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Research Article

Scenario-Planning Method for Cost Estimation Using Morphological Analysis

Sae-Hyun Ji[1] and Joseph Ahn[2]

[1]*Institute of Construction and Environmental Engineering, Seoul National University, Seoul 08826, Republic of Korea*
[2]*Division of Architecture, Civil and Environmental Engineering, Hoseo University, Asan 31499, Republic of Korea*

Correspondence should be addressed to Joseph Ahn; josephahn@hoseo.edu

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Early cost estimates are emphasized repeatedly in the initial decision-making process to set a direction for the success of construction projects. Therefore, alternatives need to be examined, and the consequences for the cost should be analyzed carefully. This study proposes a scenario-planning method that uses morphological analysis for the estimation of construction cost. A case study was conducted using public data on 102 apartment buildings from 10 housing complex projects. The results show estimation accuracy of 4.23 to 4.86% and an average stability enhancement of 1.39 to 1.73%. The proposed process can produce adaptable scenarios and evaluate the impact of the scenarios in a complicated decision-making process with limited information provided. Furthermore, this method can provide a contingency plan to cushion against uncertainties.

1. Introduction

Ackoff [1] defines three levels of a complex problem: a mess, a problem, and a puzzle. A mess is a complex issue that is not defined or structured concretely, so it is hard to find out the focal problem. A problem has a defined form with variables and shows how these variables interact, but it does not have a clear solution. A puzzle is a well-defined and well-structured problem with a specific solution. Thus, a path is needed to make a complex problem into a puzzle. In this regard, morphological analysis works at the level of messes and problems and turns messes into problems. This approach is widely applied to build scenarios that can outline entire issues or impact factors related to the problems.

A scenario can draw rich and detailed portraits of plausible futures or future states of a system. Scenario-based approaches can be viewed as strategic methodologies that can help decision makers in uncertain environments that require rapid response. A scenario-based method for supporting decision-making could be used to prepare diverse combinations of causes and effects with convincing explanations rather than a prediction from a specific point of view. Therefore, a scenario-based method could respond with predictive measures according to different demands.

Decision-making in the early stages of a project mainly aim to set a direction for the project's success [2], which is closely related to the fluctuations in project cost. Thus, early cost estimates are emphasized repeatedly in the initial decision-making process for construction projects. Many alternatives should be examined, and then the consequences for the cost should be analyzed. However, this issue is rarely dealt with in previous research, which focuses on the diversification or development of estimation methods and the enhancement of accuracy. To deal with this challenge, this study proposes a scenario-planning methodology for cost estimation of a construction project using a morphological analysis method. A case study was conducted using public data from 102 apartment buildings from 10 housing complex projects. The suggested method that applied cost estimation outputs was compared with a previous case-based reasoning (CBR) cost model [3] using the same conditions.

2. Literature Review

2.1. Cost Models in Construction. A cost model is defined as a symbolic representation of a system with contents that are expressed by factors that impact the system's cost [4]. A cost model has a crucial role of supporting and facilitating decision-making by simulating current or future situations [6]. The overall success of a construction project is often measured by how well the actual cost compares to the early cost estimates [5], and numerous cost estimations are done repeatedly, especially in the early stages. Cost models can provide more reliable cost advice. A good cost model should be simple, accurate, unbiased, timely, and stable enough to easily integrate it into the cost system. Accordingly, the significance of cost estimation of a construction project for the whole life cycle cannot be underestimated.

Recent studies apply various methods to increase the accuracy or confidence of cost estimation with focus on the initial stages. Conventionally, a parametric method that utilizes representative variables is widely used because it is quick and easy to iterate. The method can reflect changes in time, locations, and productivity changes if the data are reliable (Barrie and Paulson). However, the prediction accuracy is relatively low since the method does not reflect various factors that affect the construction cost.

Artificial intelligence (AI) approaches are also being employed. Previous research has used artificial neural networks (ANNs) to predict the cost of highway construction [7], school buildings [8], and the structural system of a building [9]. CBR has also received much attention as an alternative method for estimating cost. CBR is a process of solving problems by recognizing their similarity to past cases [10]. CBR is more flexible than ANN in updating the system, and it is more successful in handling missing information.

In recent years, numerous studies have been conducted for CBR cost estimation. Yau and Yang [12] developed a CBR estimation method for the preliminary design stage. Doğan et al. [13] proposed a CBR cost model for a structural system. An et al. [14] developed a CBR cost model for a residential building using an analytic hierarchy process (AHP). Koo et al. [15, 16] developed a CBR-based hybrid model for predicting the duration and cost of a construction project. Ji et al. [4, 17, 18] developed a CBR cost model and suggested a CBR cost estimation system for public projects.

It is important to note that cost estimation is a knowledge-intensive engineering work and requires expertise of the human professionals [18, 20]. However, there are difficulties in utilizing engineers' expertise since experienced knowledge is not often documented and this eventually leads to subjectivity [18]. Therefore, further research is required to compensate subjectivity of experts and support decision-making regarding cost estimation of plausible alternatives in a quantitative manner.

2.2. Morphological Analysis. Morphology is the study of the shape and arrangement of parts of an object and how these parts conform to create a whole or Gestalt [21]. Morphological analysis is a nonquantified modeling method for structuring and analyzing technological, organizational, and social problems [21, 22]. Morphological analysis is used to represent a problem using a matrix that has combinations of parameter conditions. The parameters on the horizontal axis represent components of the targeted object, and the conditions on the vertical axis describe the nature of each parameter. As shown in Figure 1, each of the parameters is shown in a column with the possible conditions as boxes in the column. In a given combination, conditions are assigned to a parameter by highlighting the relevant conditions. For example, $X1$-$Y3$-$Z3$-$W2$ is one of the possible configurations of this four-by-four matrix.

Morphological analysis is used to construct scenarios by outlining issues with identified driving forces. One of the most powerful and intuitive ways to incorporate the uncertainties in the planning stage is to use scenarios [23]. Scenario planning is an imagined sequence of future events and can be used as a tool to help make more effective decisions. To develop a scenario, Schwartz [24] proposed an eight-step scenario-planning process that focuses on identifying key factors, their relationships, and their impacts on future events. Morphological analysis could thus help to produce well-organized scenarios made up of parameters and conditions and to estimate the implications. In this study, building elements were used as parameters, and the grades of finishing materials were used as conditions.

3. Scenario-Planning Method

3.1. Framework. Scenarios can be defined as an imagined combination of facts and relevant results, and scenario planning can help to make robust strategic choices [25]. Figure 2 shows the scenario-planning framework and expected function in design process.

The design process plays an important role in decision-making. As shown in Figure 2, the cost estimate is usually made by the design stage. Decision-making is being made through the design process, and cost estimates are conducted in each design phases in general (Figure 2). In addition, if the error range of the estimated cost for each design phase exceeds the budget, it is necessary to review the scope defining in stage 1 in the worst case. Under these circumstances, it is not easy to determine which stage to go back to and review. Since the content and scope to be reviewed and the amount of work to be required are significantly different according to each design stage, it is very important to make proper decisions about to which stage to return. If stage 5 documentation is to be returned to stage 1 scope defining due to huge mistakes that had not been discovered before, then, the costs and time required for redesign would be immense. Damages due to subsequent delays in construction will also be greater.

As a complement to this, the scenario-planning method proposed in this study can present the criteria of the manageable limit of the cost overrun for each design stage. This should be considered separately from the design contingency. Contingency is a pure countermeasure against uncertainty in project progress, whereas the scenario matrix of this study can be regarded as a response strategy because it makes uncertainty a predictable risk that can be dealt with.

For example, there is a project manager. Suppose that the project he/she is managing is in the detailed design stage and the cost estimate result has recently exceeded +10%. At this point, the project manager will be troubled. It will be difficult to decide whether to go back to the scope definition stage and

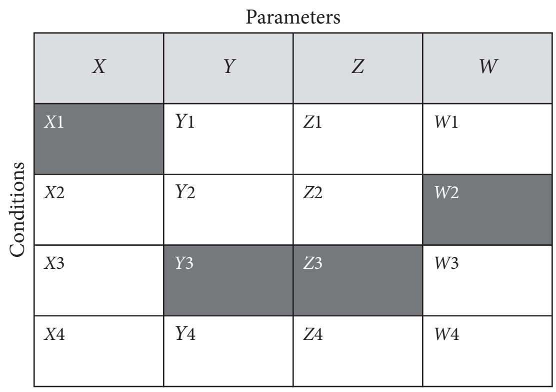

Figure 1: Scenario-planning process.

review again or move on to the next level with affordable magnitude. However, if there are applicable scenario matrices of finishing material changes, which analyze the cost variation compared to the project total cost, and indicate ± 10% variations can be allowed, in this case, the project manager will be directed to the next step with very certain confidence. If the opposite is the case, it is possible to provide a concrete indication as to whether the upgrade of the finishing material is possible. Based on this, it will be possible to support decision-making of establishment or modification of owner's sales strategy. In short, the proposed scenario-planning method diagnoses feasibility test results, confirming whether this is manageable at the certain design stage or not. This enables accurate and fast decision-making support.

If there is a high demand of comparable types of buildings, establishment of sales strategies is crucial to anyone who wants to initiate a new construction project. The strategies should be balanced between the customer-oriented quality level and developer-oriented selling price because increase of price has a negative effect on the attractiveness of the products. Thus, multiple and integrated examinations regarding optimal combinations of the quality levels and the prices should be considered that would be different depending on the given environments. In this context, contingency cost is a conventional strategy in the beginning stage to respond unexpected budget shortage. However, it is limited to support the decision-making on complex and dynamic circumstance because this method cannot provide detailed and easily selectable solutions in response to various situations but shows an amount of money that can be spent. However, a decision maker who can only utilize limited information at initial stages can analyze an element's influence on project cost variance by following the suggested research process. As an example, this research illustrated how to apply the proposed approach to real projects using Korean apartment projects.

Basically, the scenario-planning method is based on the cost analysis of project data. As diagramed in the right side of Figure 2, the scope defining, which reflect the project goal and objectives, is the beginning of the proposed planning method. What is the goal and objective of a project? It would be buyers' benefit, good reputation of a development company, sellers' benefit, and so on. If a company's determined goal is buyers' benefit, then the sales strategy is entirely focused on elevating the quality level. If the project is a multihousing construction-like case study, the interior work quality level can be controlled by upgrading interior finishing materials. Then key decision factors should be identified by analyzing cost data of construction projects which are expressed by cost proportions of a project total cost. The factors can be changed according to the formerly determined objectives. In a case study, we found key decision factors which affect the interior finishing level by calculating cost proportion. Since the level would depend upon the quality level of finishing materials, it would be discovered and described as elements.

The project cost can be segregated into work types such as preliminaries; site work; interior work, stone and tile work; and so forth. Furthermore, the work types are consisted of elemental works like living room wall finishing and ceiling in the interior finishing and bathroom floor tile works and entrance stone in the stone and tile.

The work is divided into elements, each consisting of a combination of material cost and labor cost. Therefore, each element's impact and variability on a project's total cost can be calculated when bills of quantities of the projects are analyzed.

Based on this analysis, we can move to the next step, parameters and subparameter selection. This step finds major cost variance elements (i.e., parameter) in the key decision factors and gets these divided into subelements (i.e., subparameter). The framework includes methods of categorizing and grouping items because the cost of an element is not a single but a combined price of materials and labor works or combinations of the related works. Thereafter, conditions of each subparameter which are the configurable alternatives of materials are developed.

In accordance with the combinations of these conditions, the numericalized influence on the project cost can be developed that is a kind of reflection on the required or current trends of construction projects. That is to say, the scenario matrix expresses selectable options using the alternative parameters and conditions.

3.2. Process Development. The scenario-planning process begins by defining the scope of the work. Many scenarios are iteratively applied in every production construction process, especially in the initial stages. As shown in Figure 3, the earlier the phase of a project is, the more frequent the use of a scenario-planning method to predict the consequences (e.g., a cost or schedule) in response to the changes of the project scope or business objectives. When the project progresses to the detail phases, the application of detailed scenarios is required to support decision-making, which is described by combinations of design variables. As shown in Figure 2, many alternatives based on certain scenarios at every decision-making point are used and can be customized continuously depending on the circumstances. The opportunities to apply scenarios increase according to the level of the project's development.

We examined owners' opinions about a CBR cost model without the scenario module. We interviewed skilled personnel in cost estimation from eight public enterprises in housing development in South Korea. Most of them expressed

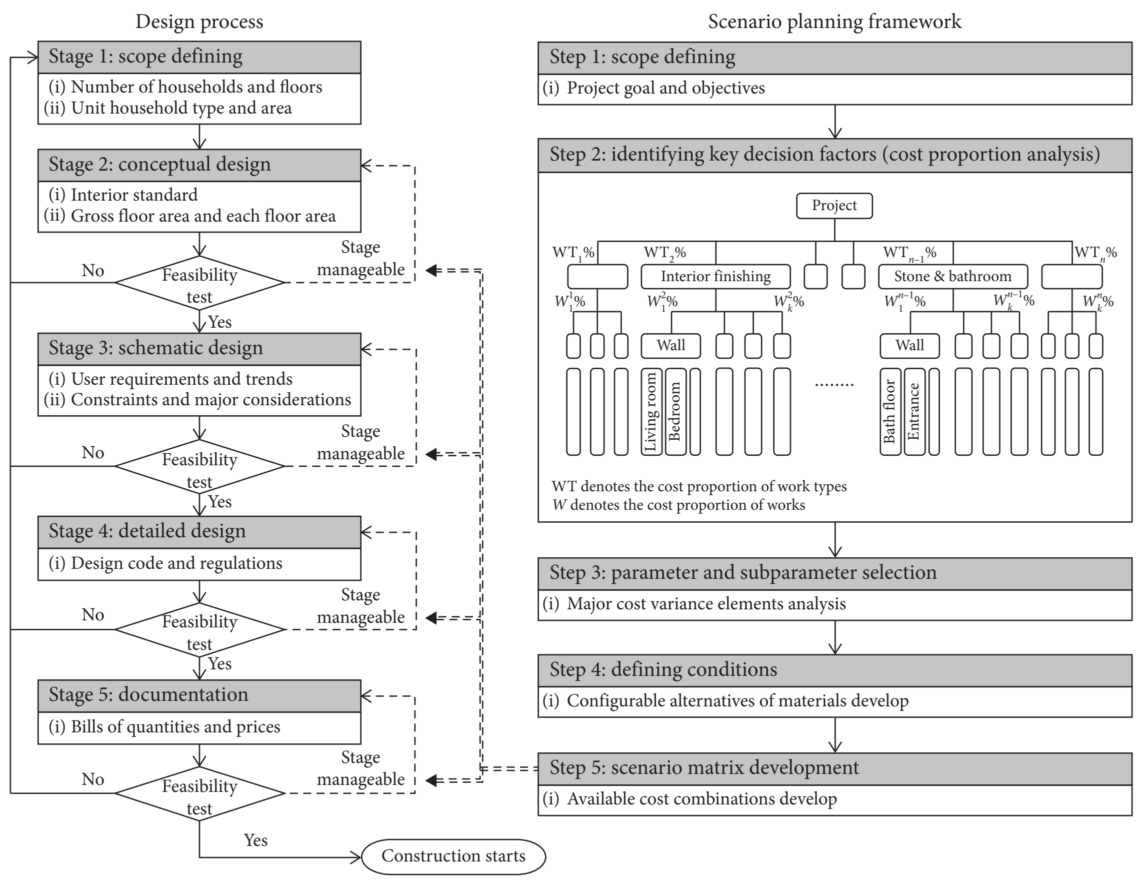

Figure 2: Scenario-planning framework and expected function in design process.

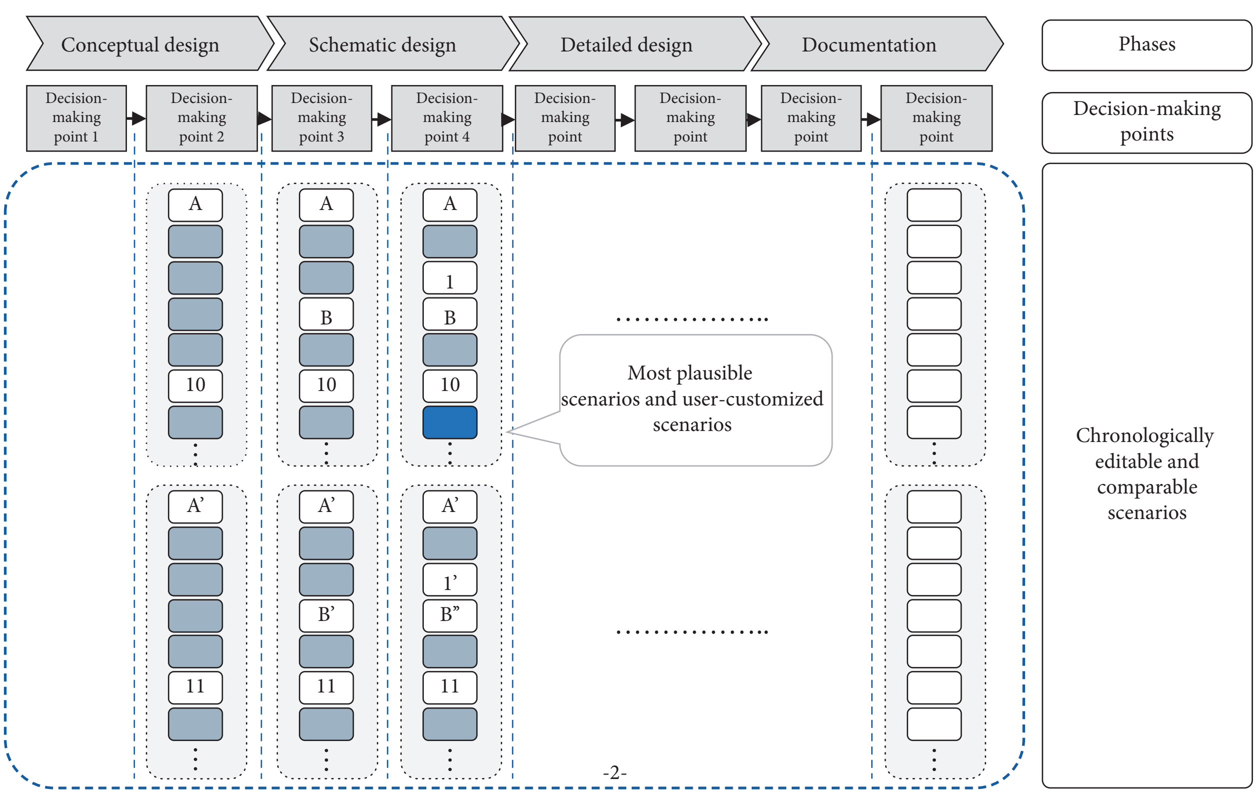

Figure 3: Opportunities to apply scenarios.

an affirmative response to our cost model, but they pointed out a deficiency related to making minor revisions. If major items such as the structural system, gross floor area, or number of floors are determined, the outputs retrieved by the cost model should be customizable. Similar cases whose similarities are calculated based on impact factors are insufficient to represent a solution of a given problem. Therefore, these cases need to be revised in response to changing conditions of lower elements such as the grade of finishing materials. This minor revision feature would allow the CBR cost model to analyze the impact on the results efficiently according to the variation of the elements without additional model runs.

In this situation, a scenario-planning method is essential to develop combinations of conditions and their consequences. Furthermore, the addition of a scenario component in the CBR cost model will magnify its advantages of quick response and high precision. The interviewees wanted to simulate or identify the impact on the fluctuation of total cost, such as in accordance with the alteration of finishing materials. They especially wanted to evaluate their designs by comparing them to 4-level finishing material standard of the Korea Land and Housing Corporation, which is regarded as a government marker of grades. Therefore, we analyzed the spectrum of construction cost elements and selected the most influential ones to develop a scenario.

4. Case Study

4.1. Identifying Key Decision Factors. The construction cost can be affected by combinations of many elements, so it is crucial to collect data and identify key decision factors. Therefore, we collected data on 102 apartment buildings from 10 housing complex projects in South Korea from public corporations. The data of each building cost are organized by work types. To examine the impact of work types, the average cost portions of trades were analyzed, as summarized in Table 1. The highest cost is from reinforced concrete work (40.94%), followed by interior finishing work (8.86%).

In South Korea, most apartment buildings are built with reinforced concrete wall structures, so structural work may not be considered as a design alternative in the design process [3]. However, seven trades are related to finishing work, such as interior finishing, stone and tile, and window works. Their impact on the cost varies significantly. Generally, an apartment building is composed of many household units. Accordingly, changes in items with low price differences can have an amplified impact on the cost variance because of their quantity. Consequently, we identified that finishing work should be treated as a key decision factor to develop a scenario. We selected the windows, interior finishing, and stone and tile works as the targets for scenario planning, which have a higher influence on decision-making than other finish work.

4.2. Parameter Extraction and Condition Definition. The items of stone and tile works are categorized by their elements, as shown in Table 2. Despite the high cost of balcony flooring, that element is excluded in the parameter selection because the balcony flooring material is used for only one item of ceramic tile in our data. This means that the element is only installed using a sort of economical consideration. For the same reason, we also exclude the corridor, lobby, and a small part of building's exterior design as parameters. Accordingly, the entrance floor, kitchen, and bathroom are chosen as parameters for stone and tile works. Furthermore, the selected parameters are separated into subparameters by their elements: the kitchen has a wall finish, the bathroom has a wall and floor finish, and the entrance floor has a floor and joists. Different finishing materials can be used according to their elemental attributes (i.e., their condition).

The parameters in the interior finishing work trade (Table 3) are divided into fixed items and selectable items to make a scenario. The base materials of other finishing work cannot be changed, such as gypsum boards, ceiling boards, and insulation materials. Therefore, we regard these as fixed parameters and exclude them. As a result, three changeable items were chosen for further development: flooring boards, wall finishes, and ceiling finishes. The parameters were categorized by their elements as the living room (which includes the kitchen), the bedroom, and the main room. Accordingly, the wall, ceiling, and floor finishing have the same subparameters that have their own conditions where alterations affect the project cost. When compared to the former analysis, the cost proportions of elements and spaces

Table 1: Building cost proportion analysis and finish-work relatedness check.

Work types	Cost proportion	Percentage rank	Finished-work relatedness check
Preliminaries	8.6%	4	
Ground works	3.18%	9	
Reinforce concrete	40.94%	1	
Steel frames	0.16%	17	
Masonry	2.09%	10	
Blocks	0.47%	14	
Stone and tile	**4.45%**	**6**	√
Plastering	3.32%	8	√
Carpentry	0.90%	13	√
Waterproofing	1.61%	12	
Painting	2.04%	11	√
Interior finishing	**8.86%**	**3**	√
Metal construction	3.85%	7	
Doors and windows	**11.34%**	**2**	√
Roof	0.34%	15	
Miscellaneous	1.20%	16	
Furniture	6.65%	5	√

Table 2: Cost proportion analysis (stone and tile works).

	Stone and tile works	
Elements	Cost proportion	Percentage rank
Entrance floor	**7.0%**	**5**
Kitchen	**5.9%**	**4**
Bathroom	**39.0%**	**1**
Balcony	19.5%	3
Other parts	28.7%	2

Table 3: Cost proportion analysis (interior finishing works).

Interior finishing work		
Items	Cost proportion	Percentage rank
Gypsum boards	0.1%	11
Ceiling boards	7.0%	4
Floorboards	**54.2%**	**1**
Wall finishes	**8.2%**	**3**
Ceiling finishes	**3.6%**	**8**
Moldings	3.7%	7
Dry partitioning	2.4%	9
Insulation board	4.8%	5
Internal insulation	3.9%	6
Acoustic board	1.4%	10
CRC board*	10.7%	2

*Cellulose fiber-reinforced concrete board.

Table 4: Cost proportion analysis (door and window works).

Door and window work		
Items	Cost proportion	Percentage rank
Household doors	**10.8%**	**4**
Household window frames	**21.6%**	**2**
Household window glazing	**13.7%**	**3**
Balcony window frames	**28.0%**	**1**
Balcony window glazing	**8.8%**	**6**
Other doors and windows (lobbies and stair halls)	9.5%	5
Miscellaneous	7.6%	7

in this parameter are analyzed in reverse because the bills of quantities in South Korea do not consist of the elemental cost. However, the values of elemental cost proportions in the matrix of parameters are not different from the figure of "stone and tile work."

Door and window work (Table 4) is composed of installation locations for each household, balcony, and common-use area. These elements are divided into framing and glazing. The conditions of subparameters are differentiated by the material used. Generally, customers are sensitive to the quality of windows in a household, whereas the grade of the windows installed in lobbies and stair halls is not selectable. For this reason, the items of the common-use area and miscellaneous items are excluded from the examination.

4.3. Scenario Matrix Development. The condition of the subparameters should be decided. This study refers to a table of combination levels of interior materials developed by the Korea Land and Housing Corporation (LH Corporation) to develop a scenario matrix. The corporation is the largest housing supplier in South Korea, and this grade table is widely used as a standard for housing complex projects. Consequently, the concepts are tabulated using the parameters to describe the building elements and the material substitutions, as shown in Tables 5–7. Acronyms are used according to combinations of the initial letters of each material.

4.4. Implication Analysis. To find out the degree of influence on the cost of each condition, the bills of quantities of three typical apartment building projects supported by the LH Corporation were analyzed. We analyzed the selected subparameter's material quantity under the conditions of fixed prices and quantities in a project to prevent the negative influence of other subparameters. The influence of a subparameter is calculated by multiplying its price and quantity.

There are many combinations of conditions, but this study applies four representative combinations developed by the LH Corporation. In this classification, various materials are designated differently from interior grades, which means the conditions of the interior work elements are decided (Tables 5–7). With the combination tables, the average influences of each subparameter are calculated by applying the prices according to the grades. To quantify the degree of influence on the total cost and the elemental cost, the condition weight (CW) and base condition weight (BCW) are defined as the ratio of the elemental cost to the total building cost, which can be selected as a subcondition of a parameter to make a scenario. In this concept, the base condition weight can be defined for a base grade, which means the condition weight of each element to make the basic scenario combination:

$$\text{condition weight (CW)} = \frac{\text{elemental cost}}{\text{total cost}}\ (\%),$$
$$\text{base condition weight (BCW)} = \frac{\text{elemental cost of a base grade}}{\text{total cost}}\ (\%). \quad (1)$$

Consequently, the scenario impact is measured by accumulating a combination of condition weights. We define the scenario impact (SI) and the base scenario impact (BSI) as the sum of parameter condition weights of a scenario as follows:

$$\text{scenario impact (SI)} = \sum_{i=1}^{n} CW_i,$$
$$\text{base scenario impact (BSI)} = \sum_{i=1}^{n} BCW. \quad (2)$$

As a result, a scenario matrix for the case study was developed (Table 8). The scenario impacts of this case study range from 7.54 to 14.68% of the total project cost, which means the matrix can provide a 6.77% contingency on the project total cost. The sum of the variance of the top six elements' condition is 7.44%, which is over 97% of the scenario impact variance (7.66%). The condition weight variance is 2.33% for the living room floor boards, 1.08% for the bedroom, and 0.91% for the main room. In the door and window work, the frame of the balcony has a condition weight variance of 0.89%, that of the window frame is 0.77%, and that of the glazing is 0.56%.

5. Results and Discussion

To evaluate the approach, we compared it with a previous model [4]. The difference between these two CBR processes

Table 5: Combination matrix (stone and tile work).

Stone and tile work				
Bathroom		Entrance floor		Kitchen
Floor	Wall	Floor	Joist	Wall
Glazed ceramic tile (small size) **SBF1**	Glazed earthenware tile (small size) **SBW1**	Glazed ceramic tile (small size) **SEF1**	BMC plastic **SEJ1**	Glazed earthenware tile (small size) **SKW1**
Glazed ceramic tile (medium size) **SBF2**	Glazed earthenware tile (medium size) **SBW2**	High-strength mosaic tile (rectangle) **SEF2**	Mock marble **SEJ2**	Glazed earthenware tile (rectangle) **SKW2**
		Mock marble **SEF3**	Natural marble **SEJ3**	Glazed earthenware tile (medium size) **SKW3**
		Natural marble **SEF4**		

Table 6: Combination matrix (interior finishing work).

Interior finishing work								
Floorboards			Wall finish			Ceiling finish		
Living room	Main room	Bedroom	Living room	Main room	Bedroom	Living room	Main room	Bedroom
Linoleum **IFL1**	Linoleum **IFM1**	Linoleum **IFB1**	Silk **IWL1**	Silk **IWM1**	Silk **IWB1**	Ecofriendly paper **ICL3**	Ecofriendly paper **ICM3**	Paper **ICB1**
Laminate floor **IFL2**	Laminate floor **IFM2**	Laminate floor **IFB2**	High-quality silk **IWL2**	High-quality silk **IWM2**	High-quality silk **IWB2**	Ecofriendly paper **ICL3**	Ecofriendly paper **ICM3**	Silk **ICB2**
Engineered wood **IFL3**	Engineered wood **IFM3**	Engineered wood **IFB3**	Ecofriendly paper **IWL3**	Ecofriendly paper **IWM3**	Ecofriendly paper **IWB3**	Silk **ICL2**	Silk **ICM2**	Ecofriendly paper **ICB3**
						High-quality silk **ICL4**	High-quality silk **ICM4**	High-quality silk **ICB4**

Table 7: Combination matrix (doors and windows work).

Doors and windows work				
Household doors	Household windows		Balcony windows	
	Glazing	Frame	Glazing	Frame
Polyvinyl chloride plastic **DHD1**	16 mm pair glass **DHG1**	Single window **DHF1**	16 mm pair glass **DBG1**	Single window **DBF1**
Natural wood **DHD2**	18 mm pair glass **DHG2**	Double window **DHF2**	22 mm pair glass **DBG2**	Double window **DBF2**
	22 mm pair glass **DHG3**		24 mm low-E pair glass **DBG3**	
			22 mm pair glass **DBG4**	

is that one has a scenario-based add-on module. We compared their predictions with the original model outcomes, which are divided by the 1-NN, 5-NN, and 10-NN adaptation methods. To evaluate the performance of each model, the absolute error ratios (AERs) were calculated:

$$AER(\%) = \begin{cases} C_A - C_E > 1, & [(C_A - C_E) - 1] \times 100, \\ \text{Otherwise}, & [1 - (C_A - C_E)] \times 100, \end{cases} \quad (3)$$

where C_A and C_E are the actual cost and estimated cost, respectively.

The experiment results (Table 9) show that the cost models with the scenario module achieved higher estimation accuracy and stability compared with the previous model. The proposed model achieved an average accuracy of 2.47% and stability of 5.54% when the 10-NN adaptation method was applied, which yielded the highest accuracy among the adaption methods.

In terms of accuracy, by using the scenario module, the negative influence of the errors within the AER of 6.77% can be absorbed (asterisk in Table 9). In other words, the estimation results can be adjusted to zero error by applying the scenario module because it allows a 6.67% contingency and provides chances for plausible alternatives. Consequently, estimation accuracies of 4.23 to 4.86% and stability enhancements of 1.39% to 1.73% were observed.

In terms of fast decision-making, generally, in planning or design stage, a modification provoked by cost overrun is an examination of planning or design alternatives. The earlier it happens, the less information can be given. Therefore, a decision maker only has a macroperspective option such as gross floor area or number of households. However, the suggested approach can provide a kind of microperspective option such as finishing material changes, which can confront more rapidly than conventional. This is because a change of scenario or an examining of representative scenarios can make the given problem be simple or excluded from decision-making issues. For example, a case study shows that a problem regarding cost overrun not exceeding 6.77% over total cost cannot be a decision-making

Table 8: Scenario matrix for an apartment project in South Korea.

			Parameters																			
		Trades	Stone and tile work					Interior finishing work									Doors and windows work					Scenario impact
		Elements	Bathroom		Entrance		Kitchen	Floorboards			Wall finish			Ceiling finish			Doors		Window		Balcony	
			Floor	Wall	Floor	Joist	Wall	Living room	Main room	Bedroom	Living room	Main room	Bedroom	Living room	Main room	Bedroom	Doors	Glazing	Frame	Glazing	Frame	
		BCW	0.16	1.21	0.04	0.01	0.01	1.17	0.46	0.54	0.11	0.07	0.08	0.03	0.01	0.02	0.16	0.46	1.19	0.52	1.37	7.63
Conditions	**A**	Subcondition	**SBF1**	**SBW1**	**SEF1**	**SEJ1**	**SKW1**	**IFL1**	**IFM1**	**IFB1**	**IWL3**	**IWM3**	**IWB3**	**ICL1**	**ICM1**	**ICB1**	**DHD1**	**DHG1**	**DHF1**	**DBG1**	**DBF1**	
		CW	0.16	1.21	0.04	0.01	0.01	1.17	0.46	0.54	0.11	0.07	0.08	0.03	0.01	0.02	0.16	0.46	1.19	0.52	1.37	7.63
	B	Subcondition	**SBF2**	**SBW2**	**SEF2**	**SEJ2**	**SKW2**	**IFL2**	**IFM2**	**IFB2**	**IWL3**	**IWM3**	**IWB3**	**ICL2**	**ICM2**	**ICB2**	**DHD2**	**DHG2**	**DHF2**	**DBG2**	**DBF2**	
		CW	0.18	1.30	0.04	0.02	0.02	2.84	1.11	1.31	0.14	0.08	0.10	0.06	0.03	0.03	0.18	0.54	1.95	0.66	2.26%	12.85
	C	Subcondition	**SBF2**	**SBW3**	**SEF3**	**SEJ3**	**SKW3**	**IFL3**	**IFM3**	**IFB3**	**IWL1**	**IWM1**	**IWB1**	**ICL3**	**ICM3**	**ICB3**	**DHD2**	**DHG3**	**DHF2**	**DBG3**	**DBF2**	
		CW	0.18	1.29	0.09	0.02	0.01	3.50	1.37	1.62	0.07	0.04	0.05	0.04	0.02	0.02	0.18	0.58	1.95	1.09	2.26%	14.40
	D	Subcondition	**SBF2**	**SBW3**	**SEF4**	**SEJ3**	**SKW3**	**IFL3**	**IFM3**	**IFB3**	**IWL2**	**IWM2**	**IWB2**	**ICL4**	**ICM4**	**ICB4**	**DHD2**	**DHG3**	**DHF2**	**DBG4**	**DBF2**	
		CW	0.18	1.29	0.15	0.02	0.01	3.50	1.37	1.62	0.07	0.04	0.05	0.08	0.03	0.04	0.18	0.58	1.95	0.66	2.26%	14.09
Analysis		Min	0.16	1.21	0.04	0.01	0.01	1.17	0.46	0.54	0.07	0.04	0.05	0.03	0.01	0.02	0.16	0.46	1.19	0.52	1.37	7.54
		Max	0.18	1.30	0.15	0.02	0.02	3.50	1.37	1.62	0.14	0.08	0.10	0.08	0.03	0.04	0.18	0.58	1.95	1.09	2.26	14.68
Variance			0.02	0.09	0.11	0.01	0.00	2.33	0.91	1.08	0.06	0.04	0.05	0.05	0.02	0.02	0.01	0.12	0.77	0.56	0.89	6.77

Table 9: Absolute error ratio (AER) comparison.

Adapt	Previous model [3]			Scenario-complemented model		
	1-NN	5-NN	10-NN	1-NN	5-NN	10-NN
Case 1	4.69%	6.99%	7.25%	*	*	0.11%
Case 2	9.08%	6.79%	6.58%	1.94%	*	*
Case 3	8.91%	0.98%	1.33%	1.77%	*	*
Case 4	4.58%	9.87%	9.24%	*	2.73%	2.10%
Case 5	4.15%	8.01%	3.33%	*	0.87%	*
Case 6	6.67%	1.65%	2.05%	*	*	*
Case 7	40.01%	30.01%	21.58%	32.87%	22.87%	14.44%
Case 8	2.13%	0.71%	2.71%	*	*	*
Case 9	4.90%	1.11%	1.02%	*	*	*
Case 10	23.77%	2.06%	1.24%	16.63%	*	*
Case 11	0.15%	8.87%	9.24%	*	1.73%	2.10%
Case 12	9.48%	6.18%	6.30%	2.34%	*	*
Case 13	1.87%	1.80%	0.79%	*	*	*
Case 14	5.96%	0.52%	0.12%	*	*	*
Case 15	0.75%	3.96%	6.13%	*	*	*
Case 16	11.70%	16.99%	19.44%	4.56%	9.85%	12.30%
Case 17	10.37%	0.55%	3.55%	3.23%	*	*
Case 18	1.07%	5.93%	1.74%	*	*	*
Case 19	3.11%	2.45%	5.69%	*	*	*
Case 20	27.08%	25.92%	25.51%	19.94%	18.78%	18.37%
Mean	9.02%	7.07%	6.74%	4.16%	2.84%	2.47%
SD	10.14%	8.29%	7.27%	8.74%	6.58%	5.54%

*The results can be modified to zero error by applying the scenario module.

subject anymore. Thus, when the proposed method is used, it helps decision-making by decreasing the number of problems and removing them.

6. Conclusions

We proposed the scenario-planning method for cost estimation and tested its feasibility by conducting a case study. Morphological analysis was introduced as an effective methodology to analyze the significance of parameters, to classify the parameters according to the elements, and to quantify the conditions of the influence on the project cost. Accordingly, we identified 11 elements of materials divided into 19 parameters that had an influence of about 15% on the project cost in the case study of a public apartment in South Korea.

We analyzed the combinations of available conditions of parameters, which were expressed by their condition weights, according to the elements. The concept of the scenario impact was suggested to calculate the consequences of each of the scenario combinations, which can play a key role in prioritizing crucial factors that can be configurable if a scenario must be changed. To test the applicability, we developed a scenario matrix for the apartment project and compared the estimation accuracy to a previous case study. As a result, both the accuracy and estimation stability were improved.

The suggested process can produce adaptable scenarios and evaluate their impact in a complicated decision-making process with limited information. Furthermore, it can provide a kind of contingency plan to cushion against uncertainty. Therefore, this methodology can show a rich and detailed portrait of plausible future results or a future state of a system that focuses on causal processes and decision points. The research outcomes could support and facilitate decision-making related to cost estimation for beginners and experts in both academia and industry. However, it is necessary to verify the generalization by applying the methodology to various kinds of construction projects besides apartment projects. Future research will require the development and comparison of various trades such as structural work, plastering, and furniture work, as well as comparative studies with other methodologies besides CBR, such as ANNs.

Data Availability

The data generated or analyzed during the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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