, one would find the alternatives that near the end of the building (gives high truth measure as "end entrance") agree with Henry's recommendation.

Quite different from Henry, Benny, a design instructor, argued that middle entrances (#3 and 6) are better than end entrances. His main argument is that end entrances make large area of the construction into traffic area for people to walk-by instead of useful area for people to study. Yet, he also realizes that such argument depends on the size of the library. Furthermore, he pointed out that if the library is on the side of a street, an end entrance near the street side is convenient.

Another participant, Franz, is a practicing architect and also a design teacher. His conclusion is similar to that of Benny's, although based on slightly different argument. His major point is that entrances should be close to geometric center except for certain exceptional uses. Benny and Franz's reasoning can be expressed in FRCs shown in Figure 9.

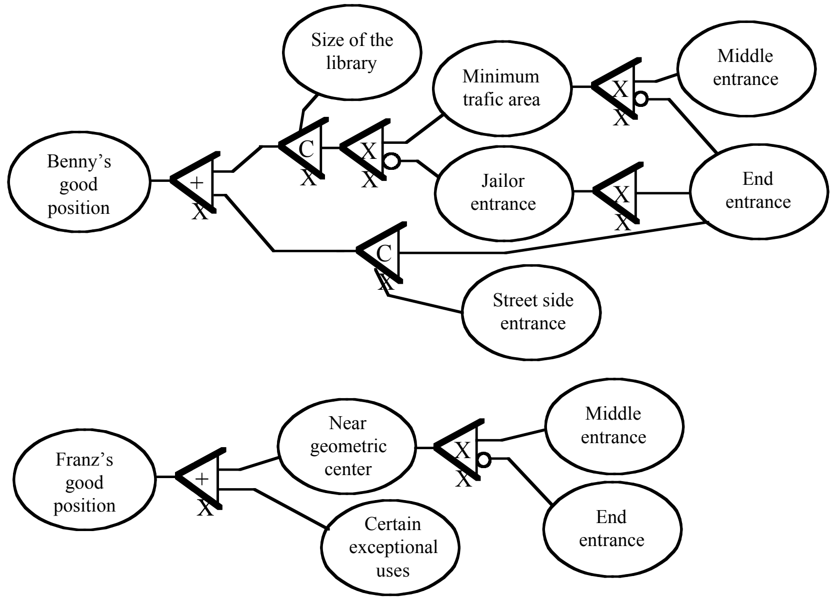


Figure 9. Benny and Franz's reasoning for good choice of entrance position.

5. Discussions

FRS-IBIS system not only records the architects' opinion but also carries the architects reasoning system and capable of conducting analysis accordingly.

Instead of trying to exhaust all possibilities (every possible entrance position in the example) with countless number of rule or cases, the FRS uses a mapping function based on reasoning that links certain characteristic measurements (such as distance to the geometric center in the example) of the possibilities to the conclusion. Therefore, the system is capable of dealing with new situations on its own without additional specific instructions from the architect regarding each and every case. In fact, this is the way human keep and use their knowledge. We do not and can not learn and remember all possible cases one by one. We use our general knowledge and reasoning skill to deal with new situations and new possibilities all the time, especially in the process of creative design.

The paradigm introduced in this article is different from expert system's approach where a universal applicable and complete knowledge system is expected. The approach we take is to allow an architect to express his/her opinion, knowledge, reasoning pattern and analysis criteria, at a certain condition under a particular context. The system is constructed for a particular design domain and even a particular design problem. For a different design problem a different system with different nodes and links are constructed. Furthermore, the system is being continuously modified and reconstructed during the process of problem resolving, for design criteria are evolving throughout the process.

6. Conclusions

In this paper we introduced Fuzzy Reasoning System (FRS) as an enhancement to the Issue-based Information System (IBIS). The enhanced FRS-IBIS not only qualitatively but also quantitatively describes the relations among various issues involved in a design problem. This system forms a general tool to facilitate design by argumentation with objectified evaluation criteria and evaluation process.

With the Fuzzy Reasoning Charts (FRC), the FRS-IBIS describes the relations among various issues in a not only more detail but also more clear form. With the Fuzzy Equations (FRE), the FRS-IBIS allows the design reasoning process be communicated not only between human designers but also between human and machines. In FRS-IBIS, the design reasoning and argumentation process are quantified through fuzzy logic techniques. With such quantification, design reasoning and argumentation process can be dictated to and, in turn, performed by a machine, a digital computer for instance. This automated reasoning capability provides an essential element, evaluating system, for an automated design assisting machine, for evaluation and composition are the two most fundamental components in a design process.

An example of hypothetical design problem given in this article, and an example of a real design analysis (Cao, 1994), demonstrated the potential of using FRS-IBIS in practices. Applications of the system in design of practical scales need to be further studied. As the FRS-IBIS offers a potential sub-component in a design assisting machine, the possibilities of combining the FRS-IBIS into an automatic/semi-automatic design assisting machine also calls for further investigation. A potential candidate for such design assisting system is based on evolution programs, where the FRS-IBIS can be used for evaluation and selection and the final design will be evolved through such selection and random mutation. Such a automated design assistant system is calling for further investigation.

7. References

Akin, O. (1993) "Architects' reasoning with structures and functions," *Environment and planning B: planning and design*, Vol. 20, 273-294.

Black, M. (1937) "Vagueness: an exercise in logical analysis," *Philosophy of Science*, Vol. 4, pp. 427-455.

Cao, Q. (1992) "Deliberated performance evaluation and application in comfort assessment," Ph.D. dissertation, University of California, Berkeley, California.

Cao, Q. and Protzen, J-P. (1994) "Aggregation and uncertainties in deliberated performance evaluation," in *Models and Experiments in Risk and Rationality*, Kluwer Academic Publisher.

Cao, Q. (1994) "Design Analysis Based on Fuzzy Reasoning," *Artificial Intelligence in Design '94*, pp. 679-696, Kluwer Academic Publishers.

Cao, Q. (1996) "A Knowledge-Based Design Analysis System," *Environment and Planning B: Planning and Design*, 1996.

Cuff, D. (1991) *Architecture: The Story of Practice*, MIT Press, Cambridge, pp. 72-84.

Grant, D. (1992) "Argumentative information and decision systems," *Design Methods: theories, research, education and practice*, 26, 1524-1588.

Hashim, S. H. (1990) *Exploring Hypertext Programming: writing knowledge representation and problem-solving programs*, Windcrest Books, Blue Ridge Summit, PA.

Hillier, W. and Leaman, A., "How Is Design Possible? A Sketch for a Theory," DMG/DRS Journal, Vol. 8, No. 1.

Kosko, B (1993) *Fuzzy Thinking: The New Science of Fuzzy Logic*, Hyperion, New York.

Kuntz, W. and Rittel, H. W. J. (1970) “Issues as Elements of Information System," Working Paper 131, Center for Planning and Development Research, University of California, Berkeley, California.

McCall, R. (1991) “PHI: a conceptual foundation for design hypermedia," *Design Studies*, Vol. 12, No 1, January.

Musso, A. And Rittel, H. R. (1967) “Measuring the performance of buildings," report about a pilot study, Washington University, St. Louis, Missouri, September.

Polya, G. (1954) *Induction and Analogy in Mathematics*, Volume I & II of mathematics and plausible reasoning, Princeton University Press, Princeton, New Jersey.

Rittel, H. (1972) “Interview with D. P. Grant and J. P. Protzen”, in D. Grant (edt.), *Design methods group: 5th anniversary report*, DMG OP1, Dept. of Architecture, University of California, Berkeley.

Rittel, H. (1973) “Dilemmas in a general theory of planning”, *Policy Sciences*, 4, 155-67.

Toulmin, S., Rieke, R. and Janik, A. (1984) *An Introduction to Reasoning,* 2nd eds., Macmillan Publishing Company, Inc., New York.

Schon, D. (1988) “Designing: Rules, types and worlds," *Design Studies*, Vol. 9, No 3, July, pp. 181-190.

Tweed, C. (1994) “Intelligent Authoring and Information System for Regulatory Codes and Standards," The International Journal of Construction Technology, Vol. 2, No 2, pp. 53-63.

Yager, R. and Zadeh, L. A., (eds.) (1993) An Introduction to Fuzzy Logic Applications in Intelligent Systems, Kluwer Academic Publishers.