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WHEN AND WHERE IS DESIGN SITUATED IN CASE-BASED DESIGN?

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Abstract. This paper depicts the process of design operations in situated design by a cognitive approach. A serial of similar sites are tested in a design experiment to identify the design situations and make case adaptation, and two groups of designers are examined in their design moves in case-based design by freehand sketches or computers respectively. The comparative analysis from the above observation and implications are presented.

1. Introduction

Understanding how designers think is a great challenge for researchers in the design field. Previous studies generally focus on the outcomes of design rather than the consequence of the design operations within the process (Broadbent, 1988). This suggests that design operations require to be carefully studied 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 (Leake, 1996; Kolodner, 1993). Analogical reasoning with cases requires that designers make topological and dimensional adaptation based on situations (Chiu, 1997). However, the complexity of design case adaptation has been underestimated (Maher et. al. 1995). Gero (1999) indicates that designing is situated and as a consequence is much more dynamic than most descriptions in the previous studies. Therefore, this paper introduces the concept of design moves to describe the design operations in case-based design in helping understand when and where design is situated.

1.1. SITUATION DESIGN IN CASE-BASED DESIGN

In general, design problems can be characterized by design situations. Situatedness and constructive memory, the concepts from cognitive science, are introduced by Clancey (1997). Gero (2000, 1999) also proposed a 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. A design situation is a premise of design that a system is exposed to some degrees of the context, and which as a consequence causes a change in the system. Indeed, design is often spatially constrained by geographic, physical, and economic conditions. These conditions are critical to designers in making decision or operations. Meanwhile, a design case generally consists of two parts - the problem and the solution. If the design knowledge is derived from cases, designers have to identify the situation and deal with new situations. Then, a case is applied to design by transforming from an old solution to a new solution after comparing the problem with a new problem in dealing with specific situations.

1.2. A DESIGN MOVES MODEL

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 (Wang, 1986). In case-based design, two main design movements are the basic movement and sequential movements. The basic movement is the solution after detecting the major situations, while sequential movements are design operations for case adaptations. 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. Thus, a design move model can be developed. An original case is transformed into new case through a series of design operations, and can be formulated as follows.

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

C: original case
C': new case
μ: design moves or operations

Design cases are considered as pairs of a problem and a solution, as shown in (2). Design moves are consists of basic moves (μb) and sequential moves (μs), as shown in (3). More precisely, basic moves can be specified as identify, propose, or verify operations, as shown in (4). Design moves 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 (5). Therefore, a case can be transformed into a plausible case by these design operations to interact with situations.

$$\mathbf{C=(Cp, Cs)} \tag{2}$$

Where Cp: design problem description, and
Cs: design solution description

$$\mu = \{\mu b, \mu s\} \tag{3}$$

Where μb: basic moves, and
μs: sequential moves

$$\mu b = \{\mu i, \mu p, \mu v\} \tag{4}$$

Where μi: an identify operation, and
μp: a propose operation,
μv: a verify operation

$$\mu s = \{\mu t, \mu d\} \tag{5}$$

Where μt: a topological adaptation operation, and
μd: a dimensional adaptation operation

The above model is based on the assumptions: (a) design situations can be perceived, (b) designers have to perceive the situation in order to define problems, and have to reconstruct the situation in order to 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 to verify the model.

Protocol analysis has become the prevailing experimental technique for exploring the understanding of the designing (Ericsson and Simon, 1993; Cross et. al., 1996; Akin and Lin, 1995). 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 what kinds of design situations are identified, how the design moves are proceeded by different designers, 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:

1) At the first part, designers are asked to examine the site and the cases, i.e., the problem and the solution. A case library of single houses designed by well-known architects is provided as shown in Figure 1. Designers need to study the cases and choose one to fit into the site. Because these houses are implicitly with a nine-grid structure, the layout can be easily understood and reconfigured.

2) At the second part, three series of similar sites with different contexts, sizes, or orientation, as shown in Figure 2, are given to designers for identifying the situations and applying case-based reasoning in case adaptation. All participants are required to design all sites, and each site can be designed around 15 to 30 minutes.

Figure 1. The original site and cases

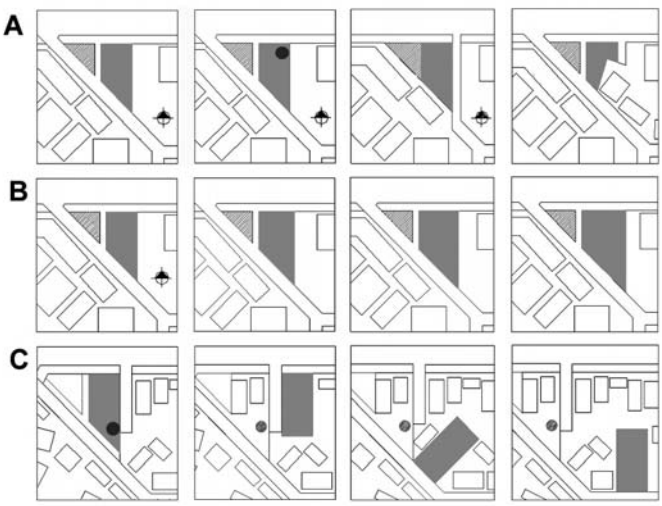


Figure 2. Three series of similar sites

2.2. THE PARTICIPANTS

The participants in the design experiment consist of two experienced designers and ten novice designers. Then the experiment is undertaken for examining how these two groups of designers make design moves or learn how to interact with design situations.

2.3. THE PROCESS

In the experiment, each participant is required to finish the first part, then the second part. A warm-up lesson is given to all participants. Designers can choose freehand sketches or computers by their preferences in design. Then, the design environment is arranged into two kinds of settings, and the process is video-recorded or recorded by the computer system respectively. Based on a retrospective study, the observation focus on examining when and where design is situated.

3. The 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 decisions in related to design moves.

3.1. WHEN IS SITUATION DEFINED

In the first part of experiment, designers study the geometric condition of sites, the characteristics of the case, and the possibility 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 (Cp), basic moves (μb), dimensional adaptation (μd), topological adaptation (μt), and problem solution (Cs). For example, Table 1 shows the layouts in four sites by tester No.1, and the process is also encoded according to the timing, design behaviors, and design decisions, Table 2. It is found that design situations are often identified when E, D, T activities occurred. While it is difficult to distinguish D and T, D and T activities are often occurred at the same time. E activities are gradually reduced, since designers are getting familiar with the case and design situations. Meanwhile, μd and μt are followed by Cp, while Cs is only occurred when basic move (μb) is occurred.

TABLE 1. Comparison of four sites designed by tester No.1

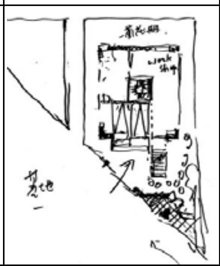
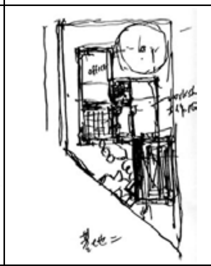
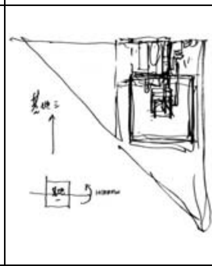
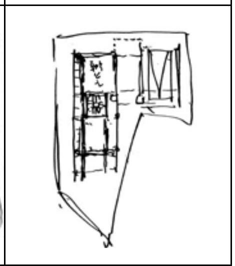
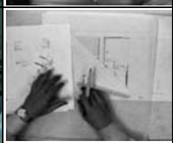
	Site-A1	Site-A2	Site-A3	Site-A4
1^{st} Floor				
Basic Moves	Define Main Entry	Setback from the tree	Define Main Entry and parking	Setback from the right-bottom corner

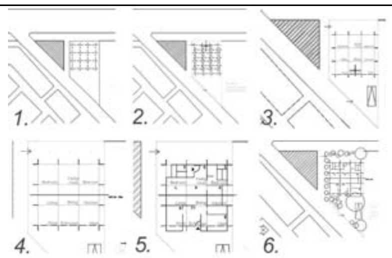
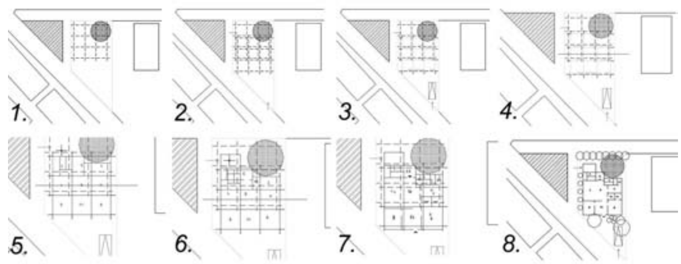
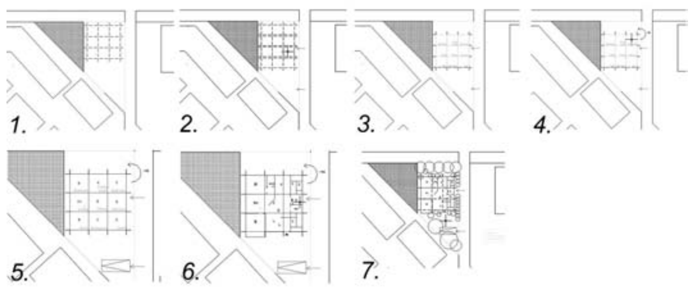
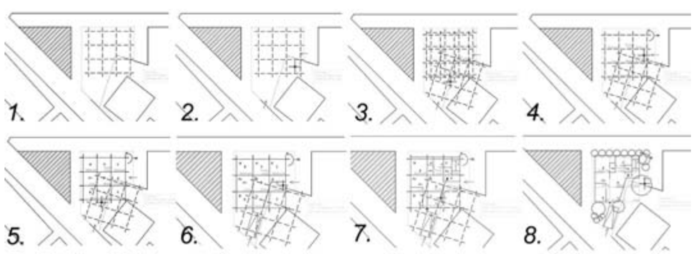
TABLE 2. Partial analysis of design activities encoded in time sequence

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				◎	◎				◎		

The study found that the sequences of design moves are similar in various sites by each designer, while each still has minor difference. There are more visible patterns of the design moves if designers use CAD for designing. For example, Table 3 demonstrates the design moves in four sites by tester No.3.

CAD layer settings are similar while minor difference exists for solving specific case adaptation such as 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 case was inserted and followed by minor dimensional adjustment. The colors and types of lines also reveal different levels of importance to designers.

TABLE 3. Comparison of design moves by computers by tester No.3.

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*	

3.2. WHERE IS SITUATION AND ADAPTATION OCCURRED

In this study, repetitive design in similar sites could provide comparative data to verify the critical operations. For example, the observation demonstrates that tester No.1 proposed and verify in 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-grid structure and the central core as shown in sketches. Furthermore, Table 1 compares the sketches in four sites (A1-A4) by tester No.1, and main design situations are identified and solved. The setback from a tree or corner is a nature response to situations. The house plans in site 2, 3 and 4 are derived from the plan in Site 1. In site 4, the design becomes more complex, and more basic moves as well as sequential moves are occurred. These changes are also found in other designers such as tester No.3, shown in Table 3. Earlier design solutions are often used in solving later similar problems.

In general, situations can be categorized into various design arrangement, such as dimension, orientation, artifact, etc. The study analyzes the design problems that designers are typically dealing with, and to classify these design factors or situations into nine types that are related with the site, environment or the building, 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. Table 4 demonstrates the design sequence of situation occurrence and solution. It is found that similar design operations occurred in these sites. 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. Therefore, solutions are confirmed by designers in response to the situation consistently.

TABLE 4. Design sequence of situation occurrence and solutions

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

4. Discussion

This paper provides a basic understanding of the design moves in situated design from design experiments. Design moves can be considered as a serial of steps to respond to the design situation. The findings in the design experiment provide the foundation for the following discussion.

4.1. OBSERVATION AND RETROSPECTIVE ANALYSIS

The approach of examining situation is feasible in identifying how designers respond to the situations by repetitive tests. In this paper, design moves in design are more easily observed in various situations because the nine-grid structured prototype is a unique instance of housing design and the top-down process of case-based design is "structurally" organized. Therefore, the model of design moves in situated design can be verified at the preliminary stage. The sequence of design moves can help determining the decision flows, while the complexity of design operations in adaptation needs more in-depth studies. However, the retrospective analysis has its constraints of revealing designers' intention. It is only useful for coding based on graphic representation without interfering the design process.

Meanwhile, design moves in situated design and case adaptation by novice and experienced designers are similar in identification of situation, while the solution timing is different. Designers using different tools demonstrate that different design behaviors require different recording and analytic methods. In general, designers indicate the usefulness of using CAD for reusing case and modification, while design thinking in the conceptual stage is still difficult by computers.

4.2. IMPLICATIONS FOR FUTURE CAAD DEVELOPMENT

Analysis of cognitive processes of a designer can serve as the foundation for support tools (Suwa et.al., 1998). Identifications of when and where that design situations may interact with design enhance our basic understanding of case-based design. New CAAD tools which have the capacity to support changes in conceptualization are required, a case-based reasoning system can be developed with the functions of automatically tracking the design moves and building knowledge into the system to enhance the learning ability of situation identification and case adaptation.

While design computation will be beneficial from converting heuristics into mechanism, design problem-solving requires the transformation of non-routine problems into routine problems (Chiu, 1997). Without an understanding of how these above conditions are met, further study of what computational tools are needed for case-based design cannot be reached.

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