Design moves in situated design with case-based reasoning

Mao-Lin Chiu, Department of Architecture, National Cheng Kung University, No. 1, University Road, Tainan 700, Taiwan, ROC

This paper depicts the process of design operations in situated design by a cognitive approach. A descriptive model is proposed for understanding design situatedness on low-level behavior and cognition. A series of similar sites are tested in a design experiment to identify the design situations and make case adaptation, and novice and experienced designers are examined in their design moves by case-based reasoning by freehand sketches or computers, respectively. The comparative analysis from the above observation and implications for future case-based reasoning systems are presented.

Keywords: design situatedness, design cognition, case-based reasoning, design studies, protocol analysis

Understanding how designers think is a great challenge for researchers in the design field[1]. Throughout the design literature, analogy has been ascribed a key role in architectural design[2–4]. Examples can be found in a number of well-known projects, such as Rietveld's Schroder House in Utrecht that was influenced by Mondriaan's painting. To our knowledge, however, the use of analogy has rarely been considered in the study of the design process. This suggests that design operations require careful study while related studies are limited.

Meanwhile, case-based reasoning (CBR) is a research paradigm that uses design cases for solving a new problem from previous design experience by analogical reasoning[5,6]. Analogical reasoning with cases requires that designers make topological and dimensional adaptation based on identified situations[7]. However, the complexity of CBR and case adaptation has been underestimated[8,9]. What are the triggers for generating the new alternative derived from the original case? How does the case perceive differently by novice and experienced designers in CBR? These and other questions become the impetus for the proposed study.

1 **Akin, O** Psychology of architectural design Pion, London (1986)
2 **Broadbent, G** Design in Architecture: Architecture and the Human Sciences John Wiley & Sons, New York (1978)
3 **Lawson, B** Design in mind Butterworth Architecture, London (1994)
4 **Rowe, P G** 'A priori knowledge and heuristic reasoning in architectural design' *Journal of Architectural Education* Vol 36 No 1 (1982) 18–23
5 **Leake, D.B.** (Ed) *Case-Based Reasoning: Experiences, Lessons, and Future Directions*, MIT Press, Cambridge, MA (1996)
6 **Kolodner, J** Case-based reasoning Morgan Kaufmann, Los Altos, CA (1993)
7 **Chen, C C** 'Analogical and inductive reasoning in architectural design computation' doctoral dissertation, ETH Zurich, 1991

ELSEVIER
www.elsevier.com/locate/destud
0142-694X/03 $ - see front matter *Design Studies* **24** (2003) 1–25
PII: S0142-694X(02)00007-8

Furthermore, the advance of cognitive psychology has developed situated cognition that is better adapted to interpretation and modeling of the reasoning processes than the descriptive models—descriptions of how the world appears and how to behave in certain situations. Situated studies assume that a better understanding of design involves the study of designers and their environments as integrated systems[10].

This paper aims to examine the phenomena of design moves in situated design by CBR. The concept of design moves in situated design, design experiments, protocol analysis, and the discussion are addressed in the following sections. Therefore, this paper introduces the concept of design moves to describe the design operations with CBR in helping understand design situatedness by the following steps: (1) to propose a descriptive model of design moves in situated design; (2) to conduct a design experiment; (3) to study the process by protocol analysis; (4) to analyze the design moves in relation with cases and design situations; and (5) to discuss the implications of the future computer-aided design (CAD) system development for architectural design.

1 *Design situatedness and design moves*

Craig[10] has compared four research strategies for studying design behaviors and reported that the situated studies focus on the design activities as they relate to the social, cultural and material contexts. In favor of such studies, a variety of researchers have argued that understanding situated behavior is essential for framing research on low-level behavior and cognition; hence, low-level research will be selective as framed by common-sense notions of situated behavior. Studies of situated behavior typically focus on one of two things: the way meaning is produced in situations or the way the social context and material environment regulate behavior.

In this paper, design is considered as a situated activity in which the designers interact with the cases (i.e. design knowledge), the program and site conditions (i.e. the problems), and the individual workplace and tools (including free-hand sketches and computers) at the micro level, while interacting with the group workplace and the culture at the macro level. This paper mainly focuses on the micro level, since each designer with similar cultural background is designing independently in this study. In dealing with cases, designing is a continuous process of learning from cases to deal with new situations. The phenomenon of continuous adaptation and interaction with design situations is often observed during the process of designing. The 'reflection-in-action' design process as described by Schön[11] can be seen as a dialogue between the designer and the design situation. During the process, designers learn how to interact with design

8 **Chiu, M L and Shih, S G** 'Analogical reasoning and case adaptation in architectural design: computers vs. human designers' in **R Junge** (ed.) *Proceedings of CAAD Futures 1997, Munich, Germany*, Kluwer Academic Press, Dordrecht (1997) pp 787–800

9 **Maher, M L, Balachandran, M B and Zhang, D M** Case-based reasoning in design Lawrence Erlbaum Associates, New Jersey (1995)

10 **Craig, D L** 'A comparison of research strategies for studying design behavior' in **C Eastman, M McCracken and W Newstetter** (eds) *Design knowing and learning: cognition in design education*, Elsevier, Amsterdam (2001) pp 13–35Chapter 2

11 **Schön, D A** The reflective practitioner: how professionals think in action Basic Books, New York (1982)

situations and propose new solutions. For further discussion, this paper first introduces the concept of design situatedness and design moves to describe the design operations in case-based design.

1.1 The concept of design situatedness

The theory of situated cognition, as presented by Clancey[12], is the study of how human knowledge development as a means of coordinating activities within the activity itself in the process. The approach brings what people perceive, how they conceive of their activity, and what they physically do together. The term situatedness has multiple meanings, which we can relate systematically by a framework of three views commonly used to describe design: functional, structural, and behavioral. The first level of the situated framework, functionality, emphasizes that the designer's intentional, purposive orientation is with respect to the design activities. The second level concerns structured mechanism—how perception, conception, and action are physically coordinated. The third level relates cognition to spatial-temporal settings. These three perspectives of the situated cognition framework are different ways of viewing human knowledge and behavior.

Gero[13] indicates that designing is situated and as a consequence is much more dynamic than most descriptions in the previous studies, and he noted, 'The particular behavior and structure variable are not only chosen a priori but are produced in response to the various situations as they encountered by the designer.' A situation is the part of the world or context which a system or process is exposed to, that interacts with it and which as a consequence causes a change in the system or process. Gero[14] also proposed an FBS (functional–behavioral–structural) model of designing that includes its situatedness, and indicated that situated design is often associated with the causes, the position, and the timing of design.

Furthermore, Gentner's Structural Mapping Theory considers an analogy as a mapping of knowledge from one situation onto another, supported by a system of syntactic relations that is transferred from the source objects to the target objects[15,16]. Meanwhile, mapping is directed entirely by the importance of the predicates to the designer's specific goals or intentions in the design process.

To summarize the above concept, a design situation is a premise of design that a process is exposed to some degrees of the context, and which as a consequence causes a change in the process. Thus, the model of situated design should include features such as sensory inputs, the processes of perception, conception, situation construction, and memory construction[13].

12 **Clancey, W J** Situated cognition: on human knowledge and computer representations Cambridge University Press, Cambridge (1997)

13 **Gero, J** 'A model of designing that includes its situatedness' in **J Gu and Z Wei** (eds) *Proceedings of CAADRIA 1999* (1999) pp 253–264

14 **Gero, J and Kulinski, J M** 'A situated approach to analogy in designing' in **M Tan** (ed.) *Proceedings of CAADRIA 2000* (2000) pp 226–234

15 **Gentner, D** 'Structure mapping—a theoretic framework' *Cognitive Science* Vol 7 (1983) 155–177

16 **Gentner, D** 'The mechanisms of analogical learning' in **S Vosniadou and A Ortony** (eds) *Similarity and analogical reasoning*, Cambridge University Press, Cambridge (1989) pp 199–239

1.2 Situated design in case-based reasoning

In CBR process, situatedness can be seen as a means of design operations. These features are interacted with cases by a series of design operations as follows.

(1) *Sensory inputs*: When there is a defined, receiving variable, sensory inputs are generated by designers manually or computationally. For example, sensory inputs may be the simple lines in a drawing representing the key elements or properties of a case. Once sensory inputs are received, they are stored and are unchanged, and are always available for other processes. These sensory inputs form one of the bases for the construction of memories.

(2) *Perceptual processes*: Perceptions are structured sensory experience and they require the existence of structuring processes. For example, if the sensory inputs are lines then the perceptions may be that the lines are joined in such a manner that they form a grid template or a closed space. A design case generally consists of two parts—the structure and components, and these are related to each other, Figure 1. The spatial relationship such as case structure and components can be retrieved together or separately, and can be adapted into new designs to deal with specific needs. The processes of perception will finally succeed in producing an appropriate structure as a function of the situation.

(3) *Conceptual processes*: Conceptions are the meanings ascribed to the perceptions. They are a function of both the perceptions and the situation. In the processes of conception, cases are often used as a 'short-cut' for conceptualization and transformation of knowledge from analogical reasoning by deduction and induction[8]. When the case structure is perceived, case representation can be encoded and decoded, and mapped into new case.

(4) *Situation construction processes*: A situation is not simply the context; it must interact with the development of the conception. In CBR processes, design situations can be characterized by the design problems

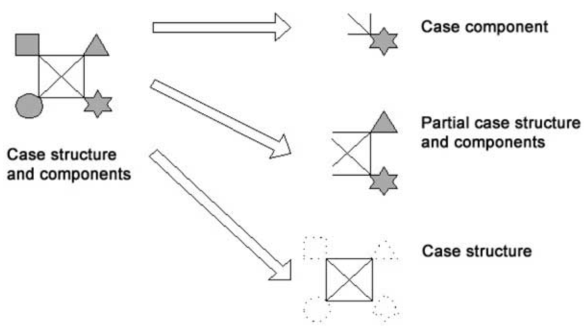


Figure 1 Case structure and components

that are associated with each case. Design is often spatially constrained by geographic, physical, and economic conditions. These conditions are critical to designers in making decisions or operations, and also becomes the trigger for generating the new case by analogy in the perceptual processes. If the design knowledge is derived from cases, designers have to perceive the situation and deal with new situations. Situations are recursively constructed. Then, a case is applied to design by transforming from an old solution to a new solution after comparing the problem (or situation) with a new problem (or situation) in dealing with specific situations.

(5) *Memory construction processes*: When cases are recalled, 'memories' are constructed from the sensory experience, the conceptions and the situation in response to the demand for a memory. Memories are added to the sensory experience and become indistinguishable from them. Thus, cases recalled in mind are accumulated as the short-term memory, and gradually become the long-term memory after repetitive uses of the particular cases. Therefore, design representation and long-term memory can be formulated as constructive memory.

The situated design described previously has to be conceived of very broadly. It includes the current perceptions and conceptions as well as the memory of the system. Because the perceptions and conceptions are related, we cannot separate each from the other. Therefore, the following section proposes to study the design operations by design moves to understand the low-level behavior and cognition of the perceptual and conceptual processes.

1.3 A descriptive model of design moves in situated design

The causes of changes in design are often related to form-making, which basically is a matter of arranging objects by establishing the spatial relation among selected elements[17]. From the design process perspective, two main design movements occurring in situated design are the basic movement and sequential movements. The basic movement is the direct reaction to the perception, and it forms the base of conceptions. Consequently, the sequential movements are the following design operations for case adaptation. A design move or an adaptation operator is defined as a transformational process of changing previous design description along the necessary evaluation and modification of the adapted design into a new design description.

17 **Wang**, **M H** 'Ways of Arrangement: The Basic Operations of Form-making' doctoral dissertation, MIT Press, Cambridge, MA, USA, 1986

In this study, a situation occurs together with the problem, the knowledge of case adaptation, and the individual workplace and tools. In order to clarify the concept of design moves for further protocol analysis and discussion, a descriptive model of design moves in situated design is proposed. An original case is transformed into new case through a series of design operations, and can be formulated as follows.

$$C' = \mu(C) \tag{1}$$

where C is the original case, C' the new case and μ is the design moves or operations.

Design cases are considered as pairs of a problem and a solution, as shown in Eq. (2). Design moves consist of basic moves (μ_b) and sequential moves (μ_s), as shown in Eq. (3). More precisely, basic moves can be specified as identifying, proposing, or verifying operations, as shown in Eq. (4). Design moves are involved in identifying the situation, proposing solutions, and verifying the validity of those solutions. Sequential moves can be specified as topological or dimensional adaptation operation as shown in Eq. (5). Therefore, a case can be transformed into a plausible case by these design operations to interact with situations.

$$C = (C_p, C_s) \tag{2}$$

where C_p is the design problem description and C_s is the design solution description.

$$\mu = \{\mu_b, \mu_s\} \tag{3}$$

where μ_b is the basic moves and μ_s is the sequential moves.

$$\mu_b = \{\mu_i, \mu_p, \mu_v\} \tag{4}$$

where μ_i is an identify operation, μ_p the propose operation, and μ_v is the verify operation.

$$\mu_s = \{\mu_t, \mu_d\} \tag{5}$$

where μ_t is the topological adaptation operation and μ_d is the dimensional adaptation operation.

The above model is based on the assumptions: (a) design situations can be perceived through the identification of case characteristics and site conditions; (b) designers have to perceive the situation to link the problem with the case to perform the design with CBR intentionally, and consequently to define and solve the problems; and (c) design solution can be produced when satisfying all constraints. However, how to identify the basic movement and sequential moves is critical in verifying the model.

Protocol analysis has become the prevailing experimental technique for exploring the understanding of the designing[18–20]. Cognitive studies have also revealed how a beginner's reasoning differs from an expert's as well as how different drawing behaviors differ from each other. Therefore, the following studies are undertaken to pursue the following issues: (1) to conduct a design experiment; (2) to study the process by protocol analysis; and (3) to analyze the design moves in relation with cases and design situations.

2 Design experiment

The purpose of the design experiment is to understand the design operations in situated design by different designers, how the design moves are preceded manually and computationally, and when and where the situated design is occurred.

2.1 The design problem

Designers are requested to design a single urban house in various similar sites in a sequenced design experiment. The test is divided into two parts as follows.

In the first part, designers are asked to examine a site and the cases, i.e. the problem and the solution. A case library of single houses designed by well-known local and international architects is provided as shown in Figure 2. Sample cases included: (1) Chen's house, (2) Wang's house 1, (3) Wang's house 2, (4) Peter Eisenman House II, (5) John Hejduk House in Texas, (6) John Hejduk House Frame II, (7) Mario Botta House 1, and (8) Mario Botta House 2. Designers need to study the cases and choose only one case to fit into the site. Because these houses are implicitly configured with orthographic grid lines, designers may first perceive a nine-cell structure or template, and consequently identify various spatial attributes such as proportion, location, circulation, and orientation. Within the process, designers start to construct the memory from recalling and comparing the cases, and then reconfigure the layout.

In the second part, three series of similar sites with different contexts, sizes, or orientation, as shown in Figure 3, are given to designers for identifying the site conditions and applying CBR in case adaptation. These sites are configured with various external (such as traffic), internal (such as tree), or combined conditions. The first series of sites has different conditions.

18 Ericsson, K A and Simon, H A Protocol analysis: verbal reports as data MIT Press, Cambridge, MA (1993)
19 Cross, N., Christiaans, H. and Dorst, K. (Eds) *Analysing design activity*, Wiley, Chichester (1996)
20 Akin, O and Lin, C 'Design protocol and novel design decisions' *Design Studies* Vol 16 (1995) 211–236

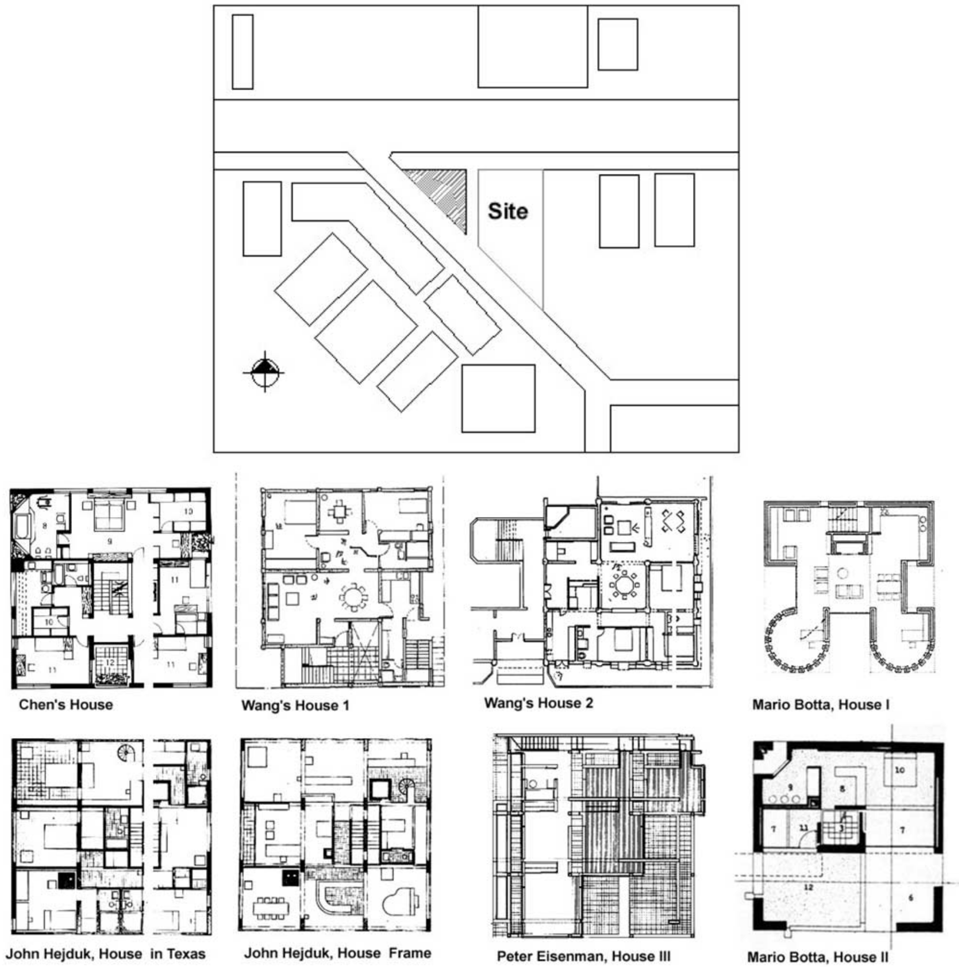


Figure 2 The original site and cases

Site A2, A3, and A4 are the variation of site A1. Site A2 has a tree on the site. Site A3 has different traffic conditions from A1. Site A4 has different site shapes from A1. The second series of site has different dimensions in width, and the third series of sites has different orientations. All participants are required to design all sites, and each site is expected to be designed around 20–30 min.

2.2 The participants

The participants in the design experiment consist of two experienced designers (architects with at least 10 year working experience, No. 1 and No. 2) and 10 novice designers (master-level graduate students, No. 3–No. 12). The participants are listed in Table 1 in terms of their design experi-

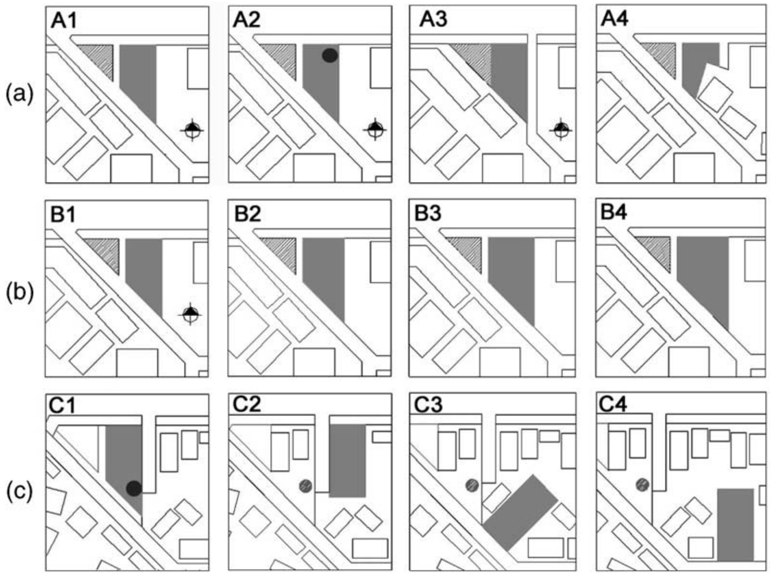


Figure 3 Three series of similar sites

Table 1 Summary of design participants

Tester	*Design experience*	*Drawing*	*Case selected*	
No. 1	Architect, 14 years	Sketches	No.8	Mario Botta 2
No. 2	Architect, 10 years	Computer	No.7	Mario Botta 1
No. 3	Graduate student, 4 years	Sketches, computer	No.4	P. Eisenman
No. 4	Graduate student, 5 years	Sketches, computer	No.7	Mario Botta 1
No. 5	Graduate student, 5 years	Sketches	No.1	Chen House
No. 6	Graduate student, 4 years	Sketches	No.4	P. Eisenman
No. 7	Graduate student, 4 years	Sketches	No.2	Wang House 1
No. 8	Graduate student, 4 years	Sketches	No.3	Wang House 2
No. 9	Graduate student, 5 years	Sketches	No.3	Wang House 2
No.10	Graduate student, 5 years	Sketches	No.1	Chen House
No.11	Graduate student, 5 years	Computer	No.4	P. Eisenman
No.12	Graduate student, 4 years	Computer	No.3	Wang House 2

ence, tools applied, and case selected. The experiment is undertaken for examining how these two groups of designers make design moves or learn how to interact with design situations. It is considered situated when designers can successfully perceive the nine-cell template from the original case and perform CBR intentionally to the new condition.

2.3 *The process*

In the experiment, each participant is required to finish the first part, then the second part. A warm-up session is given to all participants for familiarizing the process. The basic information about the site and regulation is

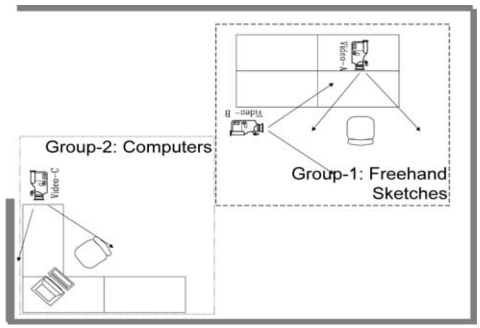


Figure 4 The design experiment environment

first explained to all designers. While designers can choose either freehand sketches or computers as their tools, eight designers choose sketches, three choose computers, and one chooses both. Then, the design environment is arranged into two kinds of settings as shown in Figure 4. If the designers use sketches, then the process is video-recorded at both the macroscopic and the microscopic views. If the designers use computers, then the process is video-taped at the macroscopic view only, and snapshots of the computer display are automatically taken and converted into sequential still images every 5 s. The protocols are kept in the analytic tables for further analysis.

Previous studies have developed two types of protocol analysis in the development of models of designing: concurrent and retrospective. Generally, researchers choose one or the other approach depending on their goals. Retrospective protocols focus on the cognitive content aspect, being concerned with Schön's notion of 'reflection in action'[11]. In CBR, designers normally adopt a top–down approach from case retrieval to adaptation. Gero and Tang[21] suggest that the retrospective protocols are used as the basis of the top–down approach, while concurrent protocols are considered better suited to a bottom-up approach to the development of design modeling. Meanwhile, Suwa and Tversky[22] suggest that the think aloud method used in the concurrent protocol may interfere with the thinking process, and the retrospective approach could be applied to study the visual data. Therefore, a retrospective protocol analysis is adopted in this study. Based on a retrospective study, the observation focuses on examining when and where design is situated.

Goldschmidt[23] proposed a method of segmentation in protocols by dividing design episodes into small units of design reasoning processes for investigating design 'actions' (or 'moves' in this study). Akin and Lin[20] studied routine and novel decisions by examining the actions of examining, designing, and thinking in protocol analysis. Researchers have further

21 **Gero, J and Tang, H H** 'Concurrent and retrospective protocols and computer-aided architectural design' in **J Gu and Z Wei** (eds) *Proceedings of the CAADRIA 1999, China, Shanghai* (1999) pp 403–410
22 **Suwa, M and Tversky, B** 'What do architects and students perceive in their design sketches? A protocol analysis' *Design Studies* Vol 18 (1997) 385–403
23 **Goldschmidt, G** 'The dialectics of sketching' *Creativity Research Journal* Vol 4 (1991) 123–143

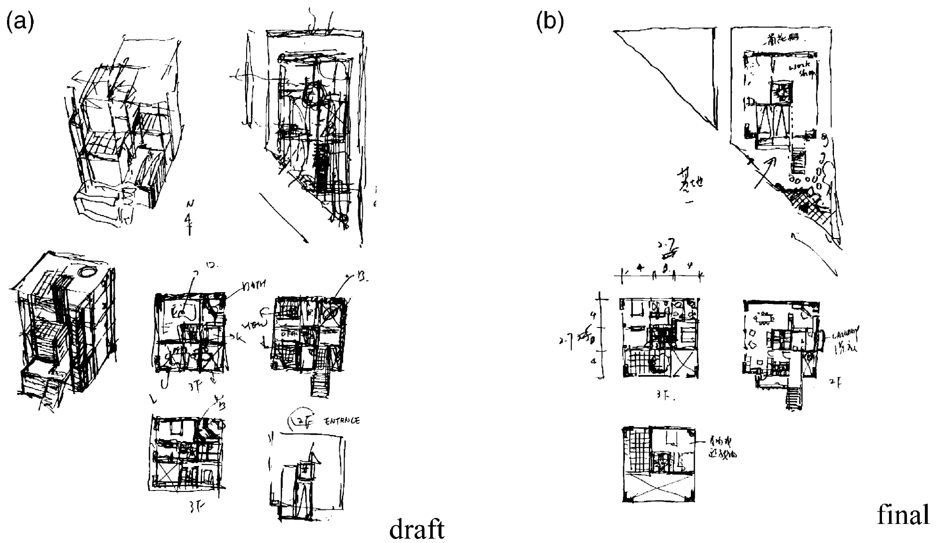


Figure 5 Draft and final sketches by tester No.1 at site A1

developed a complete coding scheme[24,25]. These techniques are selectively applied in the following analysis.

3 *Observation and analysis*

Design cases can be considered as stimuli of design solutions for different situations, and the design process can be formulated as a sequence of design moves or operations. The design moves are basically traced by the microscopic views, and eye or hand movements are traced by the macroscopic views. The retrospective protocol was used to verify the design operations in CBR.

During the design process, designers studied the site and layout for each site, and two videotapes were used to record the process from the macroscopic and microscopic views. All designers investigated the differences of all sites and perceived the main site conditions of each site. Once the condition was noticed, designers explored how the case could be better fitted into the sites. In general, designers adopted the case in the first site, and gradually modified the case from the first site to the fourth one. These evidences can be found in the notations in drawings or retrospective reports.

For example, Figure 5 demonstrates the draft and the final design sketches by tester No. 1 at site A1. The designer intended to maintain the characteristics of the original case, such as the circulation and the form. The spatial configuration is clearly dominated by the nine-cell structure and the central

24 Gero, J and Mc Neill, T M 'An approach to the analysis of design protocols' *Design Studies* Vol 19 No 1 (1998) 21–61
25 Suwa, M, Purcell, T and Gero, J 'Macroscopic analysis of design processes based on a scheme for coding designers cognitive actions' *Design Studies* Vol 19 No 4 (1998) 455–483

core as shown in sketches. Isometric perspectives were also used to study the spatial relation. It is found that designers inclined to redraw or rewrite the draft layout into the final one for defining some uncertain attributes. The draft sketches reveal the basic moves in dealing with the nine-cell structure and circulation, while the final sketches have less basic moves and more sequential moves. The sketches of the series of site A1–A4 are organized as shown in Figure 6.

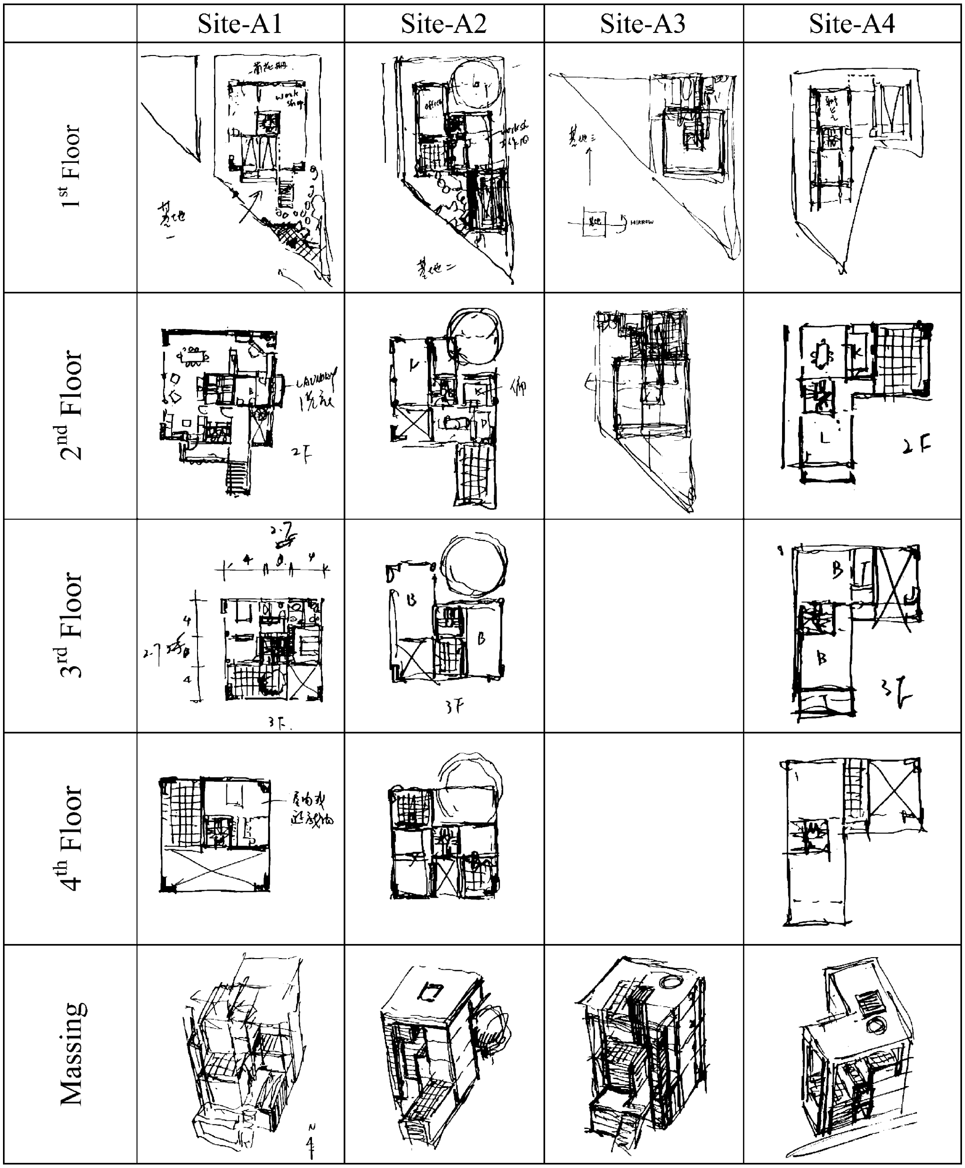


Figure 6 Comparison of four sites designed by tester No.1

Therefore, three major analytic tables (T1, T2, and T3) were defined in the study for further analysis. T1 is the summary of final design result such as sketches, Figure 7. In comparison with the original case, the spatial relations are redefined and the dimension is adjusted. The study finds regularity in design moves, while there are differences in local and global moves. T2 is the retrospective report of design operations, Figure 8. T3 consists of time and sequential records by videotapes at both the macroscopic and microscopic views, Figure 9. These tables are the basis for the following analysis.

3.1 *When is situation defined*

In the first part of the experiment, designers study the geometric condition of the sites, the characteristics of the case, and the possibilities of design moves. Then, based on retrospective protocol, this study analyzes how designers interact with design situations in the design process by encoding the design behaviors and operations, such as examining (E), drawing (D), and thinking (T), problem definition (C_p), basic moves (μ_b), dimensional adaptation (μ_d), topological adaptation (μ_t), and problem solution (C_s). The situation and decision analysis can be classified based on T2 and T3. For example, T2 (Figure 8) reveals the possible causes of design moves and situations.

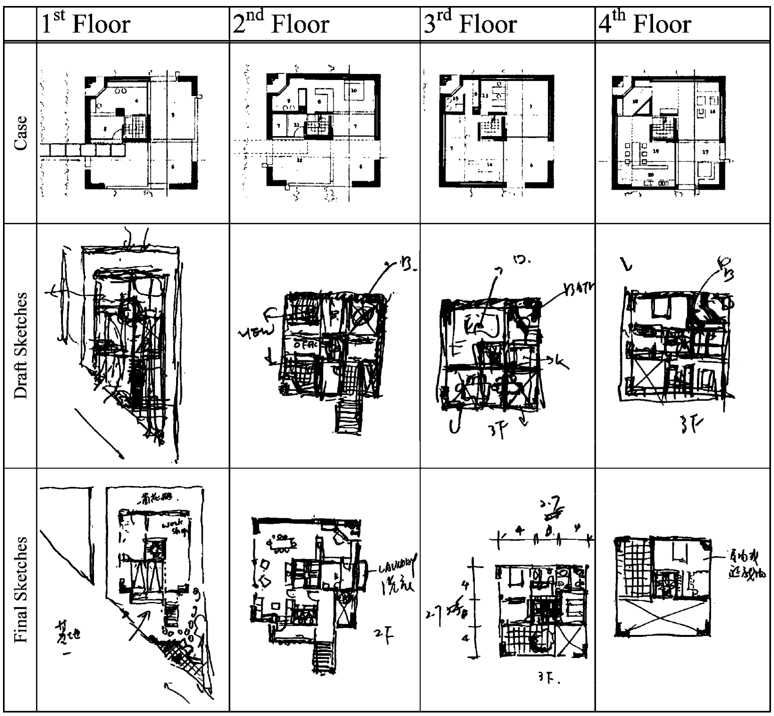


Figure 7 Comparison of floor plans in Site A1 by Tester No.1. (T1)

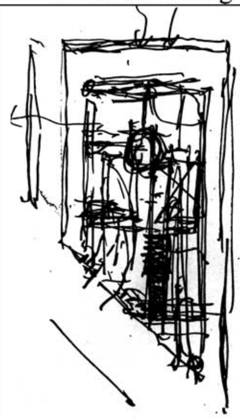
No.	Related Drawing	Retrospective report	Situation
S1-1f-01		•I want to check the size of site, …, about 4 meter? How big is the staircase? What is the relationship with the site? .Then I want to consider the main road . For this house layout, it should be kept away from the road to avoid the noise caused by traffic. •On the other hand, I am considering parking. Basically, I need to get rough measures by a ruler now,….. Since relative scale is built on my mind, I think that I do not need the rule any more. •I am thinking about the relationship of the parking with the whole house. The basic unit of 4 x 4 x 4 and parking space is not enough. .I thought about the case, the staircase is walking down from the top, but the site is flat, …..	• Site • Traffic • Parking • Dimension • Vertical circulation (retrieved from case) • Enrty (retrieved from case)

Figure 8 Retrospective report of design in site A1 by tester No.1. (T2)

No.	Time	Macroscopic	Microscopic	E	D	T	Cp	μb	μd	μt	Cs	Decisions
No1-s1-01	00' 15				•	•	•					s1-q01 (location) s1-q02 (entry)
No1-s1-02	00' 30			•		•	•	•	•		•	s1-q03 (case select) s1-q04 (dimen-sion)
No1-s1-03	00' 45				•	•	•	•				s1-q05 (noise) s1-q06 (views)
No1-s1-04	01' 00				•	•	•	•				s1-q07 (parking) s1-q-08 (main entry)
No1-s1-05	01' 15				•	•				•		

Figure 9 Partial analysis of design activities encoded in time sequence (T3)

In general, designers are typically dealing with design situations brought by factors or conditions that are related with the site, environment, or the building layout. These design factors are classified into nine types, including: (1) main entry, (2) parking entry, (3) noise, (4) views, (5) entrance, (6) vertical circulation, (7) spatial layout, (8) massing, and (9) interiors. The relationship among these factors was organized as decision flows in

Figure 10. In responding to these design factors, designers make various design arrangements such as changes of dimension, orientation, scenery, artifact, etc. Each basic design move needs to be identified, proposed and verified. Each move also triggers sequential moves.

The design process is also encoded according to the timing, design behaviors, and design decisions as shown in T3 (Figure 9). Each decision may be related to specific situations found in T2. The protocols are divided into 5-s segments and respectively. It is found that design situations are often identified when E, D, T activities occurred. While it is difficult to distinguish D and T, both D and T activities often occurred at the same time. E activities are gradually reduced, since designers are getting familiar with the case and design situations. Meanwhile, μ_d and μ_t are followed by C_p, while C_s only occurred when basic move (μ_b) occurred.

In this study, we focus on the concept of design moves and its implication on the development of CBR systems. Therefore, we do not study the statistics of design operations such as the number of analogy or actions. The time segment in T3 is only used for checking the sequence of design operations as summarized in Table 2. Therefore, the decision flows can be better understood.

The aforementioned findings indicate that design conception is closely linked with the perception of the situation. Therefore, design is situated when design moves occurred.

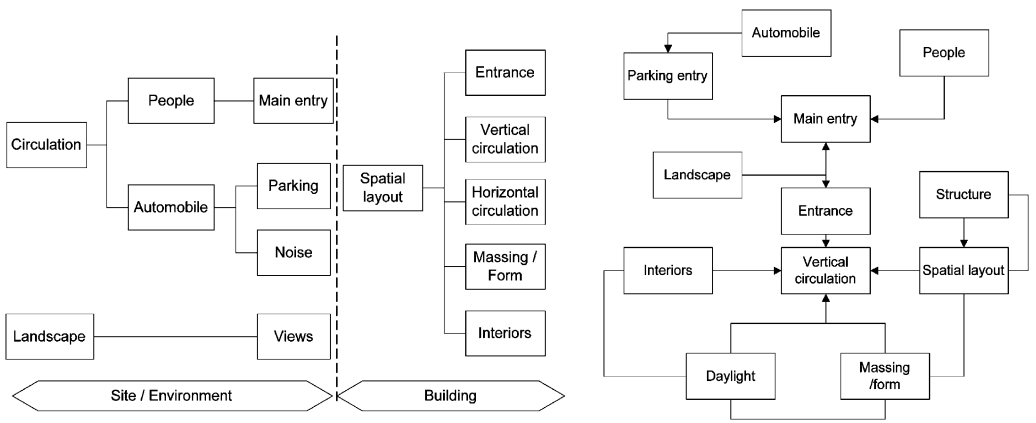


Figure 10 Design factors and decision flows

Table 2 Sample segments coded in summary of design operations

Segment id	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180
1. Main entry			●		▲								×			
2. Parking		●			▲					▲	□		×			
3. Noise																
4. Landscape																
5. Entry/lobby			●		▲	▲			▲				×			
6. Circulation				●								▲	×			
7. Space	●						▲				▲		×			
8. Form																
9. Interior																

(●) Problem defined; (▲) topological adaptation; (□) dimensional adaptation; (×) problem solved.

3.2 *Where situation and adaptation occurred*

In this study, repetitive design in similar sites could not only enhance designers' memories but also provide comparative data to verify the critical operations. For example, the observation demonstrates that tester No.1 proposed and verified the draft and final design sketches. The designer intended to maintain the characteristics of the original case, such as the circulation and the form. The spatial configuration is clearly dominated by the nine-cell structure and the central core as shown in sketches.

Table 3 compares the basic design moves in the first four sites (A1–A4) by tester No.1 in order to study how main design problems as well as situations are identified and solved. The setback from a tree or corner is

Table 3 Comparison of design moves in four sites designed by tester no.1

Sites *Basic moves*	*Define main entry*	*Setback from the tree*	*Define main entry and parking*	*Setback from the right-bottom corner*
1.Main entry	●		●	●
2.Parking	●	●	●	●
3.Noise	●			
4.Landscape	●			●
5.Entry/lobby	●	●		●
6.Circulation	●			●
7.Space	●	●		●
8.Form	●	●		●
9.Interior	●			

a natural response to situations. The house plans in site A2, A3 and A4 are derived from the plan in site A1. In site A4, the design becomes more complex, and more basic moves as well as sequential moves are occurred. These changes are also found in other designers. Earlier design solutions are often used in solving later similar problems. The design moves are more observable in the series of site B1–B4 and site C1–C4, while more sequential moves are found in site B and more design moves are founded in site C.

Furthermore, the study finds that the sequences of design moves are similar in various sites by each designer, while each still has minor differences. There are more visible patterns of the design moves if designers use computers for designing. For example, Figure 11 demonstrates the design

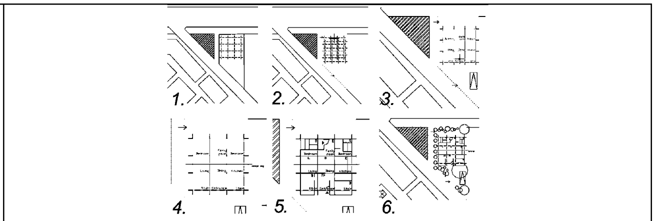
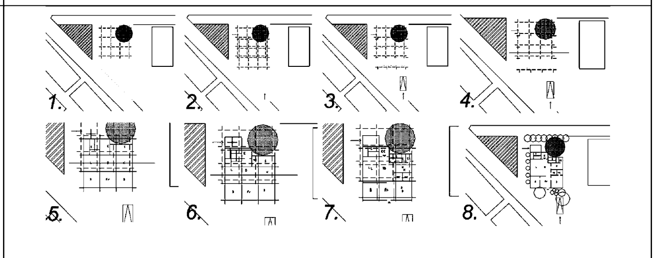
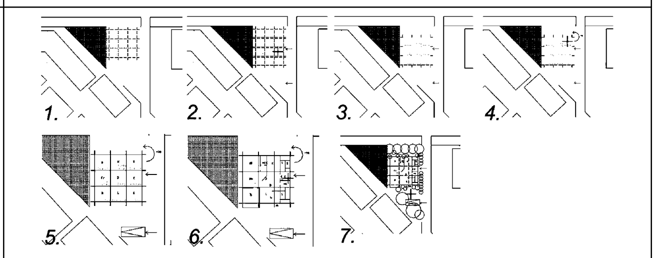
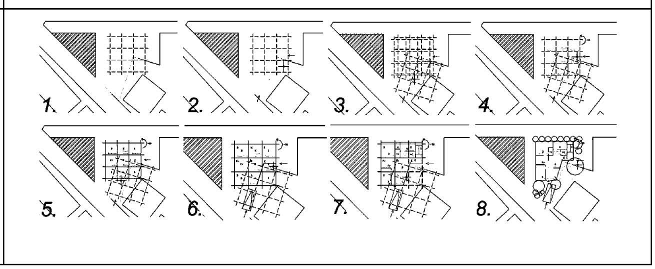
Site-A1 *0-> Line1 -> Entrance -> Line2 -> Parking -> Case2-> Mirror -> Layout -> Plant*	
Site-A2 *0-> Line1 -> Entrance -> Line2 -> Case2-> Parking -> Mirror -> Fl-1 -> Fl-2 -> Fl-3 -> Plant*	
Site-A3 *0-> Line1 -> Entrance -> Line2 -> Case2 -> Rotate -> Parking -> Fl-1 -> Fl-2 -> Fl-3 -> Plant*	
Site-A4 *0-> Line1 -> Entrance -> Line2 -> Case2 -> Rotate -> Parking -> Fl-1 -> Fl-2 -> Fl-3 -> Plant*	

Figure 11 Comparison of design moves by computers by tester No.3

moves in four sites by tester No.3. CAD layer settings are similar while minor difference exists for solving specific case adaptation such as the rotation of the case plan. The hierarchy of CAD layers is closely related to design moves. Grid lines (line1, line2) are set for preliminary layout, and then the case was inserted and followed by minor dimensional adjustment. The colors and types of lines also reveal how designers distinguish the importance of attributes and memorize the case.

Tables 4 and 5 demonstrate the design sequence of situation occurrence and solution by tester No.1 with sketches and by tester No.3 with computer, respectively. The study found that the occurrence of solution is generally in accordance with the occurrence of situations. It is also found that similar design operations in response to the situation occurred in these sites, and solutions are consistently proposed by designers. The order of situation occurrence is becoming more consistent with the solution, particularly in site A3 and A4. It is more evident in the result of series of site B and site C. The sequences of occurrence are more predictable by computers than by free-hand sketches because computers can easily manipulate changes and designers tend to duplicate the changes from the previous attempts.

The aforementioned retrospective report of design experiment provides a basic understanding of the design moves in situated design by a pair-wise comparison approach. Design moves can be considered as a series of operations responding to the site conditions. For example, the tree in site A2

Table 4 Design sequence of situation occurrence and solutions by tester No.1

Sequence of situation occurrence and solution	*Site-A1*		*Site-A2*		*Site-A3*		*Site-A4*	
	Occur.	*Solut.*	*Occur.*	*Solut.*	*Occur.*	*Solut.*	*Occur.*	*Solut.*
Environment								
1 Entrance	3	4	6	1	2	2	1	1
2 Parking	4	4	4	1	1	1	1	2
3 Noise	2	1	6	1	X	X	X	X
4 Landscape	7	3	8	3	X	X	2	2
Building								
5 Main entry	1	4	5	2	2	1	1	3
6. Vertical circulation	6	2	3	2	3	3	2	3
7 Spatial layout	5	5	2	3	4	4	2	4
8 Massing/form	9	4	7	5	4	4	3	5
9 Interiors	8	4	1	4	4	4	4	4

Table 5 Design sequence of situation occurrence and solutions by tester No.3

Sequence of Situation Occurrence and Solution	*Site-A1*		*Site-A2*		*Site-A3*		*Site-A4*	
	Occur.	*Solut.*	*Occur.*	*Solut.*	*Occur.*	*Solut.*	*Occur.*	*Solut.*
Environment								
1 Entrance	3	3	2	2	2	2	2	2
2 Parking	3	3	2	2	2	2	2	2
3 Noise	X	X	X	X	X	X	X	X
4 Landscape	X	X	X	X	X	X	X	X
Building								
5 Main entry	2	2	1	1	1	1	1	1
6 Vertical circulation	1	1	○	○	○	○	○	○
7 Spatial layout	2	2	1	1	1	1	1	1
8 Massing/form	5	5	○	○	○	○	○	○
9 Interiors	4	4	○	○	3	3	○	○

becomes the major cause for design moves. Figure 12 demonstrates that design iterations or transformation consist of the basic design moves (μ_i, μ_p, μ_v) and sequential moves (μ_t, μ_d) in comparison with site A1 and A2. The operator μ_i represents how designers not only detect and identify the site condition, but also identify the feasibility of the case structure derived from case No. 8 that has a central core surrounded by living spaces. Therefore, the operator μ_p is not only to propose the solution, but also to map the derived structure from the case into the new situation. If the operator μ_v verify the suitability of derived structure with the specific situation, then the sequential moves can be followed.

Furthermore, each basic move is also related to certain constraints. Cross-examination of the situations encountered by all designers reveals that the responses to the situation are similar when the site condition or constraint is identified, but proposed solutions can be varied. For example, Figure 13 shows pair-wise comparison of design moves in both the draft and final states in site A4 by four designers. The layouts are constrained by the inner corners, and the locations of garages are different. Experienced designers are more capable to manipulate the case structure than novice designers.

The previous study demonstrates that design is a situated activity with contextual conditions. However, the retrospective analysis has its constraints of revealing designers' intentions. It is only useful for coding based on graphic representation without interfering the design process. The

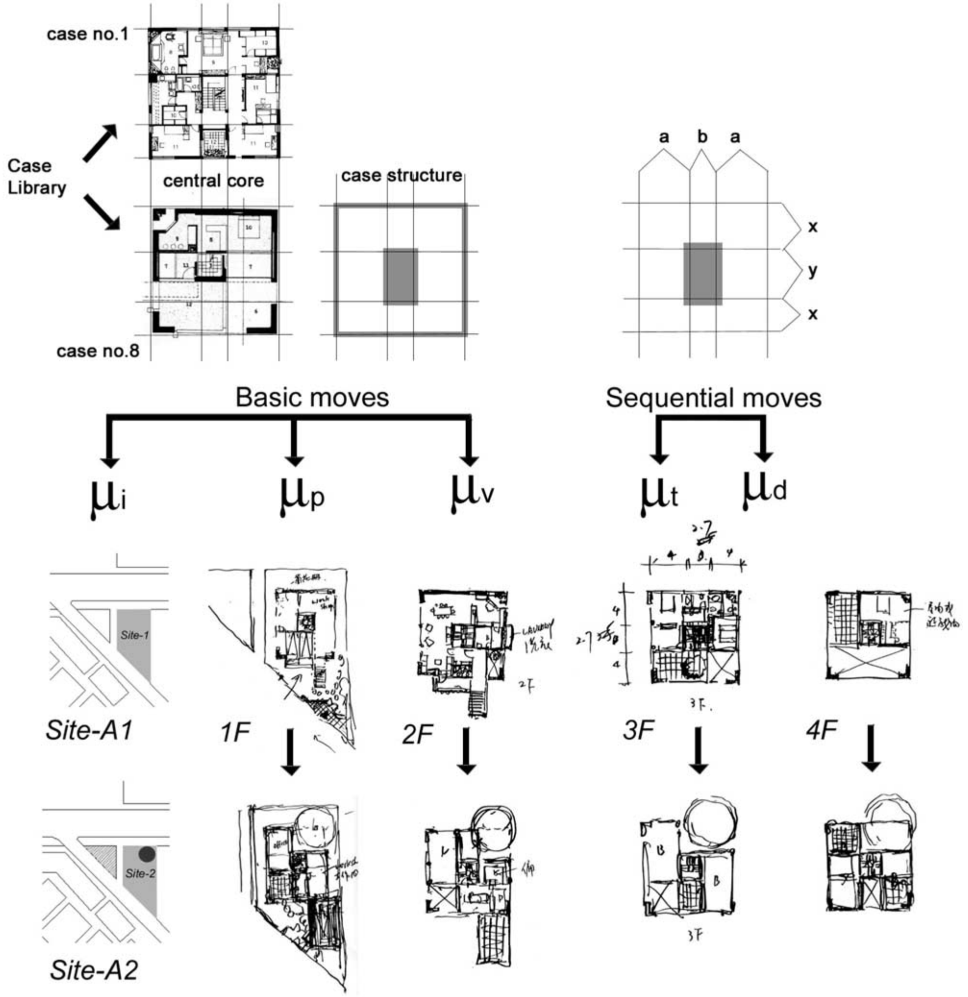


Figure 12 Design transformation and design moves

approach of examining situations is feasible in identifying how designers respond to the situations by repetitive designs and operations. The findings in the design experiment provide the foundation for the following discussion.

4 Discussion

In this paper, the concept of design moves is applied to study situated design in CBR. The intention of this paper is not only to classify behavioral patterns among different designers or design tools, these differences also contribute to the discussion on the design operations and the potential development of CBR systems.

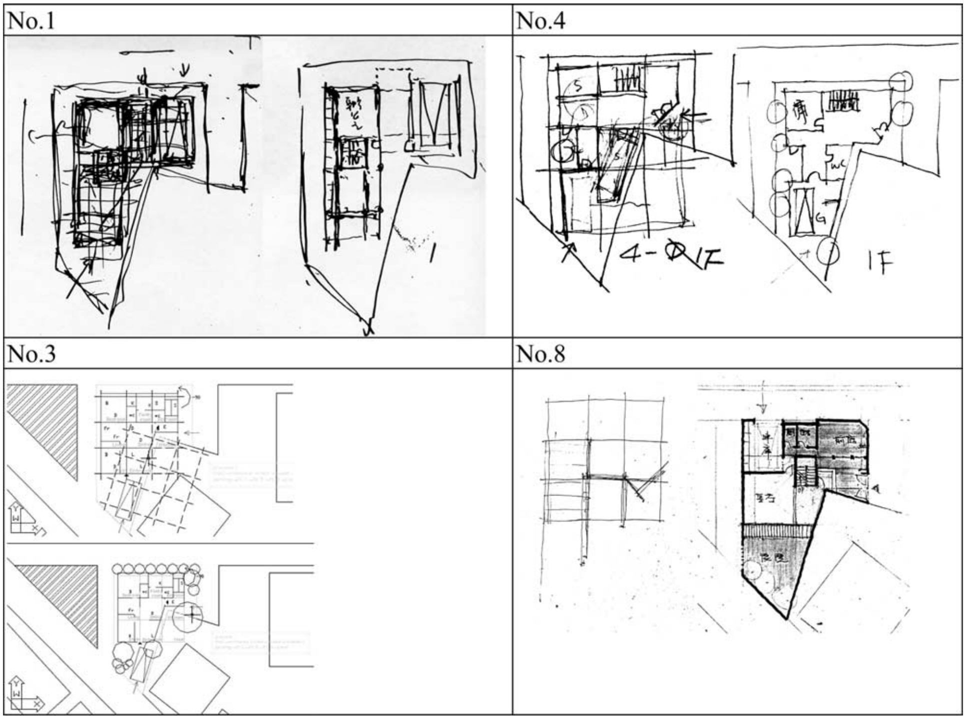


Figure 13 Pair-wise comparison of design moves in Site A4 by four designers

4.1 Constructive memory of cases

If the nine-cell template of cases and unique site shapes are the only two inputs in the design process, then both have to be perceived for initiating situatedness. The perception process consists of three parts: first, different cases are investigated and compared; second, the selected case is perceived as the nine-cell template; and third, the site conditions are perceived. Because the nine-cell urban house is a unique instance of houses, the nine-cell template is considered as a design prototype[26,27]. When different site conditions are tested, the unique interaction between the template (or case) and the designer is created based on the reflection-on-action relationship. The adoption of the template successfully translates the case into the solution in the case-based design process by mapping the case structure and components. Both the design behaviors of rewriting (or redrawing) the case and changing from the draft to the final design are building the memory in a constructive manner. Furthermore, based on the accumulation of design experience from repetitive designs, the designers' constructive memory is enhanced.

26 **Gero, J** 'Design prototypes: a knowledge representation schema for design' *AI Magazine* Spring (1990) 25–36

27 **Chiu, M L** 'Prototypes, variation, and composition: a formal design approach in urban housing design with computer assistance' in **T Kvan** (ed.) *Proceedings of CAADRIA 1996, Hong Kong* (1996) pp 287–298

Current designs are configured with various situations such as the external (such as traffic), internal (such as tree), or combined conditions. The study captures the major situations encountered by most designers on low-level behavior. The sequence of design moves can help in determining the decision flows, and provide the hint to link the cause of design moves with the consequent design actions. However, it is impossible to examine all possible design situations and responsive operations. Furthermore, the descriptive model described previously can only be used to facilitate the understanding of the routine process.

4.2 Design experience

Design moves in situated design and case adaptation by novice and experienced designers are similar in the perception process, while the conception is different. Similarly, Kavakli and Gero[28] found that there are differences in the balance of cognitive actions between the expert and novice designers by adopting the theory of mental imagery. Perhaps, remembered information is small, the perception and reflection-on-action are similar between two groups. The major differences of basic moves in CBR by novice and expert designers are noticed in terms of alternatives produced and design timing, while the sequential moves are found similar between them.

We also investigated the number of drawings produced by both groups, and the expert is more active and productive in the conceptual design process in terms of drawings and alternatives produced. Experienced designers often use multiple representations simultaneously. However, it is too early to conclude that the quantities of drawings or alternatives are related to situated design in CBR. Therefore, the statistical data are not used to compare the differences of design actions.

4.3 Design tools

The use of different design tools in design experiments indicates two aspects of design studies: design operations and observation. In terms of design operations, basic moves cannot be distinguished between different design tools, because identifying situations and proposing solutions are mainly mental activities. However, sequential moves are largely different between manual and computer operations, because drawing by computers can be manipulated or organized by useful settings such as duplication, layers, and color. Meanwhile, designers indicate the usefulness of using computers for reusing case and modification, while design thinking in the conceptual stage is still difficult by computers.

In terms of observation, designers using different tools demonstrate that different design behaviors require different recording and analytic methods. Meanwhile, how designers are familiar with the design tools directly affect

28 **Kanolya, M and Gero, J S** 'Sketching as mental imagery processing' *Design Studies* Vol 22 (2001) 347–364

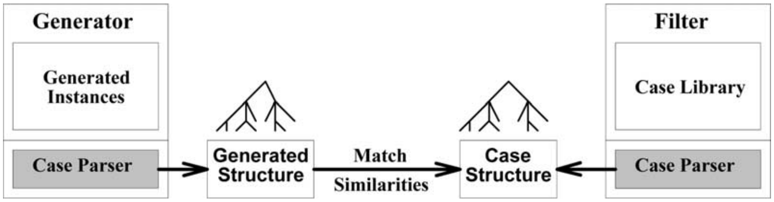


Figure 14 A case-based system framework

the quality of design and protocols. Therefore, pre-design warm-up exercises or training is necessary to improve the quality of protocol. This study demonstrates that it is easier to study the design process by computers in a structured manner. While computer display automatically records large information when designers use computers, the analysis of protocols requires a theoretic foundation that is currently based on the descriptive model.

Furthermore, it is speculative to create a CAD tool based on the observations in free-hand sketches, since the differences of free-hand sketches and computers are clearly large. Indeed, design thinking requires a lot of eye–hand coordination in free-hand sketches. Observation based on recorded materials is unable to demonstrate the dynamic activities in design, particularly from the cognitive view. Therefore, the comparison of designs by different tools can help justify the analysis.

4.4 Implications for future case-based reasoning system development

Current CAD tools are primarily useful for the detailed stages of designing, and existing models of designing are difficult for developing a suitable computational environment for designers. Analysis of cognitive processes of a designer can serve as the foundation for the development of supporting tools[29].

The study demonstrates that situations encountered by a designer can be the impetus for design moves. Therefore, a situated analogy mechanism in CBR requires more than case recall and adaptation. The CBR system should consist of three parts: the reasoning mechanism, case library, and a process (design move) recorder and parser, Figure 14. This study indicates the importance of keeping trace of the process and design moves. Identifications of when and where that design situations may interact with design enhance our basic understanding of case-based design. While each individual may encounter different situations, reactions to the various situations can be represented or regenerated as shown in Figure 15.

While design computation will be beneficial for converting heuristics into

29 Suwa, M, Gero, J S and Purcell, T 'Analysis of cognitive processes of a designer as the foundation for support tools' in **J S Gero and F Sudweeks** (eds) *Artificial intelligence in design 1998*, Kluwer Academic Publisher, Dordrecht (1998) pp 229–248

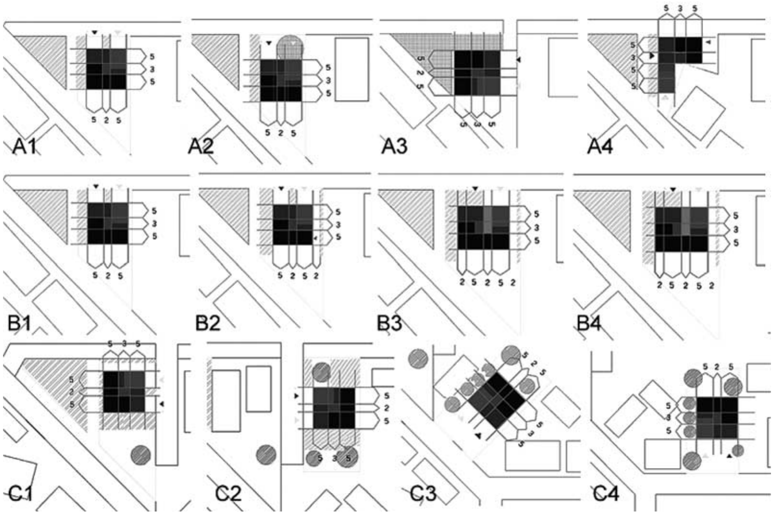


Figure 15 Possible solutions at different sites

mechanism, design problem solving requires the transformation of non-routine problems into routine problems. Without an understanding of how these above conditions are met, further studies of what computational tools are needed for case-based design cannot be reached.

5 Conclusion

The introduction of the concept of design moves and design situatedness can help in understanding of the interactions among the designer, cases, the problems, and the design environment or tools. Design moves can be seen as a means of design operations in respond to design situations by designers. The analytic framework with repetitive designs, two groups of designers of different design experience, and pair-wise comparison of design representation based on the analytic tables developed in the study are able to reveal some phenomena in situated design with CBR. Based on constructive memory, designers are able to identify and interact with situations such as the external, internal, or combined conditions. When designers encounter new situations, there are basic design moves followed by sequential moves in a routine manner.

While the descriptive model of design moves in situated design facilitates our understanding of the process, the observation of design experiments reveals that the descriptive model is a general model of low-level behaviors, and should be further developed into a situation-specific model. Meanwhile, the study is based on a design experiment with limited site conditions in house design, and the complexity of design operations in situated design needs more in-depth studies.

It is found that new computer-aided architectural design tools, which have the capacity to support changes in conceptualization, are required. A CBR system can be developed with the functions of automatically tracking the design moves and building knowledge into the system through the establishment of templates or prototypes to enhance the learning ability of situation identification and case adaptation. Future development of a process (design move) recorder/parser in the system can help understanding the dynamic process.

Acknowledgements

This research is supported by the Taiwanese National Science Council under the grant NSC-88-2211-E-006-054. The author is grateful to the assistance by Ying-Chao Kuo, Pei-Yen Wang, Ying-Tzu Lin, and all designers participated in the experiment.