Available online at www.sciencedirect.com
ScienceDirect
Expert Systems with Applications 35 (2008) 1601–1610
Expert Systems with Applications
www.elsevier.com/locate/eswa

Decision support model based on case-based reasoning approach for estimating the restoration budget of historical buildings

Huey-Jiun Wang *, Chien-Wei Chiou [1], Yi-Kai Juan [2]

Department of Architecture, National Taiwan University of Science and Technology, 43, Section 4, Keelung Road, Taipei 106, Taiwan

Abstract

Historical building conservation is an important work for most global organizations due to its potential cultural, social, economic, and urban renovation benefits. Accurately allocating budget in a limited time is a crucial factor that profoundly affects the restoration of historical buildings. An ineffective budget control mechanism often causes further damage to historical buildings that are facing urgent restoration needs. This study presents a new cost estimation concept based on the case-based reasoning (CBR) approach instead of a traditionally intuitive estimation method. In CBR model, two retrieval techniques, 'Inductive Indexing' and 'Nearest Neighbor', are then applied to retrieve relevant cases from the knowledge-based database. Two of the most common types of Taiwan historical buildings are tested to explore the restoration cost implications. The result reveals that the CBR solution can effectively predict the actual restoration cost, solve order change problems, and reduce the budget review time. These applications are also useful for many other countries, especially for those seismic belt regions, that are facing similar problems regarding historical building restoration.

Keywords: Historical buildings; Decision support; Case-based reasoning; Restoration budget

1. Introduction

Historical building conservation is an important work for most global organizations due to its potential cultural, social, economic, and urban renovation benefits (Lee, 1996; Lichfield, 1988). To actively preserve their precious architectural heritages, governments usually provide appropriate financial resources to conduct these maintenance, repair and restoration works (Pickard, 2002). An efficient cost control mechanism, however, that favors conservation work is desirable in that it can economically make use of limited resources to implement the relevant urgent works (Feilden, 2003).

In Taiwan, a lengthy budget review process, at least one year for an investigation, that lacks an effective cost estimation system has caused severe impact on conservation policy implementation. Especially the grievous and world-famous *Chi-Chi earthquake*, which occurred in Taiwan in 1999, has raised questions about the implicated budget control and review problems. Many historical buildings face increased damage (CCAEY, 2005), as well as an excessive waste of restoration time because of a complicated and ineffective review process.

In addition to the budget review process, there is a general problem in Taiwan historical building restoration. According to most implemented experiences, the inconsistency between the appropriated budget and the actual restoration cost was significant. The discrepancy usually results from the multifaceted characteristics of historical buildings. The restoration actions sometimes depend on hidden building element conditions. These elements only become visible after demolition work and can easily cause changes in the work orders and modifications to the cost.

* Corresponding author. Tel.: +886 2 27376553; fax: +886 2 27376721.
E-mail addresses: heidiw@mail.ntust.edu.tw (H.-J. Wang), D9413004@mail.ntust.edu.tw (C.-W. Chiou), D9313002@mail.ntust.edu.tw (Y.-K. Juan).
[1] Tel.: +886 2 27333141x7051; fax: +886 2 27376721.
[2] Tel.: +886 2 27376570; fax: +886 2 27376570.

0957-4174/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2007.08.095

Undoubtedly the traditional budget review process is time-consuming and the government is awkward about the whole restoration cost estimation. In fact, domain knowledge existing in historical building experts should be systematically re-used in the judgment on these restoration works. Plentiful research has paid attention to construction cost estimation problems, using many artificial intelligence methods (Adeli & Wu, 1998; Kim, An, & Kang, 2004a, Kim, Yoon, An, Cho, & Kang, 2004b; Mohamed & Celik, 2002). Among these methods, case-based reasoning (CBR) is one of the most popular and satisfactory decision support tools to discuss cost estimation issues (Doğan1, Arditi, & Günaydin, 2006; Kim et al., 2004a, 2004b; Perera & Waston, 1998) In this study, the concept of CBR and its applications provide a good opportunity to improve the budget review process and restoration cost inconsistency problems.

Based on the CBR concept, this study attempts to effectively predict the best restoration cost estimations for historical buildings. The proposed approach contains three major procedures. A knowledge-based system of historical buildings and relevant quantified processes is first built. Two retrieval techniques, 'Inductive Indexing' and 'Nearest Neighbor', are then applied to retrieve relevant cases from the knowledge-based database. These cases offer valuable information for restoration cost estimation. A Taiwan construction cost index is introduced into the case revision process to correct the acquired cost estimation data. Two common types of historical buildings in Taiwan are tested by the proposed approach and the implications of the test process are also discussed. It is expected that the result will provide useful insight for decision-makers when they are facing similar problems.

2. Restoration procedures for historical buildings in Taiwan

Historical buildings in Taiwan express the diversity of the architectural context due to the specific life style of native people and the multicultural experience due to multiple colonizers. Currently, building conservation projects are generally based on the historical, cultural and architectural values attributed to the historical buildings as reasons to conduct building preservation, maintenance and reuse. The planning process before restoration work on historical buildings consists of two sub-processes: (1) Investigation stage: it usually takes about 9–12 months to complete the building diagnosis, related maintenance plans, and the initial cost estimation plan reviewed by Cultural Affairs Institutions of Taiwan; (2) Design and Planning stage: it usually takes about 2–6 months for the architect to propose the restoration drawings, required materials and quantity information with the detailed construction cost estimation (Wang, 2004). That is, with the current restoration procedure, the government inevitably needs to spend at least one year before the restoration construction stage. It would be a great improvement to shorten the procedure, especially for those ill-conserved buildings in urgent need of repair.

The cost estimation for historical buildings is complicated and more difficult than that for other buildings. In addition to considerations of unique materials, the building appearance, and the construction method, it also involves various applications of Taiwan traditional building decorations. Furthermore, some building parts and their deteriorated conditions can not be detected from appearance, which causes uncertainty and difficulty in the cost estimation. How to construct a useful method, based on professionals' experiences and domain knowledge to provide optimal decision support information in cost estimation is the key success factor in restoration projects.

3. A new cost estimation method for historical buildings

Instead of adopting a traditional cost estimation mechanism, this study attempts to build a new cost estimation method for historical buildings based on the case-based reasoning (CBR) approach. CBR provides both a methodology for building systems and a cognitive model of how people solve problems (Perera & Waston, 1998). The central tasks involved in CBR methods are to identify the current problem situation, find a past case similar to the new one, use that case to suggest a solution to the current problem, evaluate the proposed solution, and update the system by learning from this experience (Humphreys, McIvor, & Chan, 2003; Mamaghani, 2002; Kolodner, 1993). Essential tasks needed to make a typical CBR

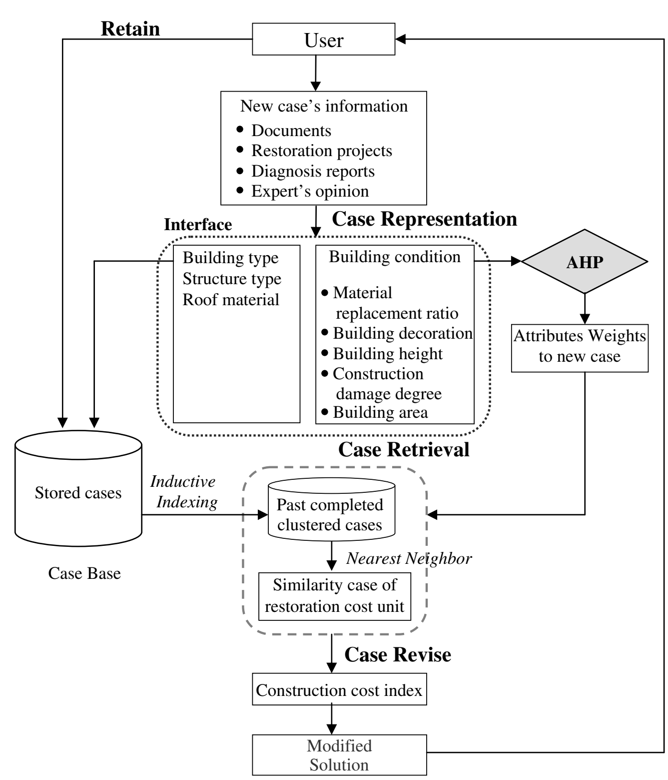


Fig. 1. CBR model for the restoration cost estimation.

system are: (1) retrieve one or a small set of the most similar cases according to the problem specification; (2) adapt to the new situation by revising former solutions; (3) retain the new case and solution as part of history for future retrievals (Chua, Li, & Chan, 2001; Jeng & Liang, 1995).

To effectively retrieve valuable information for decision making, a systematic CBR process needs to be established, as shown in Fig. 1. There is a five-stage reasoning procedure of restoration cost estimation: (1) input the new case information via the system's interface; (2) attribute identification and transformation; (3) retrieve the cases from database based on the comparison result of building type, structure type, roof material, and building condition; (4) revise or adjust the retrieval cases according to the construction cost index; (5) retain the solution.

A detailed introduction to and definition of this process, such as the case representation, case library design, retrieval method (induction tree and the nearest neighbor methods), and case revision mechanism are described as follows.

3.1. Case representation

A case is a contextualized piece of knowledge representing an experience. Cases can be represented in a variety of forms using the full range of AI representational formalisms including frames, objects, predicates, semantic nets and rules (Watson & Marir, 1994). The first step in operating the CBR process is to define common features from extensive and complicated cases, so that it is possible to retrieve useful cases. These features, as described in Table 1, are regarded as the attributes of each case in the database. After a survey of historical building investigation and experts' interviews, the eight most discriminating attributes that will affect the restoration cost estimation of historical buildings are defined.

''Building type'', ''Structure type'', and ''Roof material'' are the fundamental architecture conditions for defining the historical building. These three attributes are represented by the choice data type in the database. ''Building height'', ''Building area'', and ''Building decoration'' are three attributes that can be represented by numerical value data. It deserves to be noticed that Taiwan historical building decoration always shows diversity (as shown in Figs. 2 and 3). The assessment of the building decoration depends on the concept proposed by İpekoğlu (2006) establishing an evaluation method for traditional dwellings. In this study, according to required labor and costs for the decoration restoration, four levels of decoration for major building elements, such as the roof, the pillars and beams, the walls, and the doors and the windows, are defined. Summing up

Table 1
Case attributes of a historical building

Attributes	Definition	Description	Data type
Case name	Restored case name	N/A	Text
Building type	Based on architecture styles and material features to classify four types	Traditional Taiwanese dwelling Colonial wooden building Colonial brick wall building Primary ferroconcrete building	Choice
Structure type	Building structural system	Wooden frame Load bearing wall Hybrid structure	Choice
Roof material	The most common applications of roof materials in Taiwan	Concrete tile Slate tile Copper tile Brick tile	Choice
Material replacement ratio	The ratio of the damaged parts that need to be replaced in a building	Level 1: the ratio is less than 20% Level 2: the ratio between 21% and 40% Level 3: the ratio between 41% and 60% Level 4: the ratio between 61% and 80% Level 5: the ratio is higher than 81%	Quantitatively measurable
Building decoration	The decoration, such as the claying, painting, and wood carving, on major building elements	Four decoration levels of the roof, the pillars and beams, the walls, and the doors and windows. Summing up the level of each building element to obtain a decoration score.	Numerical
Building height	The height of a wall structure	N/A	Numerical
Construction damage degree	Damage level of each building element	Evaluation of the following elements: Site, foundation, internal wall, external wall, wooden structure, floor slab, roof structure and painting decorations	Quantitatively measurable
Building area	The floor area of a case	N/A	Numerical

the level of each building element can obtain a decoration score. A higher score means that the building has more decoration and it needs more money and labor to conduct the restoration of the decoration. "Material replacement ratio" and "Construction damage degree" are quantitatively measurable data. Five levels of material replacement ratio are defined from less replacement (<20%) to great replacement (>81%). Table 2 is an example of the illustration of the structural element damage degree with regard to Taiwan historical building damage evaluation (Wang & Hsiao, 2003). Each building restoration element can be denoted by the criteria.

3.2. Case library design

Case storage is an important aspect in designing efficient CBR systems in that, it should reflect the conceptual view of what is represented in the case and take into account the indices that characterize the case (Watson & Marir, 1994). The case library is composed of a number of historical data cases that are in the form of a frame structure, and describes the design requirements and solution (Tor, Britton, & Zhang, 2003). In this study, the construction of the database is based on information from past restoration projects implemented by the experts, including the various investigation, planning, design, and restoration construction reports. Two hundred and ninety three restoration projects on historical buildings have been collected and then refined into the database.

In these projects, the majority have experienced problems concerning work order changes or the modification of the budget due to some specific and unpredictable factors of the historical building restoration. That is, the cost estimation of these projects mostly depended on past implemented experiences, to provide useful information to avoid mistakes in future estimation procedures. After attribute comparison between the input case and the stored cases, the output information can show the reference value of restoration cost. The expression of the output cost value is the price per unit area (US$/m^2).

3.3. Inductive indexing

Case indexing involves assigning indices to cases for facilitating their retrieval (Shin & Han, 1999). Using an inductive technique for case indexing is to build a knowledge-based system that is capable of combining manifold types of knowledge (Shin & Han, 2001). Essentially the induction algorithms are used as classifiers to cluster similar cases together (Watson, 1999). This study uses one of the inductive techniques, the decision tree, to index the previous cases in the database. The decision tree can be divided into three hierarchies: (1) level 1: Building type; (2) level 2: Structure type; (3) level 3: Roof material.

Fig. 2. A historical building with fewer decorations.

Fig. 3. A historical building with abundant decorations.

Table 2
Structure damage level

Level	Damage description
1	It expresses slight deterioration. The ratio of destroyed parts to the whole building is less than 20%
2	It expresses some deterioration. The ratio of destroyed parts to the whole building is between 21% and 40%
3	It expresses moderate deterioration. The ratio of destroyed parts to the whole building is between 41% and 60%
4	It expresses serious deterioration. The ratio of destroyed parts to the whole building is between 61% and 80%
5	The building almost collapses. The ratio of destroyed parts to the whole building is higher than 80%

For the level 1, four major building types are first distinguished. The paths and checkpoints pattern for level 2 and level 3 may vary according to the case's characteristics after determining the building type. When a new case is inputted, the decision-maker will start the indexing process. At the end of the decision tree processing, potential stored cases will be selected. However, the nearest neighbor method is still needed to complete the case comparison in the further retrieval process.

3.4. Nearest neighbor: case similarity function

Nearest neighbor techniques are perhaps the most widely used technology in the CBR retrieval process (Watson, 1997; Chang, Cheng, & Su, 2004). The nearest neighbor approach lets the user retrieve cases based on a weighted sum of features in the input cases that match the cases in memory (Watson & Marir, 1994). Similarity scores for these cases are calculated by the nearest neighbor approach to find the single best match. As shown in Table 3, one of the most obvious measures of similarity between two cases is distance. To calculate the degree of match in the retrieval process, the method of numeric evaluation function is being used to measure distance. This evaluation function is using quantitatively measurable, mathematical transforms to substitute for the qualitative data. In this study, similarity scores are normalized to fall within a range of 0–1 (where zero is totally dissimilar and one is an exact match). The case with the highest score in the stored cases will be used, or modified as the suggested solution.

The nearest neighbor method, however, has difficulty in deciding a set of feature weights to accurately retrieve cases

Table 3
Similarity score with Nearest Neighbor

Attributes	Similarity function	Weights	Similarity index	
Material replacement ratio	Measure of similarity of required level of material replacement between target case (T_i) and training cases (S_i)	W_i	$W_i\left[1-\sqrt{(T_i-S_i/T_i)^2}\right]$	(1)
Building decoration	Building decoration similarity between target case (T_j) and training cases (S_j)	W_j	$W_j\left[1-\sqrt{(T_j-S_j/T_j)^2}\right]$	(2)
Building height	Building height similarity between target case (T_k) and training cases (S_k)	W_k	$W_k\left[1-\sqrt{(T_k-S_k/T_k)^2}\right]$	(3)
Construction damage degree	Measure of similarity of damage level of each structure between target case (T_r) and training cases (S_r)	W_l	$W_n\left[1-\sqrt{\sum_{r=1}^{R}(T_r-S_r/T_r)^2 W_r}\right]$	(4)
Building area	Building area similarity between target case (T_n) and training cases (S_n)	W_n	$W_n\left[1-\sqrt{(T_n-S_n/T_n)^2}\right]$	(5)

Note: (1) + (2) + (3) + (4) + (5) = similarity value. $W_r$represents the sub-weights for the different construction damage parts.

in a given situation (Barletta, 1991). Many methods are applied to improve the efficiency of the retrieval process, such as the expert's decision making (Kolodner, 1993; Shin & Han, 2001), analytic hierarchy process (AHP) (Chang et al., 2004; Park & Han, 2002), and indexing techniques (Tor et al., 2003; Tseng, Chang, & Chang, 2005), etc. Considering research requirements, this study uses the AHP method to calculate the weightings of attributes (as shows a in Table 4), which is beneficial for the calculation process of similar functions.

3.5. Case revision

Adaptation is the process of adjusting the retrieved cases to fit the current case. Once a matching case is retrieved, a CBR system should adapt the solution stored in the retrieved case to the needs of the current case. This process is called the revision process for CBR. Through the abovementioned similar function comparison, the similar cases extracted from the case base have partly satisfied the actual case. The decision-maker generally modifies the proposed solution according to his/her expertise and experiences.

In addition to the decision-maker's subjective judgment on the revision, this study also introduces objective concepts to adapt the retrieval cases. Because the restoration cost of historical buildings may be affected by the current economic condition, the construction price fluctuation, including the requirements for building materials, labor forces, etc., should be considered in the cost estimation. The revised process is depicted as below:

$$\text{Cost}_{\text{case}i} = \frac{I_{\text{TagetCase}}}{I_{\text{case}i}} \times \text{Cost}_i \tag{6}$$

where Cost_i means the restoration cost of a retrieved case (before the revision); $I_{\text{TagetCase}}$ means the construction cost index of a new case; $I_{\text{case}i}$ means the building's cost index of the retrieved case; $\text{Cost}_{\text{case}i}$ means the adapted restoration cost of the new case (after the revision).

4. Case study

4.1. Data source

Most historical buildings in Taiwan were built in the Chin Dynasty (1685–1894) and the Japanese colonial period (1895–1945), accounting for approximately 80% of all historical buildings. This study collected 293 restoration projects (as shown in Table 5), having been restored during 1991–2006, from local Cultural Affairs Institutions and relevant contractors. Restoration cost is indeed the focus of the data preparation process and the acquired projects are then refined into the case base.

4.2. Case test

Two types of historical buildings in Taiwan, traditional Taiwanese dwellings and Colonial wooden buildings, are used experimentally by the CBR operation. These two types are the most common and typical buildings in the historical inventory. The government also invests many

Table 4
Calculation of attributes weights with using AHP for case B1

Attributes	BC1	BC2	BC3	BC4	BC5	Priority vector	Attributes weights
BC1	1.00	5	3	1/3	3	$V_{BC1} = 12.33$	$W_i = 0.246$
BC2	1/5	1.00	1/5	1/7	1/7	$V_{BC2} = 1.69$	$W_j = 0.034$
BC3	1/3	5	1.00	1/5	1	$V_{BC3} = 7.53$	$W_k = 0.150$
BC4	3	7	5	1.00	3	$V_{BC4} = 19.00$	$W_l = 0.378$
BC5	1/3	7	1	1/3	1.00	$V_{BC5} = 9.67$	$W_n = 0.192$

Note: BC*i* means *i*th building condition; BC1: material replacement ratio; BC2: building decoration; BC3: building height; BC4: construction damage degree; BC5: building area.

Table 5
Data source of historical buildings

Building types	Quantity	Proportion (%)
Traditional Taiwanese dwelling	72	24.6
Colonial wooden building	85	29.0
Colonial brick wall building	71	24.2
Primary ferroconcrete building	65	22.2
Total	293	100

resources in maintaining and restoring these buildings. These two types of building are discrepant in architectural styles. For example, the traditional Taiwanese dwellings, composed of three building units to form a courtyard, usually has a larger floor area and various building decorations. Contrarily, the Colonial wooden buildings are mostly independent building units with smaller floor area and uniform decorations.

Currently, 72 traditional Taiwanese dwellings and 85 Colonial wooden buildings restoration projects have been completed. Their restoration information has been gathered. In the case test process, 10 cases are randomly selected as the test cases from each building type. Other cases are regarded as the training cases stored in the case base waiting for the case retrieval.

Table 6 describes the example of the attribute description of test cases. After the input of the attribute evaluation, the output of the restoration cost estimation will be provided by the training cases using the retrieval approach.

4.3. Result and discussion

In the retrieval process of CBR, the first stage, an inductive indexing approach, is operated by the software of Microsoft Access. The user can acquire potential restored cases that match new cases from the indexing tree. The nearest neighbor method is further used to retrieve the final cases from the potential cases. Fig. 4 illustrates one example of a test case regarding the retrieval process and similarity value computation. The construction price fluctuation has been considered in the computed process. The result of test cases, as shown in Table 7, contains the similarity value, actual restoration cost, original allocated budget, and the CBR suggested solution for these two building types. Higher similarity value means that the solution of CBR is closer to the actual cost.

It is obvious that there is a significant deviation between the actual cost and the original budget in each case. That is, the budget of many restoration projects was not allocated properly and economically. To examine the effectiveness of the CBR solution, this study introduces the concept of a deviation ratio to explore the cost implication of the actual cost, the original budget, and the CBR solution of each test case. The computed process is depicted as in Eqs. (7) and (8). The comparison result is shown in Fig. 5.

$$\text{Deviationratioof } R_i(\%) = \sqrt{\left(\frac{\text{Cost}_{\text{Act}} - \text{Cost}_{\text{Org}}}{\text{Cost}_{\text{Act}}}\right)^2} \times 100 \tag{7}$$

$$\text{Deviationratioof } R_j(\%) = \sqrt{\left(\frac{\text{Cost}_{\text{Act}} - \text{Cost}_{\text{CBR}}}{\text{Cost}_{\text{Act}}}\right)^2} \times 100 \tag{8}$$

where R_i is the deviation ratio of the original restoration budget (Cost_{Org}) from the actual cost (Cost_{Act}); R_j is the ratio of the cost suggestion provided by the CBR approach (Cost_{CBR}) to the actual cost.

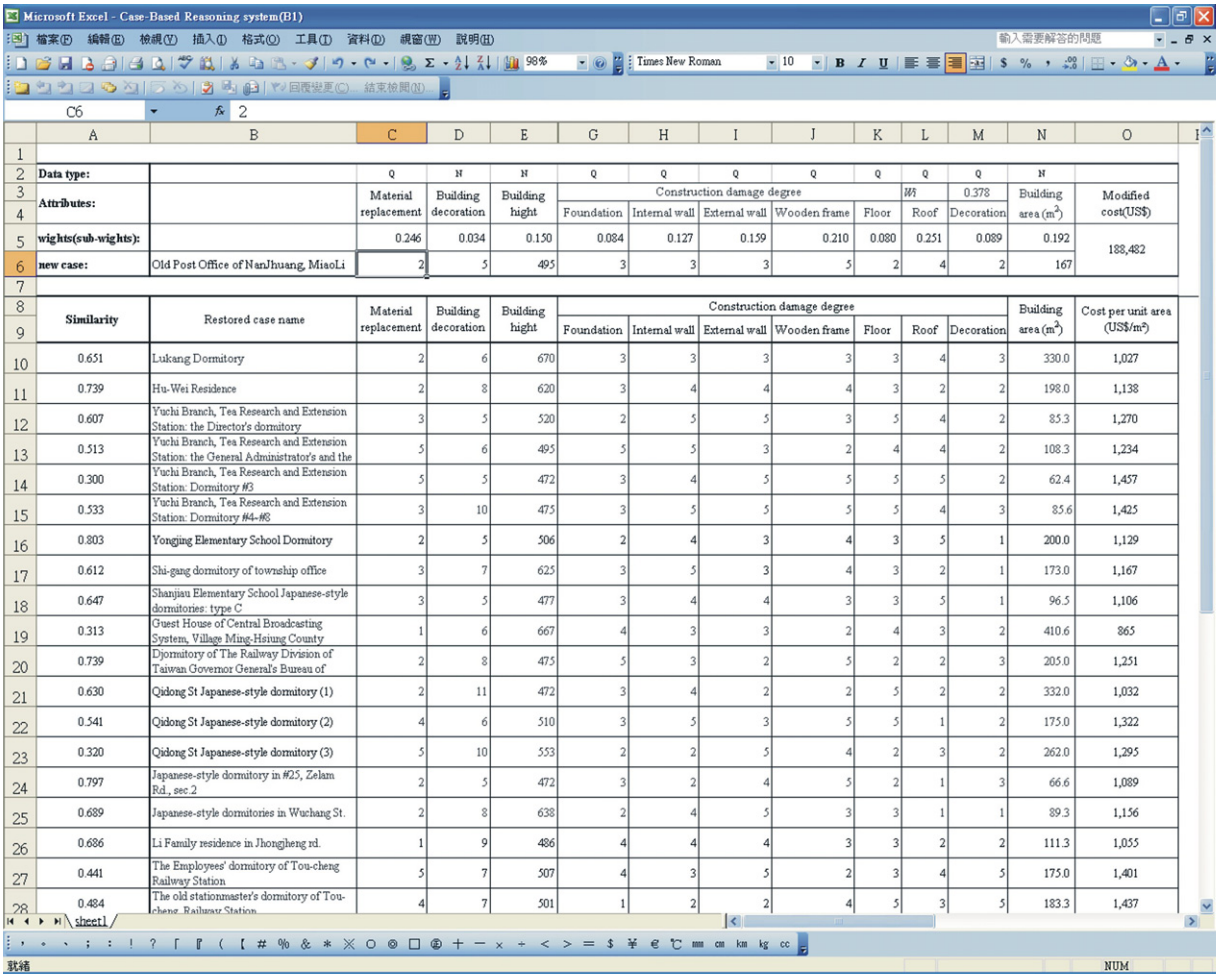
The average R_i in scheme 1 and scheme 2 is 16.6% and 12.5%, respectively, which are far higher than R_j in scheme 1 and scheme 2 with the average 4.1% and 3.8%, respectively. Distributions of the R_i are also more variable than those of the R_j in both scheme 1 and scheme 2. For all test cases, all points of the R_j obtained by using the CBR are less than 10%.

In addition, there is an observation deserving mention. Fig. 5 also shows that the average ratio, including R_i and R_j, in scheme 1 is higher than in scheme 2. This may imply that the discrepancy generally results from the characteristics of historical building types. In scheme 1, the traditional Taiwanese dwelling type, the scale and the decoration are more complicated than in scheme 2, the Colonial wooden building type. Excessively complex and various building characteristics have increased the difficulty in estimating the restoration cost. The implication of the finding is also helpful for decision-makers who administer the restoration policy.

Undoubtedly the operation of the CBR approach is more effective in the cost estimation process than the traditional estimation method that is usually based on some

Table 6
Case description attribute of test cases

Cases attributes	Traditional Taiwanese dwelling		Colonial wooden buildings	
Structure type	Load bearing wall		Wooden frame, hybrid structure	
Roof material	Concrete tile, slate tile		Concrete tile	
Material replacement ratio	Min: Level 2	Max: Level 5	Min: Level 2	Max: Level 3
Building decoration (numerical)	Min: 6	Max: 26	Min: 2	Max: 8
Building height (cm)	Min: 350	Max: 520	Min: 475	Max: 620
Construction damage degree	Min: Level 1	Max: Level 5	Min: Level 1	Max: Level 5
Building area (m^2)	Min: 309.2	Max: 632.5	Min: 83	Max: 206.5



Similarity	Restored case name	Material replacement	Building decoration	Building hight	Foundation	Internal wall	External wall	Wooden frame	Floor	Roof	Decoration	Building area (m²)	Cost per unit area (US$/m²)
0.651	Lukang Dormitory	2	6	670	3	3	3	3	3	4	3	330.0	1,027
0.739	Hu-Wei Residence	2	8	620	3	4	4	4	3	2	2	198.0	1,138
0.607	Yuchi Branch, Tea Research and Extension Station: the Director's dormitory	3	5	520	2	5	5	3	5	4	2	85.3	1,270
0.513	Yuchi Branch, Tea Research and Extension Station: the General Administrator's and the	5	6	495	5	5	3	2	4	4	2	108.3	1,234
0.300	Yuchi Branch, Tea Research and Extension Station: Dormitory #3	5	5	472	3	4	5	5	5	5	2	62.4	1,457
0.533	Yuchi Branch, Tea Research and Extension Station: Dormitory #4-#8	3	10	475	3	5	5	5	5	4	3	85.6	1,425
0.803	Yongjing Elementary School Dormitory	2	5	506	2	4	3	4	3	5	1	200.0	1,129
0.612	Shi-gang dormitory of township office	3	7	625	3	5	3	4	3	2	1	173.0	1,167
0.647	Shanjiau Elementary School Japanese-style dormitories: type C	3	5	477	3	4	4	3	3	5	1	96.5	1,106
0.313	Guest House of Central Broadcasting System, Village Ming-Hsiung County	1	6	667	4	3	3	2	4	3	2	410.6	865
0.739	Djormitory of The Railway Division of Taiwan Governor General's Bureau of	2	8	475	5	3	2	5	2	2	3	205.0	1,251
0.630	Qidong St Japanese-style dormitory (1)	2	11	472	3	4	2	2	5	2	2	332.0	1,032
0.541	Qidong St Japanese-style dormitory (2)	4	6	510	3	5	3	5	5	1	2	175.0	1,322
0.320	Qidong St Japanese-style dormitory (3)	5	10	553	2	2	5	4	2	3	2	262.0	1,295
0.797	Japanese-style dormitory in #25, Zelam Rd., sec.2	2	5	472	3	2	4	5	2	1	3	66.6	1,089
0.689	Japanese-style dormitories in Wuchang St.	2	8	638	2	4	5	3	3	1	1	89.3	1,156
0.686	Li Family residence in Jhongjheng rd.	1	9	486	4	4	4	3	3	2	2	111.3	1,055
0.441	The Employees' dormitory of Tou-cheng Railway Station	5	7	507	4	3	5	2	3	4	5	175.0	1,401
0.484	The old stationmaster's dormitory of Tou-cheng Railway Station	4	7	501	1	2	2	4	5	3	5	183.3	1,437

Fig. 4. A screen shot of the CBR system with the similarity scores for case B1.

Table 7
Extracted results of test cases

Case	Traditional Taiwanese dwelling				Case	Colonial wooden buildings			
	Similarity	Actual cost (US$)	Original budget (US$)	CBR solution (US$)		Similarity	Actual cost (US$)	Original budget (US$)	CBR solution (US$)
A1	0.665	803,749	597,798	729,732	B1	0.803	186,509	180,912	188,482
A2	0.705	693,276	634,583	718,016	B2	0.712	196,519	173,918	207,297
A3	0.755	522,122	380,100	529,875	B3	0.748	108,373	78,569	104,779
A4	0.718	599,170	727,188	626,405	B4	0.805	133,687	120,584	135,738
A5	0.699	607,346	501,068	569,705	B5	0.786	173,341	151,483	159,089
A6	0.725	618,836	691,310	598,566	B6	0.813	118,290	114,031	117,120
A7	0.736	629,905	465,502	640,858	B7	0.836	206,158	240,303	213,527
A8	0.723	825,438	812,156	838,270	B8	0.762	355,368	388,204	338,708
A9	0.686	618,669	568,460	580,079	B9	0.786	339,000	385,000	349,950
A10	0.710	667,714	547,529	643,965	B10	0.809	201,810	166,087	190,095

Note: The solutions of CBR are based on the unit price of training cases multiplying the floor area of test cases. In addition, these solutions have been adjusted according to the construction price fluctuation.

participants' intuition and experiences. Furthermore, the CBR solution also considers construction uncertainty and difficulty in the historical building restoration. That is the reason why the CBR solution is apparently closer to the actual restoration cost.

5. Conclusion and suggestions

Accurately allocating budget in a limited time is a crucial factor that profoundly affects the restoration of historical buildings. In this study, a new cost estimation method

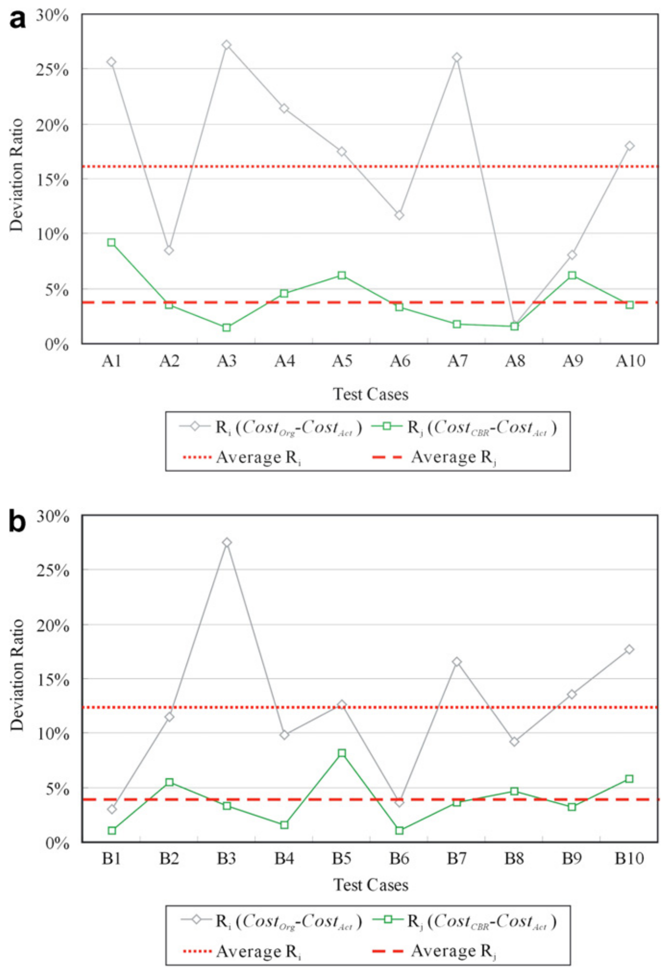


Fig. 5. Deviation ratio analysis of adopting CBR method: (a) Scheme 1: traditional Taiwanese dwelling; (b) Scheme 2: colonial wooden buildings.

based on the case-based reasoning (CBR) approach is applied to predict reasonable restoration costs. The case test result reveals that the proposed CBR approach has two advantages.

First, it can effectively improve the budget review process to avoid a lengthy and complicated procedure delaying the restoration implementation. Second, it can provide more accurate cost estimation than traditional allocation methods since the retrieval result, based on past project's experiences, has taken work order changes and modifications of the budget into account.

In future applications, the proposed approach can effectively combine experts' judgments to develop a robust decision support tool to assist decision-makers in implementing the optimal restoration budget policy. These applications are also useful for many other countries, especially for those seismic belt regions, that are facing similar problems regarding historical building restoration.

References

Adeli, H., & Wu, M. (1998). Regularization neural network for construction cost estimation. *Journal of Construction Engineering and Management, 124*(1), 18–24.

Barletta, R. (1991). An introduction to case-based reasoning. *AI Expert, 6*(8), 42–49.

Chang, C. L., Cheng, B. W., & Su, J. L. (2004). Using case-based reasoning to establish a continuing care information system of discharge planning. *Expert Systems with Applications, 26*(4), 601–613.

Chua, D. K. H., Li, D. Z., & Chan, W. T. (2001). Case-based reasoning approach in bid decision making. *Journal of Construction Engineering and Management, 127*(1), 35–45.

Council for Cultural Affairs, Executive Yuan (CCAEY) (2005). *Restorative Report: The restoration and reuse of historical building associated with 921 Chi-Chi earthquake, CCAEY, Taiwan*.

Doğan1, S. Z., Arditi, D., & Günaydin, H. M. (2006). Determining attribute weights in a CBR model for early cost prediction of structural systems. *Journal of Construction Engineering and Management, 132*(10), 1092–1098.

Feilden, B. M. (2003). *Conservation of historic buildings*. UK: Butterworth Heinemann Oxford.

Humphreys, P., McIvor, R., & Chan, F. (2003). Using case-based reasoning to evaluate supplier environmental management performance. *Expert Systems with Applications, 25*(2), 141–153.

İpekoğlu, B. (2006). An architectural evaluation method for conservation of traditional dwellings. *Building and Environment, 41*(3), 386–394.

Jeng, B. C., & Liang, T. P. (1995). Fuzzy indexing and retrieval in case-based system. *Expert Systems with Applications, 8*(1), 135–142.

Kim, G. H., An, S. H., & Kang, K. I. (2004a). Comparison of construction cost estimating models based on regression analysis, neural networks, and case-based reasoning. *Building and Environment, 39*(10), 1235–1242.

Kim, G. H., Yoon, J. E., An, S. H., Cho, H. H., & Kang, K. I. (2004b). Neural network model incorporating a genetic algorithm in estimating construction costs. *Building and Environment, 39*(11), 1333–1340.

Kolodner, J. L. (1993). *Case-based reasoning*. Los Altons, CA: Morgan Kaufman.

Lee, S. L. (1996). Urban conservation policy and the preservation of historical and cultural heritage: The case of Singapore. *Cities, 13*(6), 399–409.

Lichfield, N. (1988). *Economics in urban conservation*. Cambridge: Cambridge University Press.

Mamaghani, F. (2002). Information technology knowledge sharing using case-based reasoning. *Information Systems Management, 19*(4), 13–20.

Mohamed, A., & Celik, T. (2002). Knowledge based-system for alternative design, cost estimating and scheduling. *Knowledge-Based System, 15*(3), 177–188.

Park, C. S., & Han, I. (2002). A case-based reasoning with the feature weights derived by analytic hierarchy process for bankruptcy prediction. *Expert Systems with Applications, 23*(3), 255–264.

Perera, S., & Waston, I. (1998). Collaborative case based estimating and design. *Advances in Engineering Software, 29*(10), 801–808.

Pickard, R. (2002). A comparative review of policy for the protection of the architectural heritage of Europe. *International Journal of Heritage Studies, 8*(4), 349–363.

Shin, K. S., & Han, I. (1999). Case-based reasoning supported by genetic algorithms for corporate bond rating. *Expert Systems with Applications, 16*(2), 85–95.

Shin, K. S., & Han, I. (2001). A case-based approach using inductive indexing for corporate bond rating. *Decision Support System, 32*(1), 41–52.

Tor, S. B., Britton, G. A., & Zhang, W. Y. (2003). Indexing and retrieval in metal stamping die design using case-based reasoning. *Journal of Computing and Information Science in Engineering, 3*(4), 353–362.

Tseng, H. E., Chang, C. C., & Chang, S. H. (2005). Applying case-based reasoning for product configuration in mass customization environments. *Expert Systems with Applications, 29*(4), 913–925.

Wang, H. J., & Hsiao, C. B. (2003). *Research Report: The study of seismic damage evaluation for hybrid structure in historical building*. Architecture and Building Research Institute(ABRI), Ministry of The Interior, Taiwan.

Wang, H. J. (2004). *An Executive handbook of historical building: preservation, maintenance and reuse*. Council for Cultural Affairs, Executive Yuan (CCAEY), Taiwan.

Watson, I., & Marir, F. (1994). Case-based reasoning: A review. *The Knowledge Engineering Review, 9*(4), 355–381.

Watson, I. (1997). *Applying case-based reasoning: Techniques for enterprise systems*. San Fransisco: Morgan Kaufman.

Watson, I. (1999). Case-based reasoning is a methodology not a technology. *Knowledge-Based Systems, 12*(5-6), 303–308.