A CASE-BASED DECISION SUPPORT SYSTEM FOR HOUSING REFURBISHMENT

DE-LUN HUANG, SHEN-GUAN SHIH
Group of Architectural Synergy, Department of Architecture, National Taiwan University of Science & Technology, Taipei, Taiwan.
arranism@gmail.com; sgshih@mail.ntust.edu.tw

Abstract. Effective communication is the key to ensuring quality of housing refurbishment. This paper provides a framework of decision support system for housing refurbishment that helps designers communicate better with tenants who generally lack expert knowledge and cannot express their needs clearly. The framework is constructed using Case-Based Reasoning (CBR) for retrieving past similar cases to meet the challenges and demands of the present refurbishment project at hand. With the help of the system, users can retrieve past cases that match the users' requirements and revise them to meet current needs. It can also be used as design criteria for evaluating the final product to ensure its conformance with the initial planning. A test case is used to demonstrate the system's suitability. The effectiveness of this system is supported by a post-experiment evaluation and interview with the tenant concerning his satisfaction on the refurbishment.

1. Introduction

How to ensure the quality of housing refurbishment has been the focus of concern in recent years. One of the challenges of the housing refurbishment project lies in the fact that renovated tasks are usually complex, small scaled, labour-intensive, and constrained from the existing building, (ven Leeuwen et al., 2000). The major challenge, however, is tenants' inability to express their demand clearly to the designers. The miscommunication about requirements could lead to an unsatisfying result. Thus, understanding demand has an important influence on process and result (Fricke, 1999). In particular, refurbishment decision in the planning phase has significant influence on the project implementation and final results (Bogenstätter, 2000). However, because most tenants do not have professional architectural training and technical knowledge about housing refurbishment, they often find themselves caught in a situation about what and how to choose from the available renovating options rendered to them by the designer. The prompt, inexperienced decision made by untrained tenants could directly affect the final outcomes of a refurbishment project. To ease their clients' problems, designers usually use past refurbishment cases to help them communicate their demands.

However, the past complex, unstructured examples are often incomprehensive or unrepresentative or both to their inexperienced clients, making housing refurbishment a rather challenging and difficult task for both tenants and designers.

Case-Based Reasoning (CBR) is an artificial intelligence technology that solves new problems by adapting solutions that were used to solve old problems (Riesbeck and Schnak, 1989). Numerous researches have been done on using CBR to aid architecture design (Rosenman et al., 1991; Shih, 1991; Halime, 1998) and housing refurbishment design (ven Leeuwen et al., 2000). In particular, several studies have focused on professional design communication in design team containing architectural designers and the engineering designers using CBR (Perera and Watson, 1998; Omer et al., 1997). Despite the many studies done in design communication, there has been no study on the design communication between expertise designers and non-expertise users in the important planning stage.

This paper provides a framework of decision support system for housing refurbishment, using CBR technology. The framework attempts to help the tenants to express refurbishment needs to the designers and bridge the knowledge gap between designers and tenants. To test the system's suitability, an experiment was conducted in which the designer communicated with tenants in relation to available overhaul solutions through the CBR system's generated suggestions.

2. Design Communication and Evaluation

Design communication, in its simplest term, is to understand customers' needs and turn that understanding into a design process that produces products satisfactory to customers (Hauser and Clausing, 1988; Hauser, 1993; Prasad, 1996). To understand customers' needs and to achieve effective communication during the design process, two approaches have been widely adopted: Quality Function Deployment (QFD) and Pattern Languages (PLs). QFD provides an evaluation method for design needs and design quality (Kamara et al., 1999), while PLs supplies a structured method to describe design needs and design solutions (Alexander et al., 1977). Moreover, QFD description of customers' needs can sometimes be abstract, while PLs method is easily understood with examples, thus helping designers to develop suitable solutions. Combining QFD and PLs can achieve reciprocal relations between design needs, quality and evaluation.

3. Case-Based Reasoning

CBR is an artificial intelligence technology that solves new problems by adapting solutions that were used to solve old problems (Riesbeck, 1989). Reasoning by reusing or modifying experience is a frequently applied paradigm for human problem solving (Aamodt and Plaza, 1994). This is particularly the case when the domain is not completely understood or when the concept is open-ended (Kolodner, 1993). In CBR, a previous decision-making experience was represented as cases and stored in the case base. It contains the past lesson, which is the content of the case, and the context in which the lesson can be used (Kolodner, 1993).

4. The DESIRE Framework

The framework for the proposed decision support system, DESIRE, is depicted in Figure 1. It consists of a four-step design communication process and a case-based design data model. In this framework, the completeness of the communication process is built on the case-based design data model, and the effectiveness of the case-based design data model relies on the communication process. The interdependence of DESIRE'S process and database is crucial to the effective communication between experts (designers) and non-experts (tenants).

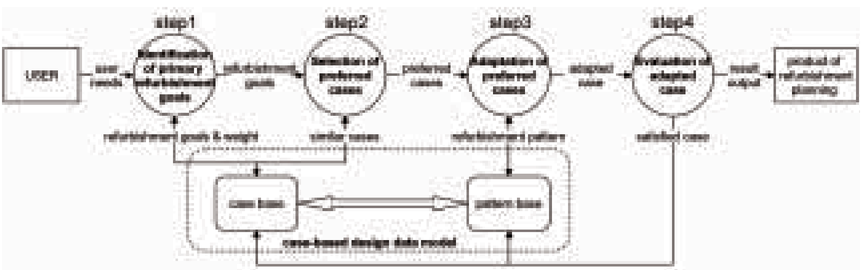

Figure 1. Context diagram of DESIRE.

4.1. A CASE-BASED DESIGN DATA MODEL

As mentioned earlier, a complex refurbishment case can be better solved when it is divided into several smaller sub-problems, and a sub-solution can be found for each sub-problem before all the sub-solutions are integrated into the main solution. Based on this sub-problem separation principle, a case-based design data model is presented in Figure 2.

This model consists of two parts: Case Base and Pattern Base. Complete information of a past successful refurbishment case is stored in the case base. The complete information includes a case's requirements, evaluations, and solutions that are written in pattern. Each bullet point in the case base represents a pattern. Each pattern describes a design problem and a solution solving this problem. While each pattern can be used to solve a similar design problem, a set of patterns can be used to solve a complex refurbishment case.

The pattern base is a place in which different sets of patterns of past cases in

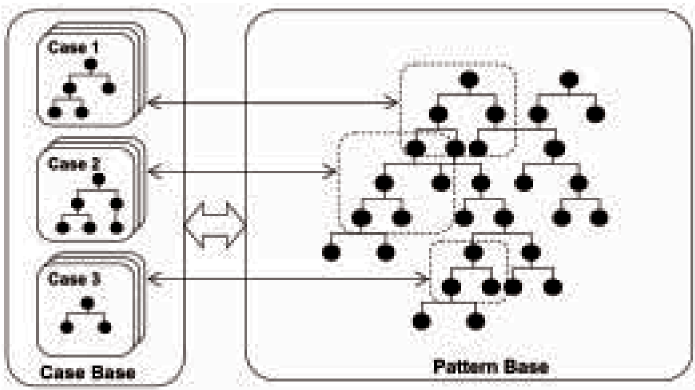

Figure 2. A case-based design data model.

the case base are stored. These sets of patterns together in the pattern base will connect to one another and become an information network of their commonly shared design requirements, problems and solutions. The sets of patterns from the pattern base can be used repeatedly to solve similar problems of a new case.

The patterns have an order that is based on reciprocal relations between patterns on the upper level and those on the lower level. Each pattern contributes to the completion of upper patterns and simultaneously helps to enrich the lower patterns. In our model, usually the patterns at the upper level are tenants' refurbishment requirements, while the lower patterns are details about design products.

A case base can provide complete refurbishment information to the users, based on the successful experience and knowledge from past cases, whereas a pattern base, possessing the characteristics of solution synthesis, can provide a new range of solutions. Thus, by incorporating the case base and the pattern base into a decision system, the users would be able to tap the rich, successful examples of past refurbishments and solve their problems by generating new solutions from the system.

4.2. CASE REPRESENTATION

A context diagram of object model that is developed by our framework is shown in Figure 3. In this model, a CASE includes three parts, INFORMATION, QFD and SOLUTION. INFORMATION describes basic information of refurbishment projects, such as project name, area, ages, and cost; resolute weight of design attributes and evaluation of results are covered in QFD; decision network is under SOLUTION.

Each CASE will have one or more primary goals that are hierarchical levels of refurbishment requirements. Each of the primary goals will receive a score on the scale '0' to '10' representing the level of urgency ("0" being least urgent and "10"

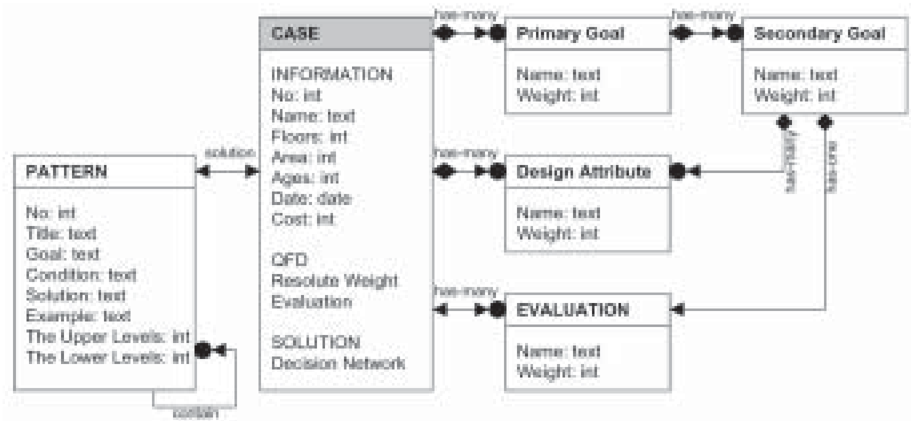

Figure 3. Context diagram of object model.

being highly urgent). Furthermore, the primary goal also is the index for retrieval case. While the primary goal serves as a general refurbishment guideline, the secondary goal deals more with specific tenants' requirements for the refurbishment project. Like the primary goal, every secondary goal will receive a rating from '0' to '10' to represent the level of urgency. The design attribute is a technicality that a designer needs to take into consideration in order to meet the refurbishment requirements, and is given a weightage of '1', '3' or '9' to show the degree of relation between design attributes and refurbishing tasks under the secondary goal ('1' being weakly related, '3' being moderately related and '9' being strongly related). EVALUATION measures the level of the tenant's satisfaction of the refurbishment solution against their needs (secondary goal).

PATTERN is the basic unit description of single design problem as well as its solution. Patterns are connected with one another and become a decision network, the base for solution. Moreover, PATTERN has a standard format. First, 'No' (number) is a value of each pattern. Second, 'Title' should be simple and definite. Third, 'Goal' describes a problem that can be solved. Fourth, 'Condition' interprets a restriction when a pattern is used. Fifth, 'Solution' is a key of a pattern. It provides several solutions to solve problems. Sixth, 'Example' shows a past success example using a picture or a diagram. The last two contents are the Upper Levels and the Lower Levels, both of which describe the contextual relationship of patterns.

4.3. FOUR-STEP DESIGN COMMUNICATION PROCESS

4.3.1. Process step 1: Identification of primary refurbishment goals

The purpose of this step is to determine the hierarchical level of refurbishment requirements. These primary refurbishment goals are stored in the case base from past refurbishment cases. At the outset, the system shows all primary refurbishment goals from the case base. The designers and tenants discuss present refurbishment problems that need to be solved in order to determine the primary goal for the refurbishment project. After identifying the problems and laying out the possible project goals, they will need to figure out the degree of urgency of each identified primary goal to determine its priority. Then the prioritized goals and their confirmed degree of urgency will become the case retrieval's features and weightages.

4.3.2. Process step 2: Selection of preferred cases

This step is to select possible, preferred cases based on users' primary refurbishment goals determined in the previous step. The primary goals are the case features for retrieval case. This paper applies the standard nearest-neighbour algorithm to calculate the degree of case similarity for matching. The selected cases that match the tenant's refurbishment needs from the system's case base will then be prioritized against the primary goals input by the tenant. Following the prioritization, the designer will inform the tenant about the result of the preferred cases retrieved and explain to him/her their detailed information. The determination of the best case resulting from the intensive communication between designers' professional knowledge and tenants' preference marks the end of this step.

4.3.3. Process step 3: Adaptation of preferred cases

After the tenant's preferred cases are selected and determined, the next step is to adapt the cases so they can better solve his/her refurbishment problems with the help of system's pattern base. It involves several tasks. First, users need to identify which secondary goals determine their degree of urgency. Second, the designer needs to confirm design attributes between input-case and source case and modify them. Next is to adjust the existing patterns network of the pattern base to form the new solution patterns and then adapt their contents so that the new patterns can best match the existing refurbishment situations, satisfying secondary goals.

4.3.4. Process step 4: Evaluation of adapted case

Evaluation is used as a measure to gauge the effectiveness of communication between the designer and the tenant. It assesses the degree of tenant's satisfaction over the planning result by reviewing whether his/her needs and refurbishment specifics have been taken into consideration; QFD is the method employed to measure the satisfaction magnitude. The planning result will be output to users and serve as design criteria and guideline for the next design stage. It will also be retained in the case base as reference for future use.

5. Test Case

For the purpose of the study, a real-life refurbishment case was employed to test the suitability of our system, which was used as a professional communication guide between tenants and designers. The case contained two phases: experiment and interview.

The experiment involved a tenant, a designer and two system operators. The tenant worked in the electronics industry and did not possess expert knowledge about refurbishment even though he had had his house renovated previously. The house was around 140 square metres and 22 years old. For this experiment, three past successful refurbishment cases had been stored in the system case base, including eight refurbishment goals and 50 refurbishment patterns.

5.1. FIRST PHASE: EXPERIMENT

5.1.1. Process step 1: Identification of primary refurbishment goals

In step 1, the designer and the tenant began by discussing the two issues about his house: its garden lacks a cool place to relaxin; its top floor lacks a toilet. Then they selected and discussed the potential refurbishment goals through the decision-support system, and decided primary goals and degree of urgency as shown in Table 1.

TABLE 1. Tenant's Primary goals and urgency degree.

Primary goals	*Degree of urgency					
	10	8	6	4	2	0
To provide a cool place and rest shelter		O				
To solve the problem of insufficient interior light						O
To add a toilet	O					
To solve the problem of inefficient use of space						O
To solve the problem of roof leaking						O
To solve the problem of short mezzanine						O
To solve the problem of poor sound insulation						O
To solve the problem of wall chap						O

*Degree of urgency rates on a scale from 0 to 10, with "0" being least urgent and "10" being highly urgent

5.1.2. Process step 2: Selection of preferred cases

After identifying the primary goals for the project, the next step was to search through the system case base for its similarity. The computing results on the degree of case similarity and prioritization are illustrated in Table 2.

As shown in Table 2, Case 02 had the supreme similarity to matching the goals out of the three retrievals and was selected for review of possible adaptation as a solution for the tenant's refurbishment in the next step.

TABLE 2. Degree of case similarity and prioritization.

Case No	degree of case similarity	prioritization
Case 01	49.5%	3
Case 02	75.0%	1
Case 03	56.3%	2

5.1.3. Process step 3: Adaptation of preferred cases

From the primary goals of Case 02, six secondary goals (tenant's preferred refurbishment tasks) were further developed and rated for the degree of urgency, based on the results of designer–tenant discussion and modification of Case 02 to address the tenant's requirements (see Table 3). Then the designer identified five design attributes (consideration of green building, function of space, relationship of space, time of work, and space of work) and matched them against the six tasks to determine their degree of urgency, respectively. The level of relationship between the attributes and the preferred tasks is reflected in absolute weights (AWs) and in resolute weights (RWs) in Table 4.

TABLE 3. Structuring of requirements.

Primary Goals	Secondary Goals (Tenant's Preferred Refurbishment Tasks)	*Degree of urgency
A. To provide a cool place and rest shelter space	A1. Shelter space that uses natural plants	10
	A2. Relax and leisure functions of a shelter	8
	A3. A theme design	6
B. To add a toilet	B1. Sufficient natural light	10
	B2. Space of adequate ventilation	8
	B3. Space saving	10

*Degree of urgency rates on a scale from 0 to 10, with "0" being least urgent and "10" being highly urgent

Then the designer explained the retrieved case's (Case 02) refurbishment needs and solution, made up of patterns (sought the tenant's comments and needs), and added other past cases' solution patterns that reflect the tenant's needs from the system's database to the Case 02's solution. Figure 4 shows how the refurbishment solution evolved from selected Case 02 to its final version (The highlighted parts are the added patterns).

5.1.4. Process step 4: Evaluation of adapted case

After the refurbishment planning was finished, we asked the tenant to measure his refurbishment goals against the planning product. Table 5 shows that except for the 'theme design', the tenant was quite satisfied with the refurbishment tasks. Thus, after discussion, the designer and the tenant decided to use the planning product as the base for the refurbishment in the next phase. This case was stored in the system case base after rated as being satisfactory and could be reused in the future.

TABLE 4. Relationship of secondary goals and design attributes.

Design Attributes		Consideration of green building	Function of space	Relationship of space	Time of work	Space of work
Secondary Goals (Tenant's Preferred Refurbishment Tasks) and Degree of urgency						
A1. Shelter space that uses natural plants	10	**9**	**9**	**9**	***9**	**9**
A2. Relax and leisure functions of a shelter	8	**3**	**9**	**9**	***1**	**1**
A3. A theme design	6		**9**	**9**	***3**	
B1. Sufficient natural light	10	**9**	**9**	**3**		
B2. Space of adequate ventilation	8	**9**	**9**	**3**		
B3. Space saving	10	**3**	**9**	**3**		**9**
Absolute Weights (AWd)		60	91.8	58.8	23.1	37.5
Resolute Weights (RWd)		2.0	3.1	1.9	0.8	1.3

*9, 3, and 1 for strong, medium, and weak relationships

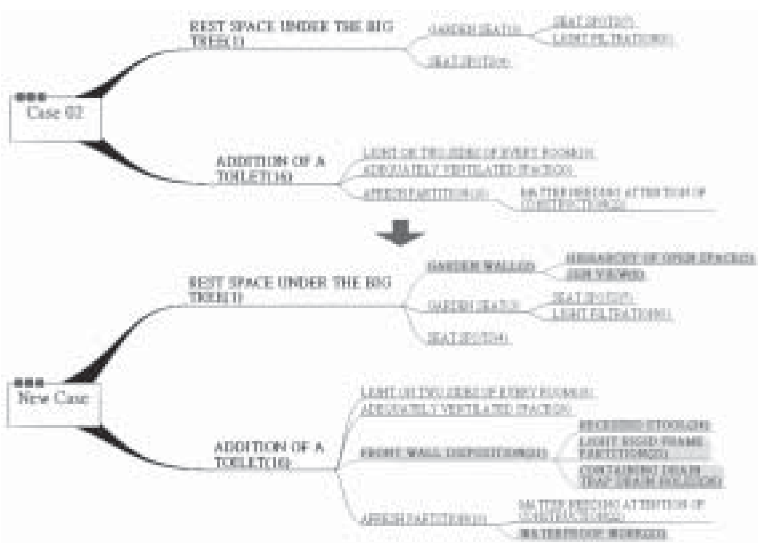

Figure 4. The planning solution of new case.

TABLE 5. Evaluation of adapted case

Primary Goals	Secondary Goals (Tenant's Preferred Refurbishment Tasks)	Degree of tenant's satisfaction
A. To provide a cool place and rest shelter space	A1. Shelter space that uses natural plants	8
	A2. Relax and leisure functions of a shelter	10
	A3. A theme design	4
B. To add a toilet	B1. Sufficient natural light	8
	B2. Space of adequate ventilation	8
	B3. Space saving	10

*Degree of tenant's satisfaction rates on a scale from 0 to 10, with "0" being least satisfaction and "10" being highly satisfaction

5.2. SECOND PHASE: INTERVIEW

After the experiment, we interviewed the tenant to understand his opinion about how the DESIRE system had helped him to identify and express his refurbishment needs and how satisfied he was with the planning results. The tenant's perspectives on the experiment are summarized as follows.

First, the tenant expressed that the past cases from the system had indeed assisted him in expressing his refurbishment needs. He pointed out that the main difference was the accessibility and acquisition of information needed to make the crucial refurbishing decision in the planning stage. In his previous refurbishment, he had no way of knowing what should be achieved in the planning stage, and therefore he had little control over what the refurbishment result should be like. In this experiment, on the other hand, he was able to define his own refurbishment needs through the structured information retrieved from the system and convey them to the designer with clear understanding. He also knew what the after-refurbishment product should be like and what it should achieve.

The other thing the tenant was impressed with was the way how the past cases had helped during the planning process. He reported, from the last refurbishment project, that he had almost nothing to keep but a few design drawings, and unless there was an expert on site, these drawings would not be worth keeping for him. But this time, he thought these data or products developed during the planning stage could be easily understood and reused on his or his friends' behalf in the future.

6. Conclusion

As far as miscommunication problems between designers and tenants in the refurbishment project are concerned, the proposed case-based system, DESIRE, improves communication efficiency. From the experiment, we find that the tenant could generally express his refurbishment problems but could not pinpoint exactly what his refurbishment needs were in the initial planning stage. Our system provides the tenant with refurbishment information by adapting refurbishment requirements of the past cases with similar criteria. We also discover that pattern, which was adopted as the means of communicating language between experts and non-experts, had also helped the tenant clearly articulating the kind of solutions that meet his needs. A significant value of refurbishment pattern bridges the knowledge gap between experts and non-experts. Moreover, the post-experiment evaluation shows that the tenant was very satisfied with the refurbishment process and results supported by system.

Compared with traditional design communication, DESIRE draws its knowledge both from the general refurbishment knowledge and the lessons that concrete cases provided. Essentially, DESIRE enhances the design communicating problem by identifying tenant's needs and bridging the knowledge gap between experts and non-experts from past similar cases to arrive at the desirable planning, avoiding miscommunication due mainly to the tenant's lack of refurbishment knowledge. Moreover, because DESIRE can help the users review the refurbishment decision-making process after the initial planning stage, it avoids the "Black box" type of design issue. Also, the refurbishment solution developed in the initial stage can be treated as design criteria for evaluating the final product to ensure its conformance with the initial planning.

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