

# FRAMEWORK FOR CASE-BASED REASONING TO SUPPORT IDEA ASSOCIATION IN A BRAINSTORMING SESSION

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**Abstract.** This research makes use of a cognitive approach to explore a mechanism for associating ideas in a brainstorming session. Firstly, we propose a linking model integrating three principles of idea association (*similarity*, *contrast* and *contiguity*) with two processes of case-based reasoning (*retrieval* and *adaptation*). Based on this linking model, an experiment is conducted to elucidate the interactions between ideas and cases, and their mechanisms of retrieval and adaptation. Finally, a framework for case-based reasoning to support idea association called *Idea-Maps* is proposed, and its mechanism is elucidated.

## 1. Introduction

Design is creative behavior that depends on the evolution of many ideas. Brainstorming provides a clear technique for generating ideas (Osborn, 1963), whose purpose is to generate a quantity of ideas that can serve as leads to the development of possible design alternatives (Petrovic, 1997). However, related problems of cognition and computation have not yet been explored. Current technology has developed a cognitive means of understanding human thinking and a computational means of retrieving experience. Brainstorming is an area of research that is now strongly affecting the development of design concepts. *Idea association*, as identified by Osborn (1963), provides some effective principles that can be applied to computation in terms of understanding the issue of brainstorming.

Brainstorming is a collaborative activity. Through interaction with different participants, designers interplay with the inner knowledge and experiences of their partners. There is a tendency to use design cases as references and to extract past experience for generating ideas. A

computational mechanism, called case-based reasoning (CBR) (Kolodner 1993), promises to support design by reminding designers of previous experiences that can be helpfully applied to new situations (Maher et al., 1995; Chiu, 2001). By introducing the principles of idea association to integrate with the processes of CBR, this paper proposes a framework of CBR to support idea association in a brainstorming session.

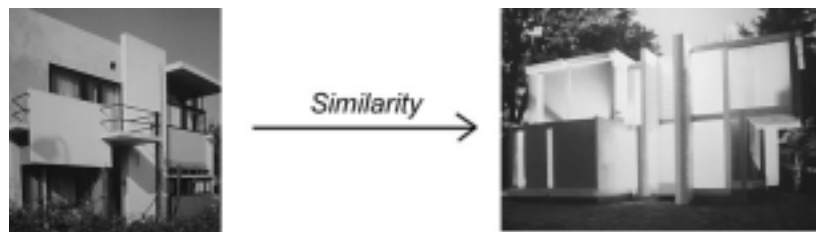
### 1.1. THREE PRINCIPLES OF IDEA ASSOCIATION IN A BRAINSTORMING SESSION

Brainstorming is a well-known method for supporting the divergent thinking process in obtaining diverse information (Osborn, 1963). A group of experts who have the same knowledge domain participate in interactive communication. Many researchers use brainstorming as a creative problem solving technique to assist design groups in exploring the problem space and generating a wide variety of novel ideas, thus obtaining an overview of potential design directions (De Bono, 1970; Lugt, 2000).

Osborn (1963) identified an important aspect of idea generation in a brainstorming session, called idea association. Idea association is a method by which one idea leads to another idea by a connection made in long-term memory. The three principles of idea association are similarity, contrast and contiguity. These principles were originally identified by Aristotle, but remain important in current context. Each principle has characteristics and applications to architectural design, as described the following sections.

#### *1.1.1. Similarity*

Similarity is a notion that objects have attributes in common with other objects. In a design process, designers always use the similarity of architectural elements (such as similar forms, programs, site conditions, etc.) to solve design problem as well as generate ideas. For example, in the case of the Frank House designed by Peter Eisenman, the idea “layering” comes from the similar form composition of the Schröder House designed by Gerrit Rietveld (Figure 1). The degree of similarity is an important factor for associating ideas.



*Figure 1. Similarity between the Schröder House and the Frank House*

### 1.1.2. Contrast

Contrast is the comparison of similar objects to set off their dissimilar qualities. Designers always are inspired to generate ideas by using a contrast factor, such as inside and outside, private and public, solid and void, figure and ground and so on. For example, Villa Savoye designed by Le Corbusier is transformed from an aristocratic town house in Paris through its inversion of the traditional interior spatial system (Figure 2). Shigeru Ben creates a curtain-like facade in Curtain Wall House by turning it inside out dynamically.

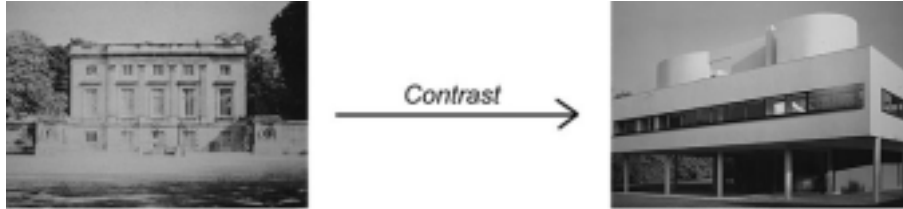


Figure 2. Contrast between Petit Trianon and Villa Savoye

### 1.1.3. Contiguity

Contiguity involves adjacent or causal relationships. Designers always generate ideas through responding to the “constraints” of design problems, such as external (site, view, prevailing winds, environmental criteria), internal (function, program, structural criteria), budget or other pragmatic criteria. For example, Villa Malaparte designed by Adalberto Libera is built on the edge of a cliff. He created the idea “roof-solarium” in response to the site constraints (Figure 3).



Figure 3. Contiguity between Villa Malaparte and site constraints

## 1.2. TWO PROCESSES OF CBR: RETRIEVAL AND ADAPTATION

In design computation, CBR is a research paradigm that uses design cases for solving a new problem based on previous design experience by analogical reasoning (Leake, 1996; Kolodner, 1993). *Retrieval* and *adaptation* are two important processes of CBR to access case bases directly (Maher et al., 1995). Therefore, many researchers are examining the

application of analogical reasoning to retrieve and adapt *similar* design cases to new cases (Flemming, 1994; Dave et al., 1994; Oxman, 2003) in different architectural design areas.

### 1.2.1.Retrieval

Reminding is a key component of analogical reasoning through cases: in other words, a person or computer must be reminded of the appropriate case at the right time (Tsatsoulis and Williams, 2000). The recall of a case in CBR is called retrieval. To retrieve a case from memory, a CBR system must decide whether it is the most appropriate one for the current situation based on comparing a degree of similarity. Therefore, similarity assessment is the main factor for recalling cases. Retrieval will be greatly influenced by the way that the case is organized.

### 1.2.2.Adaptation

In general, the process of changing the old, retrieved solution to fit the current problem is called case adaptation. Furthermore, Dave, et al. (1994) argued that there are two methods to generate design solution efficiently: case *adaptation* and case *combination*. Case combination employs the same techniques as case adaptation, but the major difference is that two or more cases need to be selected from the case library and areas of interest in each case need to be specified. In addition, these two methods of adaptation involve a series of operations to transform old cases: deleting, adding, and substituting (Chiu and Shih, 1994; Tsatsoulis and Williams, 2000).

## 1.3. A LINKING MODEL BETWEEN IDEAS AND CASES

While idea association is a method by which one idea leads to another by linking experience, design cases as experience are represented as bridges among ideas. Besides similarity, we hypothesize that contiguity and contrast provide another powerful and dynamic linkage between cases and ideas for associating ideas. Also, there are two mechanisms involved in the association of ideas in brainstorming. They are to recall the relevant cases, and to adapt or combine ideas with cases.

Based on the above hypothesis, we propose a linking model between ideas and cases for idea association. The linking model is composed of idea elements and two kinds of functions: retrieval and adaptation. The retrieval function includes three parameters: similarity ( $\mu_{si}$ ), contiguity ( $\mu_{ci}$ ) and contrast ( $\mu_{cr}$ ). The adaptation function includes two methods: adaptation ( $\varphi_a$ ) and combination ( $\varphi_c$ ). Each adaptation method is composed of several operations such as deleting, adding, and substituting. Thus, a present idea (input) linked with cases or previous ideas is transformed into new ideas (output) through the linking model, which can be formulated as follows:

$$\mathbf{I}'' = \varphi(\mathbf{I}, \mathbf{I}', \mathbf{C}) \quad (1)$$

$\mathbf{I}''$ : new idea  
 $\mathbf{I}$ : present idea  
 $\mathbf{I}'$ : previous idea  
 $\mathbf{C}$ : retrieval case  
 $\varphi$ : adaptation function

$$\mathbf{I}' = \mu(\mathbf{I}) \quad (2)$$

$\mu$ : retrieval function

$$\mathbf{C} = \mu(\mathbf{I}) \quad (3)$$

$\mu$ : retrieval function

$$\varphi = \{\varphi \mathbf{a}, \varphi \mathbf{c}\} \quad (4)$$

Where  $\varphi \mathbf{a}$ : adaptation method  
 $\varphi \mathbf{c}$ : combination method

$$\mu = \{\mu \mathbf{si}, \mu \mathbf{ci}, \mu \mathbf{cr}\} \quad (5)$$

Where  $\mu \mathbf{si}$ : similarity parameter  
 $\mu \mathbf{ci}$ : contiguity parameter  
 $\mu \mathbf{cr}$ : contrast parameter

Protocol analysis is a useful methodology for exploring the understanding of design behaviors (Ericsson and Simon, 1993). For elucidating the mechanism of the linking model, the following studies were undertaken: 1) conducting a design experiment; 2) studying the process by using protocol analysis, and 3) analysis of the transformation of ideas with reference to cases based on the linking model. Finally, a seamless integration with CBR to support idea association will be proposed.

## 2. The Experiment

The purpose of the design experiment was to understand how idea association is processed, which included the interactions between ideas and cases, and their mechanisms of retrieval and adaptation.

### 2.1. DESIGN TASK

The design task was related to the spatial organization of a single-family house in a historical temple town, and concentrated on developing ideas in the early conceptual design stage. Participants were asked to examine the site and the cases before the meeting. For understanding how degree of

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similarity influences idea association, a case library composed of two types of single-family houses was provided as shown in Figure 4. The two types were row houses and detached houses designed by well-known architects, such as Le Corbusier, Rem Koolhaas, Tadao Ando, etc. Each house has its individual design ideas of spatial organization. Participants were encouraged to study the cases, and to select several for generating ideas in the design process.

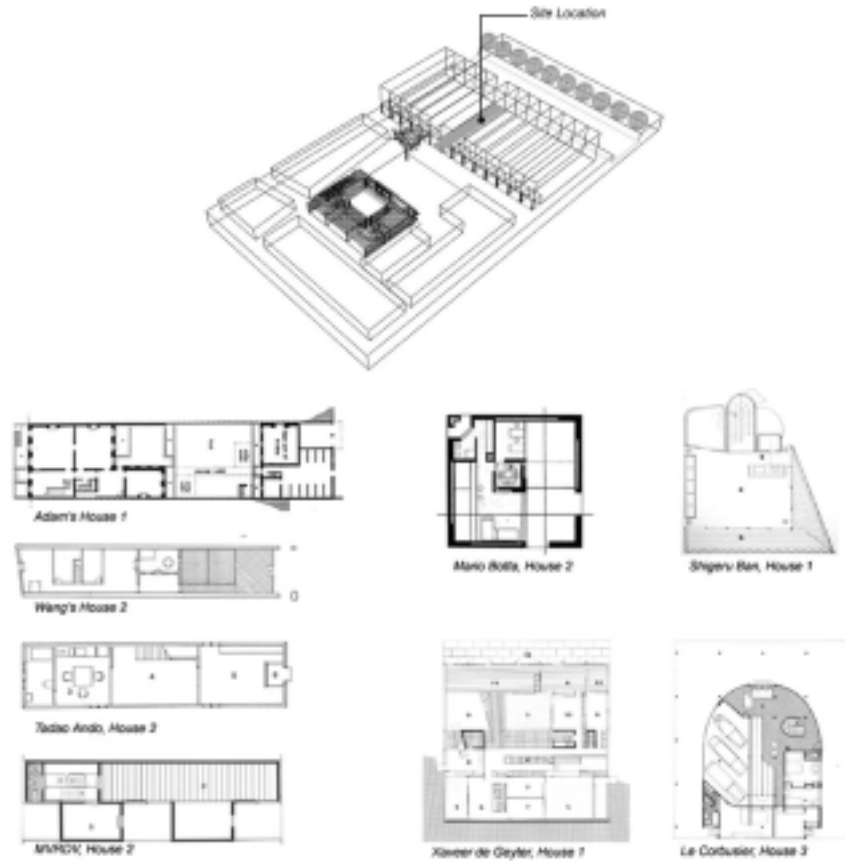


Figure 4. The design task and provided case library

### 2.2. PARTICIPANTS

We chose three designers in order to keep the group process simple and observable. Besides, we expected the group members to be very fluent in the idea generation process. They were accustomed to working together and trained in applying brainstorming techniques. All participating designers had sufficient skill levels in designing and drawing.

### 2.3.PROCESS

Three design experts were involved in a brainstorming session with a total duration of 45 minutes. A design problem was given to the participants. For generating ideas, each participant applied different media (such as sketches, words, images) and thought aloud about the ideas and cases they had retrieved from memory. At the same time, they wrote down and numbered their ideas and recalled cases chronologically. The information was recorded on flip charts that were then posted on the wall, and the whole process was recorded by digital video. Finally, 23 ideas were generated in this meeting. In brief, the brainstorming session plan consisted of the following steps (Figure 5).

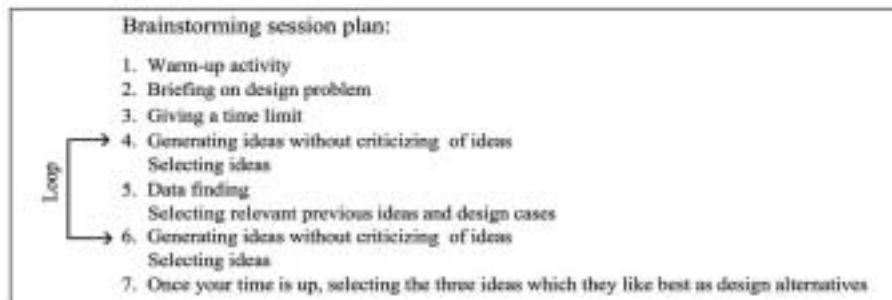







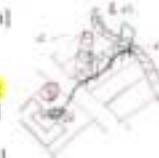
Figure 5. Process plan of the brainstorming session

### 3. The Analysis and Observations

The videotape of this meeting was transcribed into a protocol. Related sketches were pasted into the protocol at the location in which the idea came up. Several conceptual vocabularies or keywords (marked in gray) of text that could be ascribed to single ideas were selected. Each was given a title as idea name that briefly described this idea. For example, let us look at idea 09 'Placing void boxes'. At this point in the process idea 09 were generated by the designer (L), and he was invited to provide sketches. At the same time, the designer (L) recalled a design case 'Wang's house' that was marked in box (seen in Table 1).

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TABLE 1. Sample of idea fragments in the protocol

Idea/ Person	Idea name	protocol text	Sketches
05L	Floating building	L: Well, we can create a <b>floating space</b> for connecting river side and temple plaza on the ground floor. C: It's a good idea, but it will cause some problems about public domain influences house privacy. L: We should take care this situation...	
06M	Lifting lobby	M: Let me recall my case library (laugh). OK! I got one! <b>Villa Savoye</b> has a <b>lifting lobby</b> which can solve this problem. [images] C: <b>Peter Koolhaas</b> has the similar house project in France.	
07L	Elevator entrance	L: I know this project. There is a elevator room in living space. Maybe we can create a <b>elevator entrance</b> on the ground floor. [images] M: Interesting! It will cost a lot of money.....	
08C	Placing solid boxes on the ground floor	C: See my sketch, we can <b>place solid boxes</b> instead of free columns on the ground floor. [Ideasketch]	
09L	Placing void boxes	L: How about <b>placing void boxes</b> . It can respond to the traditional urban context. Just like the <b>Wang's house</b> . You see! there are two courtyard spaces here. [images] M: It can help us to solve sunlight and ventilation problems. The courtyards in <b>Xavier de Greyer's house</b> project are more dynamic and interesting. [images]	
10L	Connecting solid boxes with void boxes	L: Oh, yes. Maybe we can combine this two ideas: <b>connecting solidboxes with void boxes</b> vertically. C: Interesting!	
11M	Roof garden	M: We can create a <b>roof garden</b> to provide good views of riverside and temple plaza. Like <b>Villa Savoye</b> , the ramp can connect different void spaces in different floors, which create a vertical <b>strolling circulation</b> . [Ideasketch]	
12M	Strolling circulation	L: Oh, yes.	
13C	Bridge across garden	C: The Gardens can be across by <b>bridges</b> .	
14L	Seeing cylinder in the arcade	L: See idea 08, we can create a <b>cylinder extruding ceiling of arcade</b> to provide a visual focus in street. [Ideasketch]	
15C	Infilling water	C: How about water? Maybe we can <b>infill water</b> on the ground floor for responding river condition [Ideasketch]	

For understanding the dynamic idea network, the following analysis will be concentrated on how many types of linkages were involved in the idea network, and what were the mechanisms (retrieval, and adaptation or combination) of each type of linkage.

### 3.1. TYPES OF LINKAGES

According to the fragment of the protocol from ideas 5 to 15 (Table 1), ideas and design cases had dynamic linking relationships in the process of idea association. In addition, for generating new ideas (output), a present idea (input) links not only design cases (long-term memory) but also previous ideas (working memory). Consequently, a complex idea network involving several types of linkages was mentally constructed that inspires participants to generate diverse ideas.

In this idea network, each linkage is dynamically added or deleted according to each participant's interpretation. At the same time, two directions in linking ideas and cases were involved: forward linking and backward linking. Basically, we can classify five types of linkages in the dynamic idea network seen in Figure 6 as follows:

1. Forward linking between ideas: an input idea stimulates a designer to generate the next ideas forward.
2. Backward linking between ideas: an input idea makes a designer recall the previous ideas backward, and then is adapted or combined with the previous ideas.
3. Forward linking from cases to ideas: a case stimulates a designer to generate the next ideas forward.
4. Backward linking from ideas to cases: an input idea makes a designer recall the case library backward.
5. Backward linking between cases: a case makes a designer recall another cases in the case library backward

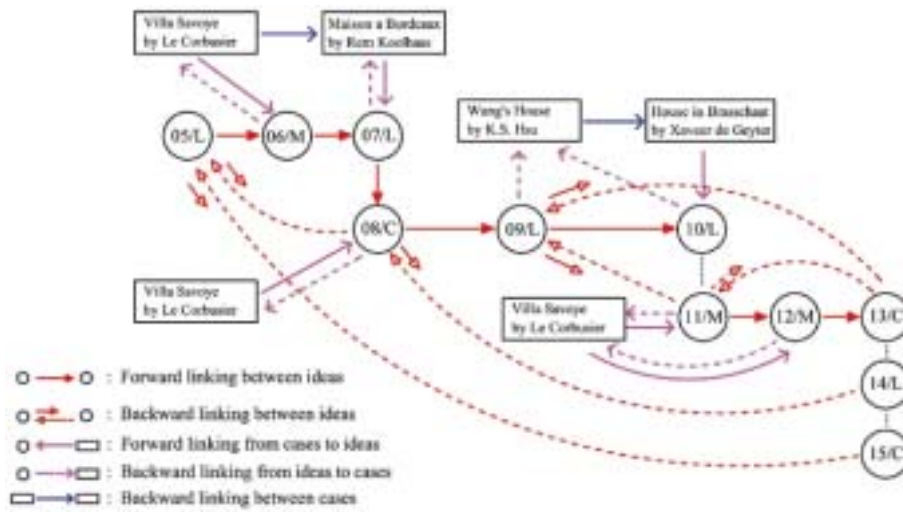


Figure 6. A dynamic idea network

### 3.2. MECHANISMS OF LINKAGES

In addition, each type of linkage has its individual mechanism in retrieving cases and adapting ideas. By encoding the three retrieval parameters ( $\mu_{si}$ ,  $\mu_{ci}$ ,  $\mu_{cr}$ ) and two adaptation methods ( $\varphi_a$ ,  $\varphi_c$ ), the study uses link matrices to understand the mechanisms of different types of linkages. Thus, two link matrices were analyzed: a link matrix between ideas and a link

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matrix between ideas and cases. In the two matrix displays, each cell of the matrix contains linking directions (backward or forward), retrieval parameters and adaptation methods (Table 2). Besides, in the matrix display between ideas and cases, the arcs signify the mechanism of linkage between design cases (Table 3).

TABLE 2. Link matrix between ideas

		05	06	07	08	09	10	11	12	13	14	15
05/L	Floating building		for uci, qc		back usi, qa							back usi, qa
06/M	Lifting lobby			for uci, qc								
07/L	Elevator entrance				for uci, qc							
08/C	Placing solid boxes on the ground floor					for uci, qc	back usi, qa		back usi, qa			back usi, qa
09/L	Placing void boxes						for uci, qc	back usi, qa		back usi, qa		
10/L	Connecting solid boxes with void boxes								back usi, qa			back usi, qa
11/M	Roof garden								for uci, qc	back usi, qa		
12/M	Strolling circulation									for uci, qc		
13/C	Bridge across garden											
14/L	Seeing cylinder in the arcade											
15/C	Infilling water											

TABLE 3. Link matrix between ideas and cases



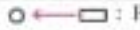
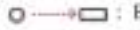

		Villa Savoye by Le Corbusier	Maison a Bordeaux by Rem Koolhaas	Wag's House by K.S. Hsu	House in Strauchan by Xavier de Geyter
05/L	Floating building				
06/M	Lifting lobby	back; for;	uci qc		
07/L	Elevator entrance			for; qc	
08/C	Placing solid boxes on the ground floor	back; for;	usi qa		
09/L	Placing void boxes			back; uci	
10/L	Connecting solid boxes with void boxes				for; qc
11/M	Roof garden	back; for;	usi qa		
12/M	Strolling circulation	back; for;	uci qc		
13/C	Bridge across garden				
14/L	Seeing cylinder in the arcade				
15/C	Infilling water				

Within the two matrices, each cell clearly articulates retrieval parameters, adaptation methods and linking directions between ideas, and between ideas and cases. For example, within the matrix between ideas, idea 09 ‘placing

void boxes' has one backward link with ideas 11 'roof garden', and a forward link with idea 10 'connecting solid box with void boxes'. One linkage uses the contiguity parameter ( $\mu_{ci}$ ) and the combination method ( $\varphi_c$ ) to link idea 09 with idea 10 forward. Another linkage uses the similarity parameter ( $\mu_{si}$ ) and the adaptation method ( $\varphi_a$ ) to link idea 11 with idea 09 backward. Idea 09 also has a contrast relationship with idea 08 'placing solid boxes on the ground floor'.

Generally, the contiguity parameter ( $\mu_{ci}$ ) and the contrast parameter ( $\mu_{ci}$ ) play important roles for forward linking between ideas as well as between ideas and cases. Though the similarity parameter ( $\mu_{si}$ ) plays an important role for linking previous ideas backward, the contiguity parameter ( $\mu_{ci}$ ) and the contrast parameter ( $\mu_{ci}$ ) provide another ways for linking cases backward. Besides, combination ( $\varphi_c$ ) is a main method for linking ideas and cases forward. Contrarily, adaptation ( $\varphi_a$ ) is a main method for linking ideas and cases backward. Also, in backward linking, the higher degree of similarity plays an important role for retrieving previous ideas and cases. Therefore, the mechanisms of five types of linkages can be identified in Table 4.

TABLE 4. Different mechanisms related to five types of linkages

Types of linkages	Retrieval parameters	Adaptation methods
 : Forward linking between ideas	$\mu_{cr}, \mu_{ci}$	$\varphi_c$
 : Backward linking between ideas	$\mu_{si}$	$\varphi_a$
 : Forward linking from cases to ideas		$\varphi_a, \varphi_c$
 : Backward linking from ideas to cases	$\mu_{cr}, \mu_{si}, \mu_{ci}$	
 : Backward linking between cases	$\mu_{si}$	$\varphi_a$

In addition, visual expression (such as sketches, images, 3D model) is a strong device for participants to communicate and generate ideas successfully in the process of idea association. Based on the above observations, we propose a framework of CBR called Idea-Maps to support idea association in a brainstorming session as described in the following section.

#### 4. Idea-Maps: A Framework for CBR to Support Idea Association

Idea-Maps is proposed to support designers for associating ideas in an interactive and immediate idea exchange meeting. Basically, Idea-Maps is

composed of five types of linkages. Each type of linkage has its individual mechanisms of retrieval and adaptation between ideas and cases (Table, 2). Therefore, Idea-Maps can be considered as a dynamic knowledge structure through a graph-like structure of nodes and links. The nodes represent conceptual elements ( $I'$ ,  $I$ ,  $I$ ,  $C$ ), while the links represent the relationships between cases and ideas depicted as three retrieval parameters ( $\mu_{si}$ ,  $\mu_{ci}$ ,  $\mu_{cr}$ ). The conceptual elements and retrieval parameters can be dynamically added, deleted and substituted according to each participant's interpretation in a brainstorming session. Also, two adaptation methods ( $\phi_a$ ,  $\phi_c$ ) can automatically track these linkages to interact with different design situations dynamically. Finally, the CBR framework should consist of three parts: the reasoning mechanism, a case library, and a dynamic linking process (Figure, 7).

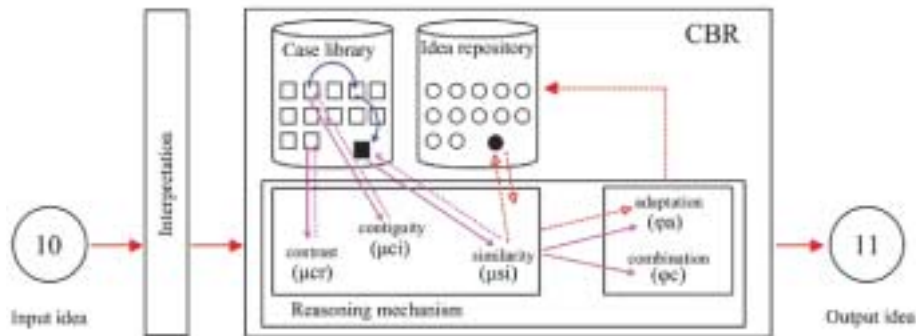


Figure 7. The CBR framework for Idea-Maps

Idea-Maps concentrates on generating design ideas related to spatial organization in the early conceptual stage of the design process. In this stage, the role of cases is to inspire designers to generate ideas by providing them with meaningful and related ideas in conjunction with those of the other participants'. Therefore, the focus of Idea-Maps is more specifically on representing the conceptual knowledge embedded within design cases, and making it fit to be searched and browsed within a computerized library of design precedents. According to our previous research (Lai, 2002; Lai and Chang, 2003), the conceptual knowledge should include design issues, affinity for concepts, and associated design solutions.

Design is a visual process involving reflective behavior (Schon and Wiggins, 1992). Using visual expression to represent ideas and cases is another important characteristic of Idea-Maps. Therefore, the conceptual knowledge in Idea-Maps can be expressed as a text associated with multimedia. Briefly, Idea-Maps can be considered as the confluence of

visual representations and metaphorically semantic content. It provides an understandable framework of organizing information about design ideas and cases. Without altering the existing conceptual structure, the conceptual elements and the mechanisms of linkages can be dynamically transformed (added, deleted and substituted) at any time. It will be beneficial to a creative problem solving meeting in the task domain of early conceptual design in architecture.

## 5. Conclusion

This paper provides a basic understanding of the dynamic linkages between ideas and cases in the process of idea association. In the process, design cases can be considered as important stimuli for generating ideas. Also, different types of linkages between ideas and cases can be formulated as a dynamic idea network that can be thought of as an implicit knowledge structure. The proposed CBR framework "Idea-Maps" can express the knowledge structure explicitly to inspire and generate diverse ideas effectively. Idea-Maps can be developed as a support system with the function of automatically tracking these linkages and generating ideas (knowledge) into the system to enhance diversity of case retrieval and learning ability of case adaptation.

In future research we will investigate a computational approach of Idea-maps, including case representation, searching mechanisms, adaptation algorithms, etc. We will also explore a pedagogical framework integrated with Idea-maps to inspire students to generate creative ideas in design studio learning.

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