ANALOGICAL REASONING IN ARCHITECTURAL DESIGN: 
COMPARISON OF HUMAN DESIGNERS AND COMPUTERS IN CASE 
ADAPTATION

MAO-LIN CHIU 
Department of Architecture 
National Cheng-Kung University 
No.1, University Road, 
Tainan, Taiwan

Abstract. Design cases were considered as the design solution or condensed knowledge of design experience. In the analogical reasoning process, case adaptation is the fundamental task for solving the problem. This paper is aimed to study the difference between human designers and computers in case adaptation. Two design experiments are undertaken for examining how designers apply dimensional and topological adaptation, exploring the difference of case adaptation by novice and experienced designers, and examining the difference between human judgement in case adaptation and the evaluation mechanism by providing similarity assessment. In conclusion, this study provides the comparative analysis from the above observation and implications on the development of case-based reasoning systems for designers.

Keywords: Case-based reasoning, analogical reasoning, computer-aided architectural design, case adaptation

1. Introduction

Design cases were considered as the design solution or condensed knowledge of previous design experience (Leake 1996, Dave et. al. 1992, Rosenman et. al. 1991). Kolodner (1993) defined "a case, which generally represents a concrete situation, integrates a multitude of complex information in a very concrete way." Reasoning with cases involves case retrieval, adaptation, and justification.

Analogical reasoning consists of (1) transferring knowledge from past problem solving episodes to a new problem that shares significant features with corresponding past experience, and (2) applying the transferred knowledge to construct solutions to new problems (Chen 1991). In the analogical reasoning
process, case adaptation is the fundamental task for solving the problem. Case-based reasoning (CBR) is a research paradigm that also uses the adaptation mechanism for solving a new problem from past experience. Analogical reasoning can be case-based reasoning, but is more general in the problem-solving process.

In this paper, the main goal is to study the difference between human designers and computers in case adaptation. Therefore, four steps are undertaken: (1) first analyzes how different adaptation algorithms for computation can be applied; (2) then examines how designers apply dimensional adaptation and topological adaptation; (3) continues the previous experiments and explores the difference of case adaptation by novice and experienced designers; and (4) finally examines the difference between human judgement in case adaptation and the evaluation mechanism by providing similarity assessment.

In the following sections, ways of making case adaptation, and the comparison between human designers and computers are explored by design experiments of a housing project and a street facade renovation project.

2. Adaptation Algorithms

In most situations, solutions from retrieved cases needed to be adapted so they can solve a new problem. Generally, case adaptations are considered as a constraint satisfaction problem in design computation. Kolodner's (1993) case-based reasoning textbook describes ten methods by which adaptation can be done. Among these methods, adaptation algorithms fall into four categories: (1) substitution, (2) transformation, (3) special-purpose adaptation and repair, and (4) derivational replay.

More than one of these algorithms may be used in the CBR system. Different systems implement their algorithms of each category differently. This paper focuses the first two categories, i.e., substitution and transformation methods. Substitution methods substitute values appropriate for the new situation for values in the old solution. Reinstantiation and parameter adjustment are frequently used by CBR systems. Transformation methods are used to transform an old solution into one that work in a new situation.

![Diagram](image)

*Figure 1. The Case-based Reasoning Process and Adaptation*
Furthermore, in the case-based reasoning process as shown in Figure 1, dimensional, topological, and other factors may affect the adaptation of design solution (Maher 1995, Hua et. al. 1992). To make case adaptation useful, justification need to be evaluated.

The design process is considered as a learning process in which designers are learning from analogy and induction (Chen 1991). Design is also a situated activity. Two situations may be occurred in adaptation as shown in Figure 2. In the situation A, one case may generate many new cases by analogical reasoning by deduction. In situation B, many cases may be retrieved and developed into to one new case by analogical reasoning by induction. In the adaptation process, dimensional or topological adaptation can be used.

![Figure 2. Two Situations of Case Adaptation](image)

To make the demonstration explicit, this paper will conduct two design experiments based on both situations. Each experiment is assigned to two testing groups. Group A consists of novice designers who have no previous design experience and Group B consists of experienced designers.

3. Dimensional and Topological Adaptation

The first design experiment of a housing project was given to Group A for exploring the dimensional and topological adaptation (Chiu and Shaw 1996). Prototypes are derived from design knowledge and developed as a conceptual model (Gero 1991). Two prototypes of each housing unit are given to designers. Based on their preference and judgement, designers can only choose one prototype and try to fit into different sites of incremented width of 1.5 meter from 6 meter to 10.5 meter, as shown in Figure 3.
The design result indicates that one third of designers basically maintain the original structure, one third maintains the structure with minor changes of width, and one third change the structure greatly. Dimensional changes, including change of proportion and scales, work easily within the 1.5 meter incremental range, and topological changes are occurred beyond the range. Designers tend to give up further development beyond the 3 meter range. Only few designers are able to change dimension and topology simultaneously. The most difficult task for designers is to maintain the characteristics of the prototype.

Parameter adjustment is a technique for interpolating values in a new solution based on those from an old one. The above adaptation process can be modeled as the parameter adjustment of the housing unit. The SAR theory was applied for defining the structure (Wiewel 1976). The supports (the structure and the partitions) and the infills (space units) are shown in Figure 4. As accepted and feasible solutions, most of the developed schemes by designers can be simulated by parameter adjustment. Therefore, new cases can be developed by dimensional and topological adaptation. However, the limitation of dimensional and topological adaptation is clear as shown in the experiment.
4. Substitution and Transformation

A second experiment is also given to Group A for exploring the substitution and transformation in case adaptation. Reinstantiation is used to instantiate an old solution with new objects for suggesting substitutions. Transformation is a process of adapting an old solution for a new problem by structurally deleting, inserting, substituting, or adjusting parts of the solution.

Environmental changes in Taiwan are accelerated because of economic development. The focus on contextual influence was given to traditional row houses which are rapidly demolished and needed to be infilled. Figure 5 demonstrates the facade of the Di-Hwa Street in Taipei. Figure 6 illustrates a new problem and a possible new case based on the analytic structure.

![Figure 5. The Original Facade of the Di-Hwa Street in Taipei](image)

![Figure 6. The New Problem and New Case in the Di-Hwa Street](image)

Furthermore, as shown in Figure 7, various situations in series 1 and 2 are simulated. Series 1 consists of all two-story houses. Series 2 are mixed with two-story and three-story houses. Each situation is specified with width and height. Designers are requested to infill the empty block in each situation based on existing conditions. Case retrieval and selection is critical to adaptation. Figure 8 demonstrates the adaption of facade C derived from neighbour A and
B, i.e. components of A and B are retrieved. In the case of substitution, facade A is selected, partial substitution is implemented by using components of facade B. In the case of transformation, a two-story building can be transformed into three-story building by inserting the middle section.

Reinstantiation of an old solution may be used when the structure of the solution to the problem and an old case are the same, but roles in the problem solution may be filled differently than roles in the old case. Local reinstatiation may be applied when only parts of an old solution need to be reinstated. The result of 17 designers from Group A shows that most of designers conduct analogical reasoning based on the direct neighbours (right and left sides) of the empty blocks. Few designers are based on all facades in the street. This phenomena can consider that designers tend to use partial substitution of the all facade. Meanwhile, all designers are based on supports and infills to construct the basic frame, while few rules are implemented and constraints are imposed.

Figure 7. Simulated Situations of the Street Facade
As shown in Figure 9, the supports of the street facade is connected to certain contexts. Based on the present of certain features, each building facade as precedent can be organized and retrieved. Coyne and Yokoza (1992) indicate that a connectionist approach can be used for automating the classification and designing with precedents.

5. Case Adaptation by Novice vs. Experienced Designers

The above two design experiments of were also given to the second group of designers, i.e., experienced designers. In the first experiment, the results show that experienced designers are more capable to resolve topological adaptation, and topological adjustment generally follows dimensional changes. The reasoning time of experienced designers is usually shorter than the novice designers. Meanwhile, novice designers occasionally misuse cases. Generally, in Group A, the ability of topological adaptation is weaker than the dimensional adaptation. On the other hand, in Group B, experienced designers are more capable to conduct dimensional and topological adaptation simultaneously.

In the second experiment, experienced designers typically have individual intentions and consideration based on semantic relations. More importantly,
attitudes toward historical and environmental context vary, and could be harmony, neutral, or contrast to the existing situations. Figure 10 demonstrates two examples by experienced designers in the street facade experiment.

Can CBR systems provide innovative or creative design become an interesting issue? Innovative design may arise during routine design when a new requirement is introduced that takes the design away from routine, requires new components and techniques. Since some design knowledge remains constant, designers do not have to re-develop a new design schema, parts of the original building are transformed while some new parts are built. Often designers modify other architects’ schemata because their design requirements are almost identical.

![Figure 10. Two Street Facades Designed by Two Experienced Designers](image)

Furthermore, similarity is addressed by most designers in the design experiment 2. Therefore, similarity assessment is a major concern in adaptation. Apparently, the selected street facade is built in the same period. The building styles can be said as similar or uniform. Designers tend to retrieve adjacent cases for developing the new cases. It would be interested to examine in the semi-uniform or heterogeneous situation of the street facade. However, no designers want the new cases to be identical to the old ones. Variation are generated in the substitution and transformation process. When rules or contraints are applied, the level of variation can be manipulated.

### 6. Case Similarity Assessment

Case-based research assumes that cases whose solutions are most similar to a new solution will most likely be useful in designing it (Dzeng 1995). If a new case is developed as shown in Figure 11, four cases are retrieved by key features (the structure or components). The similarity assessment by human judgement will give a sequence of case C, D, A, B from the closest to the less
closest. Case C is most closed to the new case, while case D has same width and height, case A has same components, and case B has same width. This kind of assessment may be inconsistent due to the complexity of contexts and designers' intentions.

Kolodner (1993) argued that some classes of matches, "easy-adapted" matches, should be referred over "hard-to-adapted" matches during retrieval. This study uses nearest neighbour retrieval in case retrieval instead of using the index-based method which have been studied in most CBR research. Typically, the query case (Q) and a case (C) in the case-base S(Q,C) is the weighted sum of similarity of each attribute: \( \sum W_i \times s(Q_i,C_i) / SW_i \), where \( W_i \) is the weight of the attribute, \( s(Q_i,C_i) \) is a similarity between the value of the i-th attribute of Q and C. Traditional implementations would compute the similarity value for all cases, and sort cases based on their similarity. However, this is a time consuming task as computing time increase linearly as the number of cases in the case-base and as the number defined attributes.

<table>
<thead>
<tr>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
<th>Case D</th>
<th>Structure</th>
<th>New Case</th>
</tr>
</thead>
</table>

![Figure 11. Similarity Assessment of The Original Facade and The New Facade](image)

If the user can specify and assign similarity value, then the difference between human judgement in case adaptation and the evaluation mechanism by computers is quite narrow. Therefore, for each assessment, a similarity value will be assigned using similarity between values of attributes specified by the user and values of case created in the previous stage. Calculation is similar to weighted nearest neighbour, except that not all attributes are involved. Then computation time will be saved. While design computation will be beneficial from converting heuristics into mechanism, problem-solving requires the transformation of non-routine problems into routine problems (Maher et. al. 1995).

7. Conclusion

This paper provides a basic understanding of the human design and computers
in case adaptation by observation from design experiments. The findings indicate the limitation of dimensional adaptation and the complexity of topological adaptation. Case adaptation by novice and experienced designers are different in approaches of dimensional adaptation and topological adaptation. While design computation will be beneficial from converting heuristics into mechanism, problem-solving requires the transformation of non-routine problems into routine problems. If the user can specify and assign similarity value, then the difference between human judgement in case adaptation and the evaluation mechanism by computers is quite narrow. Without an understanding of how these above conditions are met, further study of what computational tools are needed for case-based design and reasoning cannot be reached.

In general, the complexity of design case adaptation has been underestimated, with a tendency for it to be modeled as the manipulation of simple algorithms and heuristics. From the preliminary observations, existing CBR systems are constructive tools which produce correct answers but not necessarily good ones because:

1. They do not consider characteristics of an individual user or the problem. The outcomes are standardized regardless of problem constraints and the context of the domain.

2. They do not address semantics and design justification. Architectural plans are usually constrained not only by their dependency relationships through spatial reasoning, but also by the designer's experience and heuristic rules.

In conclusion, design is a significant human activity. Computers open up new realms of possibilities for design assistance. However, a computer is not a designer. It is best understood as useful tools which provides means of storing information and carrying out potentially useful computations (Sun 1993). The research indicates that case-based design in architectural design can proceed effectively through the cognitive science of views for proceeding future research.

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