B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010,* 371–380.

PLAYING JIGSAW

Finding the underlying structure of assembling ideas within design productive process

CHIA-HUI LO, IH-CHENG LAI
Department of Architecture, Tamkang University, Taipei, Taiwan
nicoinschool@gmail.com, ihcheng@ms32.hinet.net

and

TENG-WEN CHANG
Graduate School of Computational Design, National Yunlin University of Science and Technology, Yunlin, Taiwan
Tengwen.chang@gmail.com

Abstract. Idea generation in design productive process often occurs within brainstorming sessions. Linking ideas is the key mechanism in this process to produce design. Through linking ideas, a graph-like knowledge is representing the individual memories with the nodes and arcs that are the ideas and the links between ideas respectively. Design is the process of puzzle-making, such thinking process is similar to play jigsaw. This research applies a computational tool (called DIM) to produce a graph-like knowledge including diverse jigsaw-like ideas and their relationships. Then we use protocol analysis to understand how designers organise the ideas. The objective is to find the hidden patterns of assembling ideas in the design productive process. Some feasibilities of the game mechanisms are proposed in this paper.

Keywords: design production; linking ideas; graph-like knowledge; protocol analysis; puzzle-making.

1. Introduction

One of important steps in design process is generating ideas. Idea generation in design productive process often occurs within brainstorming sessions with more than two participants involved. Such production of design is often carried out by two or more members in participation of a group meeting (such as brainstorming) to generate diverse ideas (Goldschmidt 1995). Through assembling the ideas, the assembled ideas can serve as a basis for designers to develop possible conceptual designs for solving a specific design problem.

Linking ideas is the main mechanism during the process of design production. A designer links ideas through his / her individual memory as well as other participants' knowledge which are often graphically linked. Consequently a graph-like knowledge is naturally the representation for representing the individual memories with the nodes and arcs that are the ideas and the association between ideas respectively (Lai and Chang, 2006). To enhance the student's comprehension of design, the graph-like knowledge provides the constructive meaning of design ideas (Oxman, 2004). With its simplicity, this kind of graph-like knowledge is often used in design studio teaching (Goldschmidt, 1995; Oxman, 2004; Lai, 2005).

In addition to the problem-solving model, Archie (1987) believed that design process is also a puzzle-making process. Further, designers often decompose the design into different attributes, and then use specific rules to organise the different attributes in their design spaces. This is similar to putting together the pieces of puzzles to solve the problem. For example, during a process of puzzle-making, a designer often applies the combinational rules to organise different attributes within ideas based on their relationships within the puzzle-like design space for solving problems. Design puzzles (Chang, 2004) map the operation of puzzle games onto specific types of design problems. Among those, the jigsaw is one frequently used design puzzle that can support the purpose of this research. The player will recognise the attributes such as shapes, colors, images from vast amounts of puzzle pieces, and then assemble the puzzle pieces in order to generate a design or a design-like outcome.

2. Design as playing jigsaw

The jigsaw is a kind of puzzle-game. Puzzle-games are a special class of games that will require a player's logical reasoning capability to overcome the obstacle (the puzzle) in order to complete the game (Bates, 2002). For example, "finding a missing information piece" will require players to know the background of the situation and reasoning with the hints in order to solve the puzzle (Chang, 2004). From children's puzzle games, there are basically two kinds of jigsaw-like puzzle games: creative puzzles and traditional puzzles (seen in figure 1).

The goal of traditional puzzles like a normal jigsaw is to assemble the pieces of the puzzle based on the only outcome. Compared to the traditional puzzle, the creative puzzle emphasises open outcomes without limitation on the final layout of the puzzle. The player will not know the outcome until he / she has completed the puzzle which relies on the hints provided within the puzzle images. Three sequential means to assemble puzzle pieces are as below.

1. **Classification:** grouping the puzzle pieces into several clusters by the hints of the puzzle pieces such as shape, colour or clearly defined images.
2. **Selection:** choosing puzzle pieces with similar hints to assemble a complete image according to the clusters.
3. **Combining:** combining will be conducted when the border and image of the two puzzle pieces match.

Figure1. Creative puzzle (left) and traditional puzzle (right).

Design production focuses on developing diverse conceptual designs for solving a specific design problem. Creative puzzles provide an open-ended process that is close to what the design production process did. Thus we adapt creative puzzles as the metaphor of the design puzzles in this research. Some researchers apply design puzzles as a method to assist students to inspire their designs in the design production process. By using the name of "game," this research tends to focus on the conceptual level of play (Woodbury et al., 2001). Through the playful characteristic of the puzzle, the design is viewed as a playful learning process (Klugman and Smilansky, 1990). Chang (2004) has categorised the elements of the design puzzle into: 'hint,' 'puzzle rules' and 'puzzle goal' which provides a way to describe teaching capability through emphasis in methods of learning through puzzles.

However, the research emphasises the advantage of outcomes of design puzzles (especially jigsaws) in the productive design process. They don't pay attention to the underlying structure of constructive meaning within the assembled puzzle-like design ideas. In addition, due to the limitations of the information processing of the human short-term memory, the completion of the puzzle assemblage cannot be done immediately through classification, selection and combination. Such a situation is similar to the process of design production. A large number of scattered but related ideas is unable to be effectively linked together for solving design problems. By applying the mechanisms of playing jigsaw, the objective of this research is to find the underlying structure (called hidden patterns) of assembling ideas from a graph-like knowledge in the design production process. Based on the found hidden patterns, some feasibilities of the game mechanisms are proposed.

3. Research tools: DIM and protocol analysis

For finding the underlying structure of assembling ideas via mapping the gaming behaviours of playing jigsaw, one possibility is to observe the behaviours of actual game play. For such an experiment, we need a mapping mechanism and an observation method over the experiment. The mapping mechanism should generate a graph-like knowledge structure which composes a vast amount of ideas (puzzle pieces) and their links (the relationships between puzzle pieces). Thus the DIM (Dynamic Idea Map) proposed by Lai and Chang (2006), which can generate the graph-like knowledge (called *idea map*) of links and nodes, can support the mapping mechanism. Also, protocol analysis can help us to observe and understand design behaviors of assembling ideas in the design production process.

3.1. DIM

In the DIM, an idea map composes of idea entities *(ie)* and three types of linking relationships among idea entities. They are similarity *(SI),* contrast *(CR)* and contingency *(CI).* Based on the ICF schemata proposed by Oxman (1994), each idea entity includes three attributes. They are issue *(I),* concept *(C)* and form *(F)* which are represented and visualised by keywords, texts and image photos respectively (figure 2). The DIM includes two kinds of components: agent entities and design knowledge. Agent entities are assigned to different sub-tasks that are decomposed from a specific design task. According to different design situations, these agent entities with specific design knowledge collaborate together to generate design ideas and links.

3.2. PROTOCOL ANALYSIS

Protocol analysis is a useful methodology for exploring the understanding of design behaviors (Ericsson and Simon, 1993). Through the process of encoding, recording and data analysis, the design behaviors of designers can be comprehended. Based on the methodology, this research applies think aloud and conceptual sketches to understand design behavior of assembling ideas.

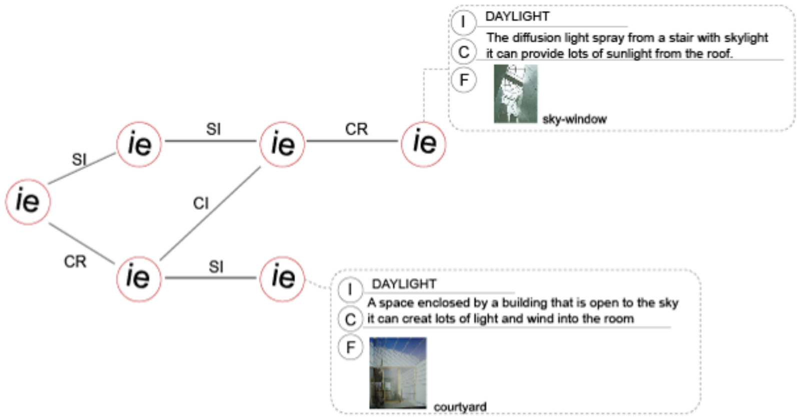


Figure 2. Idea map and ICF (issue, concept and form) representation.

4. Design experiment

In order to understand the puzzle-making process of participants during design, this research conducts an experimental observation on a residential design project. It aims to probe into the structure of the relationship between idea combinations, to observe how participants use DIM as a tool to translate scattered ideas into vast amount of co-related puzzle pieces, and to know the process of forming an integrated image through those image pieces.

The experiment is divided into 2 sessions. The first session discusses the participants' methods in classifying vast amount of information. The same process occurs at the start of puzzle-making when visual searches for distinct features of the pieces. The second session focuses on the process of how participants move forward after classifying information to selecting and organising linked concepts and forms that combine scattered pieces in groups to create idea map. The elements of this experiment are as below:

- **Participants.** Three 3rd-year architecture college students who are equipped with basic architecture training and familiar with the mechanisms of DIM. These students are coded as A, B and C.
- **Design task.** In order to allow the experiment observe directly the thinking transition during designing, the topic is set for simple function on a design project of a residence for two people located by the Tamsui River. How to take the natural lighting is the design problem.
- **Process.** The test is divided into 2 sessions of 45 minutes each. The participant will carry out a DIM experiment warm-up and operation for 30 minutes prior to the test. During the last 15 minutes, he / she needs to draft his / her conceptual sketches whilst thinking aloud. The whole process will be videotaped.

5. Analysis and observations

After the above-mentioned test, a total of 50 design ideas are created by 3 participants within 45 minutes. Through DIM calculation, 29 *SI,* 18 *CR* and 3 *CI* combinations are formed between ICF cards. The DIM map is like the formation of vast amount of puzzle pieces that participants must first find the hidden image fragment and reassemble them to form an integrated image.

5.1. ANALYSIS

Through translation, encoding and information analysis of protocol analysis, the re-assembling of image of forms and concept keywords by the participants leads to the production of new ideas. The experiment discovers that the 3 participants perform similar assembling module in the process of design production. This research takes the design behavior of Participant B as an example in verbal illustration and conceptual sketches.

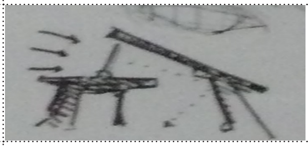
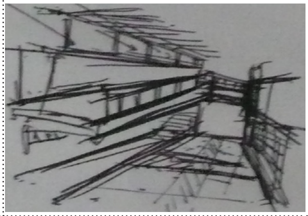
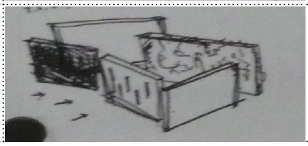
During the first session, each participant is required to select from the ICF database a concept related to the design task, and to place the concept together with the ones selected by the others. In this stage, the link between ICF cards has not yet been established. The observation traces how participants classify and select before graph-like knowledge is created (table 1). It shows that participants produce 3 diverse ideas, and shift from forms to concepts.

During the second session, the participants choose the concept to be applied from the DIM constructed with the linked graph-like knowledge resulted from computation based on 3 principles of similarity *(SI),* contrast *(CR)* and contingency *(CI).* The participants start their sketches and having their thinking aloud recorded it is to establish the design process in which the organisation concept is similar to the one in puzzle-making (table 2). From table 2, the research presents the process of how participant moves from scattered thoughts towards concentration. It also shows the fragments revealing hidden images, and the image after reassembling.

5.2. OBSERVATIONS

During the first session when the design idea is to be created, the participants will classify forms based on one single key word and image. For example, Participant B selects the image of a slanted roof *(F)* in accordance with personal preference during his / her first design idea, which leads to the finding of keyword in western exposure *(C).* Further from the slanted roof, it develops the form of sky window *(F)* capable of introducing indirect light *(C)* (table 1, idea 1). The formation of the participant's design is derived after watching the image on the ICF card prior to the search in concept keywords,

Table 1. Protocol analysis in the first session

Idea	Description of idea combination	Sketch
1-1 Idea 1	I would like to add a slant roof on the building, in order to lead indirect light into loft. To avoid facing west of room.	
1-2 Idea 2	At the beginning, I would like to create a linear opening that purpose leading day-light into courtyard. Second, I would put a sky-window on the top in order to create a spray light.	
1-3 Idea 3	This idea is trying to make two volumes embedded with each other. Creating an overhead corridor connected two volume and bringing great view into house.	
1-4 The combination structure of ideas	1 F ---> C → F → F 2 F → C → F 3 F → F ---> C → F	

followed by going to 2 or 3 more ICF cards before the final decision is made. Similar to the puzzle-making, the eyes will search for a distinct fragment containing more hints. The image leads to the searching of the next piece. But due to the limitation of the short-term memory, the links between concepts are not sufficient. Therefore, the participant develops forms directly from one single concept. Due to the missing links between independent images, fewer combination forms are created, displaying scattered design ideas. The thinking combining pattern is similar to figure 3.

Table 2. Protocol analysis in the second session.

Idea	Description of idea combination	Sketch
2-1 Idea	In this house, the stair is a transitional space that connected loft and second floor. A sky-window on the roof is leading daylight into house that creates a spray light for interior. And I extended a court-yard from second floor with a great view. Then create a corridor to connect another volume.	
2-2 The combination structure of ideas	F → C → F → F ---> C → C → C → F → F → F → F	

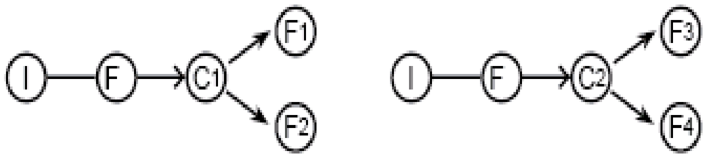


Figure 3. The combining pattern during first stage of the experiment

During the second session, the participants will discover the relationship between concepts through linkage between ICF card given by the calculation results of DIM, providing the participants a platform for continuous correction, displacement, editing and reassembling. Within the participant's thinking pattern, the link between scattered images has begun to form (table 2, 2-1). The idea-linking pattern has shown the extension of ideas from one image *(F)* to concept *(C)* keyword followed by the development of other forms *(F)* of image. During the process of sketching in this stage, the participant create total of 7 forms of image and keywords and 4 key concepts. With convergence, it results in a comparatively more integrated form of production process and unified idea linkage. From analysing table 2, the participants' image organisation formation *(F)* and concept keyword *(C)* can be categorised as the design thinking process of the form of *F-C-F-C-F* (Table 2, 2-2).

6. Hidden patterns of assembling ideas

In the experiment, we can summarise four types of hidden patterns of assembling ideas (seen in figure 4).

- **Pattern 1:** participants first find keywords of concept through the image of form. The linkage of *C1* and *C2* brings out scattered numbers of images of forms *(F1*, *F2*, *F3* and *F4)*. According to the combination of 2 forms *(F1 + F2, F2 + F3,* and *F3 + F4)* to converge the concepts *(C3, C4* and *C5),* the reassembling generates image of forms *(F5, F6)*.
- **Pattern 2:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F3* and *F2 + F4),* different concepts *(C3* and *C4)* are produced, which lead to the generation of *F5*.
- **Pattern 3:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F2 + F3* and *F2 + F3 + F4),* different concepts *(C3* and *C4)* are produced, which lead to the generation of *F5*.
- **Pattern 4:** participants go through the same process as in pattern 1 to find keywords of concept through the image of forms and search for scattered forms

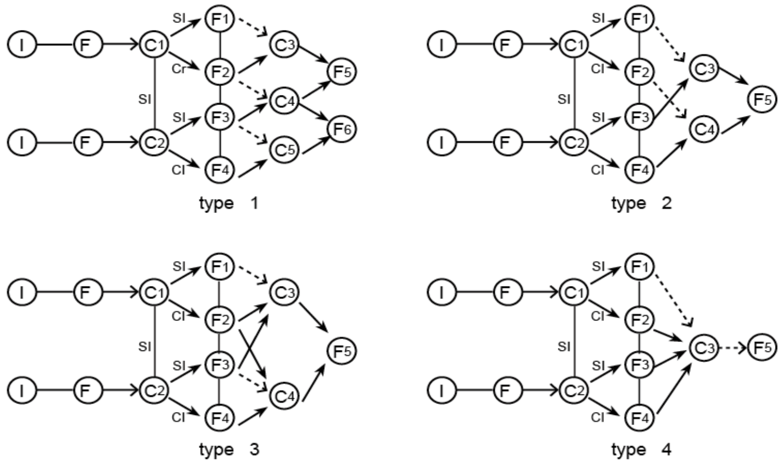


Figure 4. Four types of hidden patterns of assembling ideas.

through the linkage of *C1* and *C2*. With the different combination of those forms *(F1 + F2 + F3 + F4),* different concepts *(C3)* are produced, which lead to the generation of *F5*.

Based on the four patterns of assembling ideas, students can engage in design production, just like putting puzzles together. Such a game mechanism can supports students to reveal the constructive meaning within the graph-like knowledge structure represented by the sequential description integrated with multi-media (figure 5). Besides, it can provide a playful design environment. Three main steps of the game mechanism are:

1. Classifying idea entities based on an issue *(I)* which is a designated design problem in a design task.
2. Selecting idea entities according to preferred values of concept *(C)* or form *(F)*.
3. Combining the idea entities through the linking rules of similarity *(SI)* or contrast *(CR)* between concepts *(C)* or forms *(F)*.

7. Conclusion

In this research, we find that the mechanisms of playing jigsaw provide an effective method to understand the underlying structure of assembling ideas from a graph-like knowledge. Four types of hidden patterns of assembling ideas are found. Based on the ICF representation of an idea entity, issue plays the key role in classifying idea entities. Concept and form are the important attributes for designers to select preferred idea entities. Similarity and contrast links provide rules of combining idea entities. This research will provide an

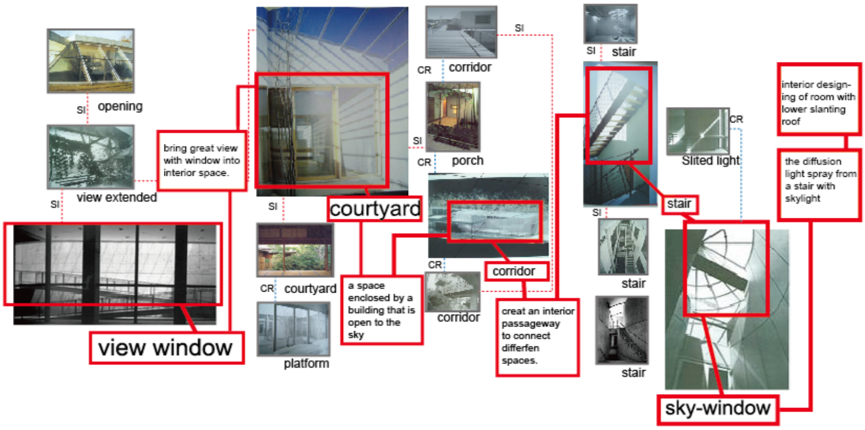


Figure 5. The sequential description integrated with multi-media

essential prerequisite of preparation for supporting design decision in any creative problem solving meeting.

References

Archea, J.: 1987, Puzzle-making: what architects do when no one is looking, *in* Y. Kalay (ed.), *Computability of design,* John Wiley and Sons, 37–52.

Bates, B.: 2002, *Game design: the art and business of creating games,* Premier Press.

Chang, T.-W.: 2004, Supporting design learning with design puzzles, *in* J. P. Van Leeuwen and H. J. P. Timmermans (eds.), *Recent advances in design and decision support systems in architecture and urban planning,* Kluwer Academic Publishers, 293–307.

Ericsson, K. A. and Simon, H. A.: 1993, *Protocol analysis: verbal reports as data,* MIT Press, Cambridge, Mass.

Goldschmidt, G.: 1995, The designer as a team of one, *Design studies,* **16**(2), 189–209.

Klugman, E. and Smilansky, S.: 1990, *Children's play and learning: perspectives and policy implications (early childhood education series),* Teachers College Press.

Lai, I.-C.: 2005, Dynamic idea maps: a framework for linking ideas with cases during brainstorming, *International journal of architectural computing,* **3**(4), 429–447.

Lai, I.-C. and Chang, T.-W.: 2006, A distributed linking system for supporting idea association in the conceptual design stage, *Design studies,* **27**(6), 685–710

Oxman, R. E.: 1994, Precedents in design: a computational model for the organization of precedent knowledge, *Design studies,* **15**(2), pp. 141–157.

Oxman, R. E.: 2004, Think-maps: teaching design thinking in design education, *Design studies,* **25**(1), 63–91.

Woodbury, R. F., Wyeld, T. G., Shannon, S. J., Roberts, I. W., Radford, A., Burry, M., Skates, H., Ham, J., and Datta, S.: 2001, The summer games, *Proceedings of 19th eCAADe,* Helsinki, 293–297.