Dynamic Idea Maps: A Framework for Linking Ideas with Cases during Brainstorming

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This research makes use of a cognitive study to explore a mechanism for associating ideas during brainstorming. First, we propose a linking model that integrates three principles of idea association (similarity, contrast and contiguity) with two processes of case-based reasoning (retrieval and adaptation). Then, a design experiment and its protocol analysis are conducted in order to identify the types and mechanisms of linkages between ideas and cases, and to explore a computational mechanism for this linking model. Finally, a framework for case-based reasoning to support idea association called Dynamic Idea-Maps (DIM) is proposed, and its mechanism is elucidated.
1. INTRODUCTION

Design as a creative behaviour is dependent on the evolution of many diverse ideas, especially in the early conceptual design stage. Brainstorming provides a clear technique for evolution of design ideas, the purpose of which is to generate a quantity of ideas that can serve as leads to the development of possible design alternatives [1]. Idea association, as identified by Osborn [2], is an important behaviour in brainstorming for generating diverse ideas. Through linking designers' long-term memory internally and various participants' knowledge externally, diverse design ideas are generated during the design process. Therefore, a computational system for supporting the linking process of idea association is the critical issue for further understanding of design behaviour in the early conceptual design stage.

In addition, idea association provides some cognitive principles that are investigated in this paper. These principles play important roles for generating diverse ideas in architectural design. We applied such principles to modelling of our computational system according to the needs of supporting idea association during design brainstorming meeting.

There is a tendency to use design cases as references and linking past experience with current ideas for generating ideas during brainstorming. A computational mechanism, called case-based reasoning (CBR) [3], promises to support design by reminding designers of previous experiences that can be helpfully applied to new situations [4-5]. Retrieval and adaptation are two important processes of CBR that provides some computational ways to link ideas with design cases.

By integrating the principles of idea association with two processes of CBR, this research intends to explore the linking relations between ideas and cases. The objective is to propose a framework of CBR to support idea association during brainstorming. The principles and CBR processes are elaborated in the following sections.

1.1. Three principles of idea association during brainstorming

Brainstorming is a well-known method for supporting the divergent thinking process involved in obtaining diverse information [2]. A group of experts who have the similar knowledge domain participate in an interactive idea exchange meeting. 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 the potential design directions [6, 7]. Idea association is a behaviour by which one idea leads to another idea by a linking made in long-term memory. During brainstorming, participants apply this behaviour to link and generate diverse ideas through three principles of idea association. The three principles summarized by Ancient Greek are similarity, contrast and contiguity.

In Greek, the word "idea" means "appearance of a thing". Rhodes [8]
defines idea as “...a thought which has been communicated to other people in the form of words, paint, clay, metal, stone, fabric, or other material”. In architectural design, Lugt [7] argues that ideas need to be related to the design task at hand and they need to provide some kind of a solution besides communication. Therefore, an idea can be considered as a solution for solving a specific problem within a given task, including design problem and its solution. By applying different media (such as sketches, words, or image photos), an idea can be represented in different views effectively as shown in Figure 1.

For design behaviours, designers are used to decomposing a design into several architectural elements and their attributes [9], and use these elements’ attributes as keys to look for relevant ideas. In addition, human are unique in their capacity to use symbols to represent idea meanings and construct relationships between ideas to explain how things appear or work [10]. Therefore, designers are used to applying the domain conceptual vocabularies as symbols to represent these attributes and elements within design ideas and construct their relationships [11]. For example, in order to solve the circulation problem between a riverside and a temple plaza, the designer uses several conceptual vocabularies (such as circulation, view corridor and path through) as symbols to describe the problem and its solution within a design idea (Figure 1).

For linking related ideas in conjunction with other participants’ during brainstorming, Goldschmidt [12] and Lugt [7] indicate that the relationships among generated ideas play the important role for building on other ideas. They call such relationships as design move and linking respectively. Three principles of idea association mentioned before provide human to generate ideas as well as relationships [2]. Therefore, designers often apply the three principles as the strategies for generating diverse design ideas and their relationships based on designers’ individual interpretation of ideas. According to the context and information attributes of ideas described
above, these principles have different mechanisms to link design ideas, as described in the following sections.

**Similarity**

Similarity is a notion that elements have attributes in common with other elements. Designers use the similarity principle to link ideas with similar design solutions for the same design problem. For example, the Schröder House designed by Gerrit Rietveld and the Frank House designed by Peter Eisenman have similar design solutions “layering walls” for the problem about “wall composition”. By linking the two design cases through the similarity principle, a designer can generate two similar ideas that use “layering walls” for solving the problem about “wall composition” (Figure 2).

**Contrast**

Contrast is the comparison of similar elements to set apart their dissimilar qualities. Designers use the contrast principle to link ideas with contrast design solutions for the same design problem. In view of the fact that designers often describe design ideas with conceptual vocabularies [11], contrast conceptual vocabularies (such as public and privacy, solid and void, linear and centre etc) can be used to link contrast design ideas. Compared with the case of Villa Savoye designed by Le Corbusier, the aristocratic town house in Paris has a “solid form” on the ground floor for the problem about “form organization”. Thus, a designer can apply the contrast principle to generate a contrast idea that uses “void form” for solving the problem about “form organization”, and then link to the design case of Villa Savoye (Figure 3).
Contiguity

Contiguity involves causal relationships between elements. Since the mapping between design problems and their solutions, the contiguity principle can be practiced for finding ideas with different design problems according to the same solution. For example, Villa Malaparte, designed by Adalberto Libera, is built on the edge of a cliff. An idea is to use “roof-terrace” for solving the problem about “view” requirements. Through the contiguity principle, the designer can use the idea to link to another idea that uses “roof-terrace” for solving the problem about “landscape” (Figure 4).

1.2. Two processes of case-based reasoning

Designers are used to using design cases as references for generating design ideas [4]. Therefore, linking ideas can be treated as searching for relevant ideas among design cases. Design cases are considered as condensed knowledge of previous design experience that provides design solutions for problem solving [13-14]. Design cases are described as design stories, scripts, frames, etc. [11, 15]. Besides, Kolodner [3] defines “a case, which generally represents a concrete situation, integrates a multitude of complex information in a very concrete way.”

In design computation, CBR is a research paradigm that uses design cases for solving a new problem from previous design experience by analogical reasoning [3, 15]. Retrieval and adaptation are two important processes of CBR to access case bases directly [4]. By applying different case representation, many researchers examine the application of analogical reasoning to retrieve and adapt design cases to new cases [14, 16-19] in different architectural design areas. For linking ideas with design cases, the two processes of CBR provide some computational mechanisms that can be used in realizing our idea association.

Case retrieval

The recall of a case in CBR is called retrieval. The process of retrieval mainly contains two steps: case comparison and case selection [4, 20]. During retrieval, each case must be compared with the current problem and be assigned a degree of similarity. Then the retrieving mechanism will select...
the cases with the highest degree of similarity. 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 its degree of similarity with
the current situation.

**Case adaptation**

The process of changing the old, retrieved solution to fit the current
problem is called case adaptation. Dave, et al. [14] argues that there are two
kinds of case adaptation: adaptation and combination. Combination employs
the same techniques as adaptation, but the major difference is that two or
more cases need to be selected from the case library. Furthermore,
adaptation and combination use different operations to transform old cases,
including deletion, addition, and substitution [20-21].

Briefly, the three principles of idea association, including similarity,
contrast and contiguity, are applied as the strategies for generating design
ideas and their relationships during brainstorming. In employing knowledge
from prior design experience for problem solving, design ideas can be
accessed from design cases through retrieval and adaptation processes in
the computational way. Consequently, the three principles provide different
relationships among design ideas and cases.

**2. A LINKING MODEL BETWEEN IDEAS AND CASES**

While idea association is behaviour by which one idea leads to another by
linking experience, design cases as experience are represented as bridges
among ideas. For generating diverse ideas, we hypothesize that the three
principles identified in previous sections provide dynamic linking
relationships (called linkages) between ideas and design cases. Through the
three principles, there are two main processes involved in the process of
idea association as follows:

1. A designer retrieves previous ideas or design cases through comparing
current ideas, and selects the optimal idea.

2. The designer then adapts or combines current ideas with the
retrieved design cases or previous ideas.

Based on the above hypothesis, we propose a linking model for idea
association. The linking model is composed of idea entities and different
types of linkages. These idea entities include current ideas (Icurrent), design
cases (Ccase), previous ideas (Iprevious) and new ideas (inew). Through the
similarity (_si), contiguity (_ci) or contrast (_cr) principles, each linkage
employs retrieval (_r), adaptation (_a) or combination (_c) functions to link
these idea entities. In the linking model, the three principles and three
functions can be regarded as the linking principles and linking functions
respectively. Thus, the proposed linking model can be formulated as follows:
Inew = __(_Icurrent, _Iprevious, _Ccase) (1)

Inew: new idea
_Icurrent: current idea
_Iprevious: previous idea
_Ccase: design case
_: linking function
_: linking principle

_Iprevious = __r(Icurrent) (2)
_r: retrieval function

_Ccase = __r(Icurrent) (3)
_r: retrieval function

_= {_r, _a, _c} (4)
Where _r: retrieval function
_a: adaptation function
_c: combination function

_= {_si, _cr, _ci} (5)
Where _si: similarity principle
-cr: contrast principle
_ci: contiguity principle

Protocol analysis is a useful methodology for exploring the understanding of design behaviours [22]. For the purpose of 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) analyzing the transformation of idea entities with reference to cases based on the linking model. Finally, a seamless integration with CBR framework to support idea association will be proposed.

3. THE EXPERIMENT

The design experiment was conducted in order to identify the types and mechanisms of linkages between ideas and cases, and to explore a computational mechanism for the linking model described above.

Before the formal test, a ‘warm-up’ exercise was given to ensure that
participants completely understand the design task. The meetings were recorded on videotape that was then transcribed into protocols. In the design process, participants applied different media (such as sketches, words, image photos) to describe their ideas and recalled cases. At the same time, they wrote down their ideas and recalled cases, and numbered the ideas chronologically. The documentation was recorded on flip charts that were then posted on the wall.

3.1. Design task

The design task was related to the spatial organization of a row house for a single-family in a historical temple town, and concentrated on developing ideas in the early conceptual design stage. For understanding how to compare and select design cases, a case library composed of two types of single-family houses was provided: ten row houses and ten detached houses (Figure 5). These houses are designed by well-known architects, such as Le Corbusier, Rem Koolhaas, and Tadao Ando. Each house has its individual design ideas related to spatial organization. Participants were asked to examine the site and these design cases before the meeting. During the design process, participants were encouraged to select these design cases for generating design ideas.

![Figure 5: The design task and a provided case library.](image-url)
3.2. Participants

We chose three participants to keep the group process simple and observable. We expected the group members to be very fluent in the process of idea association. All participants were design experts who worked at the same architect office and were accustomed to working together. Also, the three design experts with similar design domain knowledge had sufficient skill levels in design and drawing, and were familiar with the above design cases.

3.3. Process

The meeting shared a general session plan with a total duration of 45 minutes. A design goal was given to each participant before associating ideas. Within the predefined duration of time, the design goal was to generate diverse design ideas that were related to three specific design problems including circulation, day lighting and view. Within the general plan, participants were encouraged to generate ideas without criticizing of ideas. All generated ideas and related documentation were collected for protocol analysis. In brief, the meeting plan consisted of the following steps (Figure 6).

4. THE ANALYSIS AND OBSERVATIONS

In this experiment, 23 ideas were generated by the participants. The videotape of the meeting was transcribed into a protocol. In the protocol from idea 5 to idea 15, we found some noticeable linking relationships between ideas and design cases. Therefore, the idea fragments were selected to analyze the transformation of idea entities in the process of idea association.

In the sample of idea fragments in the protocol (Table 1), related sketches were pasted into the protocol at the location in which the idea
came up. Several domain concept vocabularies (marked in grey) of text that could be ascribed to ideas were selected. Each was given a title as idea name that briefly described the solution within this idea. Besides, the recalled design cases were marked with boxes.

For example, let us look at idea 09 “Void boxes”. For solving the problem about day lighting, idea 09 was generated by the designer (L) that built on idea 08 generated by the designer (C). At the same time, the designer (L) recalled a design case “Wang’s house” that was marked with a box shown in Table 1. Furthermore, the designer (L) was invited to provide the idea sketch and image photos of Wang’s house.

<table>
<thead>
<tr>
<th>Idea name</th>
<th>Protocol text</th>
<th>Sketches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floating building</td>
<td>I: Well, we can create a floating building. It can solve the day-lighting problem and be responsive to the traditional Chinese context. Like the Yuan’s house.</td>
<td><img src="image" alt="Sketch of floating building" /></td>
</tr>
<tr>
<td>Lifting lobby</td>
<td>M: Let me suggest the idea of lifting the lobby. I have read about Villa Savoye.</td>
<td><img src="image" alt="Sketch of Villa Savoye" /></td>
</tr>
<tr>
<td>Elevator entrance</td>
<td>C: But I recall a new project in France. I have seen.</td>
<td><img src="image" alt="Sketch of elevator entrance" /></td>
</tr>
<tr>
<td>Solid house</td>
<td>B: Yes, we can place solid rooms instead of columns on the ground floor.</td>
<td><img src="image" alt="Sketch of solid house" /></td>
</tr>
<tr>
<td>Void house</td>
<td>1: How about placing void rooms? It can solve the day-lighting problem and be responsive to the traditional Chinese context. Like the Yuan’s house.</td>
<td><img src="image" alt="Sketch of void house" /></td>
</tr>
<tr>
<td>Solid house and void house</td>
<td>C: Oh, yes. We can combine the two ideas. Solid houses and void rooms are placed vertically.</td>
<td><img src="image" alt="Sketch of solid and void house" /></td>
</tr>
<tr>
<td>Roof garden</td>
<td>M: We can create a roof garden to provide good views of rivulets and temple plans. Like the Savoy House, the many can connect different void spaces in different floors.</td>
<td><img src="image" alt="Sketch of roof garden" /></td>
</tr>
<tr>
<td>Sterile circulation</td>
<td>M: We can create a sterile circulation which provides a small focus on the ground floor.</td>
<td><img src="image" alt="Sketch of sterile circulation" /></td>
</tr>
<tr>
<td>Bridge across garden</td>
<td>C: Yes, the bridge across garden will be interesting. Good idea!</td>
<td><img src="image" alt="Sketch of bridge across garden" /></td>
</tr>
<tr>
<td>Caffè in the air</td>
<td>1: In addition, we can create a Caffè in the air which provides a small focus on the ground floor.</td>
<td><img src="image" alt="Sketch of Caffè in the air" /></td>
</tr>
<tr>
<td>Infilling water</td>
<td>C: How about water? We can infill on the ground floor for improving air conditions. Also, it can solve the problem of view in mist.</td>
<td><img src="image" alt="Sketch of infilling water" /></td>
</tr>
</tbody>
</table>

**Table 1:** Sample of idea fragments in the protocol.
4.1. Types of linkages

According to the fragment of the protocol from ideas 5 to 15 (Table 1), ideas and design cases have various linkages in this process. For generating new ideas (I_{new}), a current idea (I_{current}) links with not only design cases (C_{case}), but also previous ideas (I_{previous}). Consequently, a complex idea network involving several types of linkages is constructed explicitly shown in Figure 7.

Basically, there are two linking directions (forward and backward) called forelink and backlink respectively. For example, in this idea network, idea 07 generated by the designer (L) has forlinks and backlinks with idea 06 and idea 08 that are generated by the designer (M) and the designer (C) respectively. Also, idea 07 has a forlink and a backlink with the design case of Maison a Bordeaux designed by Rem Koolhaas. Therefore, there are five types of linkages in the idea network as follows:

1. Forelink between ideas: a current idea stimulates a participant to generate new ideas forward.
2. Backlink between ideas: a current idea makes a participant recall the previous ideas backward.
3. Forelink from cases to ideas: a case stimulates a participant to generate new ideas forward.
4. Backlink from ideas to cases: a current idea makes a participant recall design cases in the case library backward.
5. Backlink between cases: a design case makes a participant recall other design cases in the case library backward.

4.2. Mechanisms of linkages

Each type of linkage has its individual mechanism to link with these ideas.
entities. By encoding the three linking principles \((\text{si, ci, cr})\) and three linking functions \((r, a, c)\), the study used two matrices to understand the mechanisms of different types of linkages: a matrix among ideas and a matrix between ideas and cases. Each cell of the matrices contains linking directions, linking principles, and linking functions (Table 2 and 3). Furthermore, the arcs signify the mechanism of the linkage between design cases (Table 3).

Within the two matrices, each cell clearly articulates the mechanism of the linkage. For instance, within the matrix among ideas (Table 2), idea 09 “Void boxes” has one backlink with idea 11 “Roof garden”, and a forelink with idea 10 “Solid box and void boxes”. The forelink uses the combination function \((c)\) to link idea 09 with idea 10 forward. The backlink uses the similarity principle \((\text{si})\) to link idea 11 with idea 09 backward. In addition, idea 09 also has a contrast principle \((\text{cr})\) linking with idea 08 “Solid boxes”.

In the matrix between ideas and cases (Table 3), idea 8 “Solid boxes” has two linking directions (a forelink and a backlink) with the design case of Villa Savoye designed by Le Corbusier. While the designer \((C)\) received idea 07 “Elevator entrance” from the designer \((L)\), the designer \((C)\) first applied the similarity principle \((\text{si})\) and the retrieval function \((r)\) to link the design case of Villa Savoye backward. Then he applied the similarity principle \((\text{si})\) and the adaptation function \((a)\) to link idea 7 “Elevator entrance” to idea 8 forward.

While the designer \((L)\) received idea 06 “Lifting lobby” from the designer \((M)\), the designer \((L)\) first applied the contiguity principle \((c)\) and the retrieval function \((r)\) to link the design case of Villa Savoye backward. Then he continuously linked the design case of Maison a Bordeaux designed by Rem Koolhaas through the similarity principle \((\text{si})\) and the retrieval function \((r)\) backward. Finally, the designer \((L)\) used the contiguity principle.
(\_ci) and the combination function (\_c) to link idea 07 “Elevator entrance” forward. According to the design problems, participants selected and compared design solutions within design cases through linking two types of design cases. Furthermore, these linkages were made with these design solutions rather than the whole instances of design cases.

Based on these analysis described above, the mechanisms of five types of linkages can be identified in Table 4. In forelinks, combination (\_c) and adaptation (\_a) are main functions to generate new ideas (\_new) through linking current ideas (\_current) with design cases (\_case) and previous ideas (\_previous) forward. As a sequence, these idea entities are combined through the congruity principle (\_ci), and are adapted through the similarity principle (\_si) and the contrast principle (\_cr). While two idea entities contrast each other in conceptual vocabularies and can either be applied to solve the same design problem or be used to solve different design problems, the two idea entities can be combined together through the contiguity principle (\_ci) such as idea 10 “Solid boxes and void boxes”. In addition, retrieval (\_r) is the main function in backlinks. In backlink between ideas, current ideas (\_current) can be linked with previous ideas (\_previous) backward through the three linking principles (\_si, \_cr or \_ci). In the backlink from ideas to cases, current ideas (\_current) can be linked with design cases (\_case) backward through the similarity principle (\_si) and the contiguity principle (\_ci). The similarity principle (\_si) also plays the important role in the backlink between cases. Besides, the higher degree of similarity plays an important role for retrieving previous ideas and design cases in backlinks.

\begin{table}[h]
\centering
\caption{The matrix between ideas and cases.}
\begin{tabular}{|c|c|c|c|}
\hline
\hline
\textbf{Idea} & \textbf{Case} & \textbf{Case} & \textbf{Case} \\
\hline
\textbf{Idea 07: Elevator entrance} & \textbf{Case 01: Floating Staircase} & \textbf{Case 02: Elevator Feature} & \textbf{Case 03: Solid House} \\
\hline
\textbf{Idea 08: Solid Boxes and Void Boxes} & \textbf{Case 04: Floating House} & \textbf{Case 05: Solid House} & \textbf{Case 06: Void House} \\
\hline
\end{tabular}
\end{table}
In addition, visual expression is a strong device for participants to communicate and generate ideas successfully in the process of idea association. Therefore, these participants often used idea sketches or image photos of design cases as concrete examples to substantiate the solutions using concept vocabularies. For example, the designer (L) used an image photo of Villa Savoye designed by Le Corbusier and an idea sketch to substantiate idea 05 “floating building” seen in Table 1 and Figure 8. Based on the above observations, a CBR framework called Dynamic Idea Map (DIM) to support idea association is proposed.

5. DYNAMIC IDEA MAP: A FRAMEWORK FOR CBR TO SUPPORT IDEA ASSOCIATION

During brainstorming, idea association involves an interactive and immediate process for linking memory dynamically. Due to the limitations of human memory, designers always have production blocking problems for generating ideas [23]. For example, during brainstorming, the waiting time can cause designers to forget the ideas, or to be less original or relevant with respect to the presently viewed idea. Therefore, DIM is proposed to support designer experts who have the similar design knowledge for linking and generating related ideas in conjunction with other participants’ immediately during brainstorming.

Basically, DIM is composed of five types of linkages. Each type of linkage has its individual mechanism for generating idea entities through different linking principles and linking functions. Therefore, DIM can be considered as an idea map generator, which can generate a dynamic knowledge structure through a graph-like structure of nodes and links. The nodes represent

<table>
<thead>
<tr>
<th>Types of linkages</th>
<th>Retrieval</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forelink between ideas</td>
<td>$p_{r}$</td>
<td>$p_{s}$</td>
</tr>
<tr>
<td>Backlink between ideas</td>
<td>$p_{r}$</td>
<td>$p_{s}$</td>
</tr>
<tr>
<td>Forelink from case to ideas</td>
<td>$p_{r}$</td>
<td>$p_{s}$</td>
</tr>
<tr>
<td>Backlink from idea to cases</td>
<td>$p_{r}$</td>
<td>$p_{s}$</td>
</tr>
<tr>
<td>Backlink between cases</td>
<td>$p_{s}$</td>
<td>$p_{s}$</td>
</tr>
</tbody>
</table>

In addition, Table 4 shows different mechanisms within the five types of linkages.
different idea entities (Inew, Icurrent, Iprevious and Ccase), while the links represent the relationships between cases and ideas depicted as three linking principles (_si , _ci , _cr ). The idea entities and linking principles can be dynamically added, deleted and substituted by automatically tracking these linkages through the three linking functions (_r, _a, or _c).

DIM allows participants to dynamically link and generate diverse ideas in the process of idea association. While a designer receives a current idea from other participants, he/she uses the retrieval function to link different idea entities through the similarity or the contiguity principle. The designer also can continuously link similar design cases through the similarity principle. For generating contrast ideas, the designer can use the contrast principle to link previous ideas with contrast conceptual vocabularies. These linked previous ideas can provide the designer to continuously link contrast design cases through the similarity principle. In addition, the designer applies the similarity and the contrast principles to adapt the current idea. Also, he/she can apply the contiguity principle to combine the current idea with other idea entities.

Therefore, the CBR framework for DIM should consist of five elements: a user interface, a dictionary, a reasoning engine, a case library and an idea repository seen in Figure 9. The interface is an entry point for input and output of idea entities. The dictionary stores keyword pairs to interpret different conceptual vocabularies embedded within the attributes of idea entities that are from different participants. The idea repository stores generated idea entities and linkages among them. The case library stores idea entities within design cases. In addition, the reasoning engine controls the retrieval and adaptation processes of applying the three principles to the case library and the idea repository in order to obtain the outputs of the system.

DIM concentrates on generating design ideas in the early conceptual design stage. In this stage, the role of design cases is to inspire designers to generate ideas by providing them with conceptual and related ideas in association with those of the other participants. Therefore, case
representation more specially focuses on representing the conceptual knowledge. While viewing an idea as a solution for a specific design problem [7], each the idea entities within design cases should provide different solutions with conceptual knowledge for design problems. Also, the concrete example provides an artefact of the conceptual solution. Thus, an idea entity is composed of three attributes: a design problem, a design solution and its concrete example. For linking design cases dynamically, the different idea entities in the case library mentioned before may have linking relationships with each other based on the three principles of idea association.

Additionally, design is a visual process involving reflective behaviour [24]. Using visual expression to represent ideas is another important characteristic of DIM. Therefore, DIM employs conceptual vocabularies associated with multimedia as symbols to represent knowledge of the attributes within an idea entity. Through matching conceptual vocabularies of the attributes, the idea entities can be retrieved and adapted or combined in the process of idea association. Briefly, DIM can be considered as the confluence of multi-symbolic 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 idea entities and the linkages can be dynamically transformed (added, deleted and substituted) through different linking mechanisms at any time.

6. CONCLUSION

This paper provides a basic understanding of the dynamic linking relationships between ideas and cases in the process of idea association. In the design process, design cases can be considered as important stimuli for generating ideas. By integrating three principles of idea association with two processes of CBR, this approach provides different types of linkages with individual mechanisms to dynamically link idea entities in conjunction with other participants. The idea entities and the linkages form a dynamic idea network, which provides the computational mechanism of idea association.

DIM is a CBR framework for supporting idea association during brainstorming, especially in the early conceptual design stage. Therefore, DIM can be developed as a design support system with the function of automatically tracking these linkages and generating ideas 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 DIM, including case representation, searching mechanisms, adaptation algorithms, etc. For linking different participants’ knowledge, distributed interaction is another crucial issue for idea association. Therefore, integrating DIM with the technology of distributed artificial intelligence (such as agent system) will be investigated in our future research.
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