Design Adaptation for Handling Design Failures

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This research deals with two important issues in Case-based Design(CBD): a structure of design cases and a process of design adaptation for handling design failures. The structure of design cases involves problem situation, design specification, design tasks, design solutions, causal explanation, past design failures as well as design performance. It has been noticed that how to represent a structure of design cases and how it can be used in actual a process of design adaptation process are important in Case-based Design. Adaptation process in Case-based Design is also crucial, especially in handling design failures. The description and the analysis of design adaptation process in the context of Case-based Design paradigm is the major focus of this research. A model of casual explanation is presented as an useful tool for identifying sources of design failures. For efficiently handling design failures based on causal explanation, it is essential to characterize various design failures and to devise an adequate structure of adaptation process. Applicability of adaptation process is demonstrated in an exemplary kitchen layout task.

Key words: design failures, design adaptation, causal explanation, adaptation strategies.

1 Introduction

Architectural design decision making is an extremely complex process in which designer should be able to handle diversified criteria, constraints and variables. By being motivated to have enhanced problem solving capability, especially when existing design cases are applicable to the new design requirements, Case-based Design(CBD)paradigm provides an efficient way of hand ling inherent complexities in design. In fact, Case-based design approach has the advantage of achieving a new, complex design solution by minimal search, while maintaining the quality of the design[1]. Case-based design not only enables a designer to have access to the structure and information of old design cases, but also attempts to avoid unnecessary efforts and complex reasoning in new design problem solving process by utilizing past design cases.

In general, architectural design process includes various design failures so that the designer should develop adequate strategies to resolve them. Design failure handling is a ubiquitous phenomenon and yet a very difficult task in most of design problem solving processes. Adapting a chosen design case to a set of new design requirements is typically a conflict resolution process. Design adaptation process to resolve design failures usually is based on new design requirements. This adaptation process which modifies chosen design case in response to the detected design failures, is an essential process in Case-based Design paradigm. In spite of its importance in CBD, major difficulty of design case adaptation lies in the lack of more structured representation of design case closely tied to its actual adaptation process. Representing a design case is an important issue since the information stored in the design case often characterizes potential design solutions dependent on it Therefore, it is always necessary to develop a novel way for storing information within design cases which can facilitate design adaptation process. When we think of design adaptation process as a major component of CBD, it is also indispensable not just for achieving feasible design solutions but for saving time and efforts throughout the whole design process.

Even though, design adaptation for handling design failures is an important aspect of design process, since they frequently happen during overall design processes, many researches on CBD have been restricted mainly to the issues of case representation and case retrieval[2] [3] [4]. From the perspective of above view, this paper basically focuses on design adaptation process. Firstly, we tried to identify the elements of a typical design case.

Secondly, various design failures which can occur during the design process are characterized . Thirdly, we also provide a causal explanation model for selecting proper failure handling strategies based on the identified design failure types. Finally, this paper deals with the question of how design adaptation model can be constructed in such a way that it can demonstrate its usability in design case adaptation by handling design failures.

2 Representation of design cases

A design state can be described in terms of its components. Any design configuration be expressed by a collection of components representing design solution in an abstract form. Component-based design paradigm basically deals with hierarchies and geometries of design components as well as the spatial relationships among them. For example, a component-based design approach can be established to handle specific design failure such as spatial conflicts normally occurring in design process.

One of the major advantages of component-based design[5] is that it enables a designer to focus on each component separately, which has significant value in reducing complexity of the given design problem. The reasoning mechanism is dependent on various expertise concerning each domain area needed for design problem solving. Therefore, it is particularly crucial to note that rules, procedures, and knowledge for the assembly of multiple design components play an important role in any design activity. The componentbased design process facilitates a designer to operate both the abstract design variables and physical ones. It not only drives design decisions on design components, but also offers great potential for producing ideas associated with design case adaptation. Componentbased design process does allow us to validate or test concept of design adaptation by demonstrating its applicability to design. In this research, representation of design cases is also examined under the component-based design approach. Design cases representing knowledge in an un-compiled form are quite different from those design prototypes which contain more generalized knowledge in a compiled form[6].

Deciding what a design case should contain is important because it is supposed to provide sufficient knowledge for design adaptation. A design case may consist of several different types of information:problem situation, design specifications, design tasks, design solutions, causal explanation, past design failures and design performances. Problem situation represents the environment or the context where the design case is addressed to.

Design specifications include design goals and design constraints while design solution is a derived design state satisfying these goals and constraints according to the specified problem which is used for proposing solutions to new design cases. Design solutions may contain abstraction of geometry, configurations of design components and topological relationships among design components. Design tasks designate sequence of actions taken to derive a design solution. This type of design sequences can guide design adaptation process by which different design solutions are to be produced. Past design failures guide a designer to avoid making the same errors in a new context by providing the way in which a certain type of design failures were fixed. Finally, Design performance is the outcome, the resulting state of a design case when a design solution is carried out.

3 Causal explanation

Causal explanations is frequently proposed for resolving design failures because of its wide range of applicability, robustness as well as its capability to provide sufficient information and explanations of design reasoning. The causal explanation is to create descriptions of design failures by being represented as a semantic network of design attributes which is composed of nodes and links, where the nodes represent the design components and their attributes and the links represent the causal relationships between the nodes [7][8]. Explicit casual explanations facilitate design adaptation for handling design failures. Causal explanation is a useful and strong basis for identifying design failures and actual causes of those failures can be derived from it. Furthermore, causal explanation describing a design case with respect to design failures provides a basis for design adaptation to remove those failures and to guide appropriate design changes. In this sense, causal explanation has a significant impact on design case adaptation. Figure 1 shows an example of causal explanation of spatial relationship between the kitchen room and the refrigerator center which appears in the graphical presentation of design case(Figure 2). It shows positions of design components and positional relationships between design components using causal links such as 'greater than' and '+'. The + sign forms the computational equation providing a means of computing the value of unknown variables. For example, Refrigerator xl and Refrigerator Width which are linked to Refrigerator X2 by + symbol makes the equation: Refrigerator xl + Refrigerator Width = Refrigerator x2. The equation provides a basis for determining appropriate changes to handle design failures.

4 Design adaptation strategy

Typical design failures in component-based design process can be classified into several categories: geometric failures, topological failures, configuration failures, consistency failures and goal conflicts. Geometric failures can be identified when dimensional constraints are violated. Topological failures imply that spatial relationships between design components are not properly established. Configuration failures indicate that there are design components which cannot be assembled together in design. Consistency failures happen when inconsistent values of design variables exist in design. Finally, goal conflicts occur when not simultaneously satisfactory goals are defined in design. Design adaptation strategies[9][10][11] for resolving those design failures are crucial in the design adaptation process because a specific adaptation strategy determines directions of design adaptation and the possibility of its success, as well. There can be five different design adaptation strategies: dimensional adjustment strategy, configurational adjustment strategy, topological adjustment strategy, case utilization strategy and goal relaxation strategy. The dimensional adaptation strategy, being based on the parameter adjustment strategy, is tied with the changes of components' numerical dimensions to find legal value of them. Parameter adjustment is to change design values in response to emerged design failures by attempting to find appropriate design values which are likely to resolve design failures. The configurational strategy tries to resolve design failures by changing the location and the assembly of design components. It is a method to derive a satisfactory design solution through various design operations such as component substitution, component elimination and component addition. Component substitution is to replace the faulty design component with another without changing the overall structure of design solutions in a design case while component addition or elimination inevitably changes the internal structure of design solutions. Component elimination usually results in overall size reduction of design geometry which may resolve design failures. In general, it is possible only when other design component can perform the same function in design or that function is not required any more. Addition of design component can be implemented to improve design performance or to introduce new functions in design. Topological adjustment of design components rearranges the locations of design components. Design case utilization focuses on making use of knowledge in other design cases. Finally, goal relaxation strategy is more straightforward in a sense that it simply ignores design goals of insignificant importance. Sometimes, it can be suitable adaptation strategy especially for goal conflicts resolution.

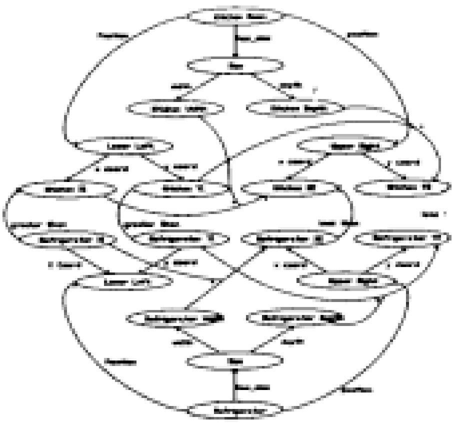

Figure 1 Partial causal explanation of spatial relationship between the kitchen room and the refrigerator center

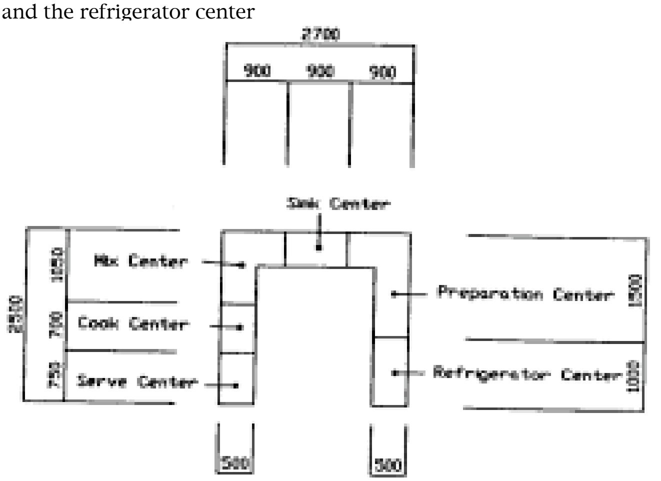

Figure 2 Graphical presentation of the design case

5 Design adaptation process

A chosen old design case frequently confronts design failures, and an adaptation process is required when these design failures are identified. Central to case-based design is how a failed design case can be fixed. Design process needs to have an adaptation mechanism that can reorganize old design cases into the new ones to meet the current design situation. Design adaptation[12][13], as a crucial process in Case-based Design, is required to resolve emerging design failures and improve design performance. On the other hand, design adaptation process for handling a failed design case should be addressed to identify what to adapt as well as possible adaptation strategies. The mechanism dealing with these issues consists of five basic steps: characterization of design failures, identification of attributes to adapt, selection of adaptation strategy, generation of design adaptation and evaluation of a design case adapted (Figure 3).

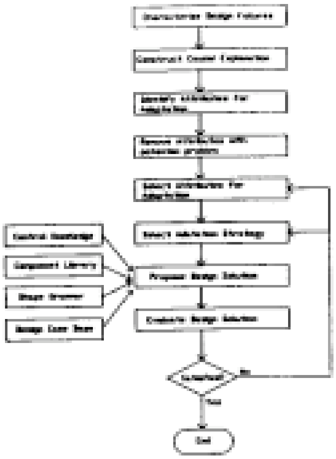

Figure 3 A model of design adaptation process for handling design failures

As the first step of design adaptation, identifying causes of design failures needs to describe design failures and to recognize potential sources and types of those failures. Again, causal explanation can provide a basis for how to identify the causes of design failures and why they happened. Searching for the sources of design failures is important because it often reveals the potential causes of design failures. Causes of design failures can be identified by indicating faulty attributes of the node on the causal explanation network where the design failures are likely to happen. Typically, there can be multiple attributes which possibly are responsible for specific design failures. Those attributes indicated as the potential failure sources need to be adapted to resolve design failures. Generating a list of attributes to adapt is the second step. And then, the attributes which are expected to have potential problem can be eliminated.

During this process, past design failures of the chosen design case provides a basis to determine which attributes to be removed, because elimination of the attributes which caused design failures in the past would be desirable. Once the attributes for adaptation are identified, the adequate adaptation strategy needs to be determined. Selection of an appropriate adaptation strategy is the third step in design adaption process. Selecting an appropriate adaptation strategy depends on the characterization of design failures. A set of different rules can be applied in this process to determine proper adaptation strategies, but in general, those strategies in the order of the easiest adaptation which potentially causes less changes of the given design solution are to be applied. Usually, adaptation strategies are applied in the order of configurational adjustment(location adjustment, dimensional adjustment, elimination or addition of components), topological adjustment, case utilization and goal relaxation. Generation of design adaptation assumes the certain design changes can be made to remove design failures encountered during design process. Finally, evaluation process tests the adapted design case to determine whether it delivers the specified design requirements without design failures or not. If the adapted design case is successful in satisfying given design requirements, the adaptation process terminates.

6 Example

Kitchen layout task is chosen for the demonstration of the design adaptation process handling design failures. Given exemplary design task is to configure a set of design components with redetermined room size and design requirements of a kitchen space. As a starting point for' the design adaptation process, new problem situation as well as a retrieved case in response to these requirements are provided as shown in Table 1 and Table 2.

Adaptation process includes two phases: phase 1 and phase 2

Phase 1: The first task is begun by constructing the causal explanation network. Topological relationships among design components are automatically established from the design solutions and the causal explanation network is constructed. As the result of this task, it was found that the case involves the configurational failures and the topological failure.

The configurational failures were caused since locations of refrigerator center and preparation center exceeds the boundary of the specified kitchen room as shown in Figure 4 and Figure 5. Figure 5 shows the partial causal explanation which shows reasons why the configurationar failure happened. The topological failure was caused sin the entrance to kitchen was blocked by the refrigerator and the preparation center(Figure 4 and Figure 6).

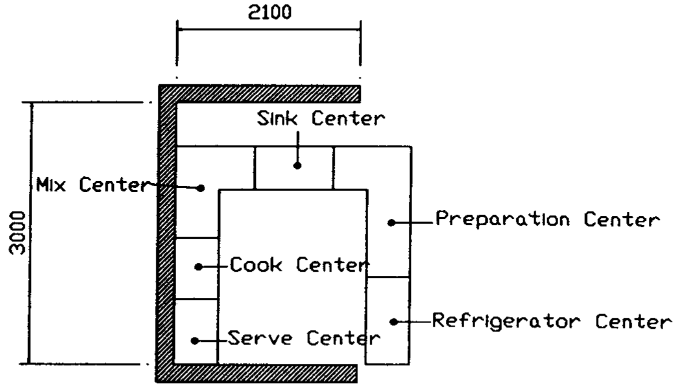

Figure 4 Design failures occurred in the retrieved design case

New Problem Situation
kitchen room width: 2100 x kitchen room depth: 3000
primary user: right-handed cooks
origin of entrance to kitchen: 2100, 0
width of entrance to kitchen: 3000
orientation of entrance to kitchen: vertical

Table 1 New Problem situation

Problem Situation
kitchen room width: 2700 xkitchen room depth: 2500
primary user: right-handed cooks
origin of entrance to kitchen: 0, 0
width of entrance to kitchen: 2700
orientation of entrance to kitchen: horizontal

Design Solution
Size of Design Components
Kitchen Room: kitchen room width: 2700 x kitchen room depth: 2500
Refrigerator Center: refrigerator width: 1000 x refrigerator depth: 500
Preparation Center: preparation_width: 1050 x preparation_length: 900 x
preparation_depth: 500
Sink Center: sink_width: 900 x sink_depth: 500
Mix Center: mix_width: 1050 x mix_length: 900 x mix_depth: 500
Cook Center: cook_width: 700 x cook_depth: 500
Serve Center: serve_width: 750 x serve_depth: 500
Location of Design Components(X Coordinate, Y Coordinate)
Refrigerator Center: refrigerator x1: 2200, refrigerator y1: 0
Preparation Center: preparation x1: 1800 , preparation y1: 2000
Sink Center: sink x1: 900, sink y1: 2000

Mix Center: mix x1: 0, mix y1: 1450
Cook Center: cook x1: 0, cook y1: 750
Serve Center: serve x1: 0, serve y1: 0

Design Performance
total length of work triangle: 4300

Table 2 Partial description of the retrieved design case

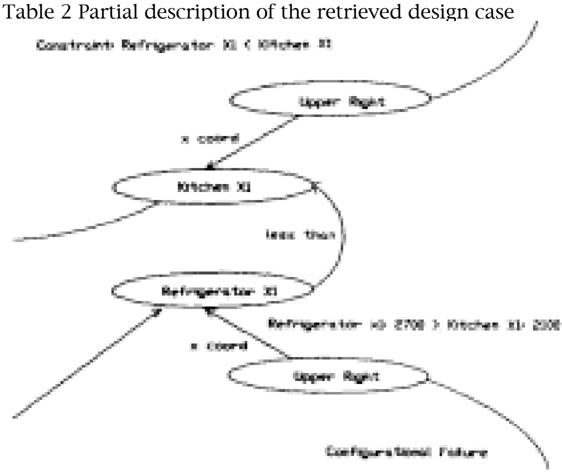

Figure 5 Causal explanation of the configurational failure

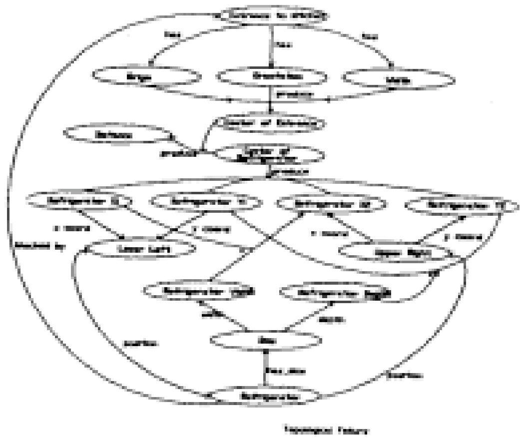

Figure 6 Causal explanation of the topological failure

The adaptation process commences to avoid this undesirable situation. The list of changeable attributes are constructed based on the causal explanation network. They include refrigerator xl, the refrigerator x1, preparation center x1 and preparation center y1. The refrigerator xl, the refrigerator y1, the preparation center xl and preparation center y1 caused design failures. Between these attributes, attributes for the configuration strategy(eg, refrigerator xl, refrigerator y1) can be considered. However, the configurational strategy is supposed to fail since it cannot make the clear space for the entrance to the kitchen. Therefore, it is necessary to use the topological strategy. The topological strategy rearranges design components and leads to changes of topological relationships. Shape grammar can be used to make the changes of topological relationships between design components. Figure 7 shows the shape grammar which is assumed to be selected between various shape grammars to change topological relationships. By the application of the shape grammar[14], the result which resolves the topological failure is obtained as shown in Figure 8. Once the topological failure has been resolved in this way, it is required to evaluate the obtained result. The result of the evaluation reveals that there are still configuration failures as shown in the result. The locations of the refrigerator and the serve center exceed the given area of the kitchen room caused configurational failures.

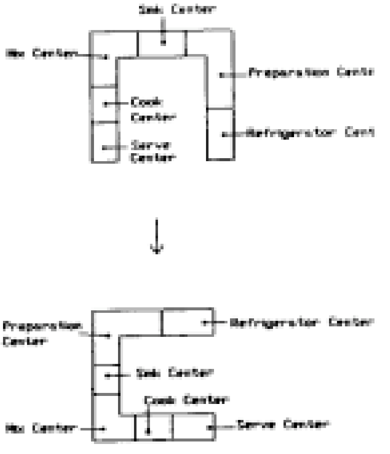

Figure 7 An example of shape grammars for resolving design failures

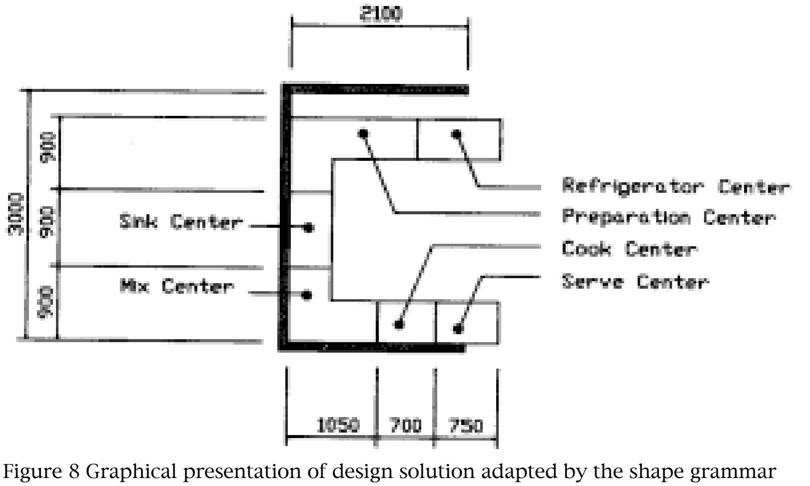

Figure 8 Graphical presentation of design solution adapted by the shape grammar

Phase 2: The causal explanation are constructed and attributes such as refrigerator x1, refrigerator y1, refrigerator width, refrigerator depth, serve x1, serve y1, serve width and serve depth are identified for adaptation. The refrigerator x1, refrigerator y1, serve x1 and serve y1 are chosen. The configuration strategy is chosen based on the selected attributes to position the refrigerator center and the preparation center within the specified kitchen room. The strategy moves the locations of the refrigerator center and the serve center to the left so that they be fitted within the area of the kitchen room. And then it produces the modified design solution. The design solution is evaluated if it satisfies specified requirements. The result reveals a dimensional failure of that the refrigerator center overlaps the preparation center and the serve center overlaps the cook center. For the design failure of the overlapping between the design components, the reduction of sizes of components may resolve the overlapping failures. The component substitution strategy can be used to reduce dimensions of the components. It substitute the different preparation center for the current center and the different cook center. The component substitution strategy will produce the design solutions resolving design failures. The repetition applications of similar processes will produce final design solution(Figure 9) satisfying requirements and the adaptation process will be completed.

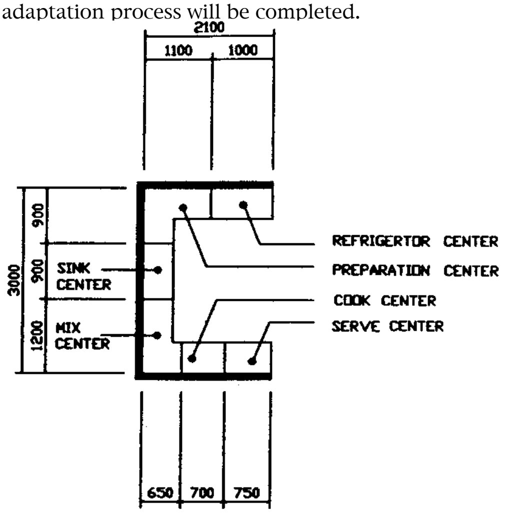

Figure 9 Final design solution as a result of design adaptation

7 Conclusion

This research has been focused on the capability of design adaptation process in handling design failures. One of the major contributions of this paper is to introduce and describe design adaptation process in the context of Case-based Design paradigm.

Case-based design is an approach which deals with complexity of design. It was argued that adaptation process in Case-based Design is a suitable method, especially for handling design failures. Given a set of new design requirements, design adaptation process appeared to be feasible way for resolving design failures. Actual application of design adaptation to design failures raises a number of issues such as representation of cases, characterization of design failures, selection of adaptation strategy as well as the structure of adaptation process. In this paper, major efforts have been made to characterize various design failures and to devise adequate structure of adaptation process. A design adaptation process model in which the adaptation strategies are essential has been developed and its applicability in actual design was tested in the exemplary kitchen layout task.

Conclusively, it turned out to be that causal explanations can provide a basis for design adaptation process in resolving design failures.

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