Determining Value at Risk for Estimating Renovation Building Projects by Application of Probability-based Fuzzy Set Theory

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Abstract
Building renovation projects are mainly affected by not only the design constraints of existing buildings but also various influential factors (e.g., building age, structural stability, site condition). However, conventional estimation methods deal with renovation projects similar to new construction and do not effectively consider potential risk factors. Thus, unexpected problems can make it difficult to proceed with the initial project execution plan. A three-phase framework is proposed for a probabilistic cost estimation process model that reflects the uncertainties of residential building renovation: (1) roughly estimating the cost based on industry means data; (2) converting the estimated costs to probabilistic values to consider the project characteristics; and (3) adjusting the converted probabilistic values according to risk factors. The value at risk of a specific construction can then be calculated to improve the reliability of the cost estimation. The proposed model was applied to a case study to demonstrate its feasibility. The results showed that the distribution of cost estimates reflecting the project characteristics and risk factors could be objectively confirmed at the initial stage. Thus, the method can help facilitate the decision-making process for homeowners, especially those reluctant to choose renovation.

Keywords: cost estimation; probabilistic; value at risk; renovation; residential

1. Introduction
In many economically developed countries, the housing market has transitioned from new construction to the operation and maintenance of existing buildings. The upgrading program of Singapore's Housing Development Board (HDB) and the renewal program of Japan's Urban Renaissance Agency are representative building renovation programs that have been implemented nationwide to enhance the quality of life through the renovation of old residential buildings (HDB 2016, URA 2016). However, private residential buildings cannot be renovated without the consent of the owners, and when no economic benefit is estimated, they hesitate over such a project. The main reasons are the various risks caused by design constraints, structural stability, and adjacent buildings that cause the work environment to be difficult to secure. Consequently, these risks should be accurately identified, predicted, and evaluated by project participants to realize a reasonable decision, which is indispensable for a successful renovation project.

When a building is too old to serve its original purpose, its owner should decide between reconstruction and renovation. In South Korea, over 60% of the total population lives in high-rise residential buildings, but the percentage of renovated buildings is less than 10% (CAK 2015). In other words, most owners opt for reconstruction. There are two main reasons for the stagnant renovation market for high-rise residential buildings: the performance of renovated buildings is inferior to that of reconstructed ones; and renovation produces a much smaller economic effect than reconstruction.

However, reconstruction necessitates an enormous waste of resources and conflicts with eco-friendly policies. Therefore, many countries have been launching a national-level policy to encourage renovation projects. As long as no cost analysis model is established, no rational cost estimate can be provided for a renovation project, so it is difficult for concerned parties to come to a reasonable decision. In the case of reconstruction, the cost can be easily determined with very high accuracy by calculating the quantities from design drawings. On the other hand, renovation depends on many uncertainties, which makes cost estimation much more difficult. Especially, risk factors neglected during the renovation process often generate excessive costs, which results in project failure.

Many studies have attempted to reflect the uncertainties in cost estimation. The probability-based method and fuzzy theory applications are good examples. However, because most of those attempts...
focused on new construction projects and theoretical approaches, few cost estimation methods are available for considering the uncertainties of renovation building projects from a practical point of view. Partial demolition and structural reinforcement are necessary for any renovation project where the existing building must be reused. Because of uncertainties such as the demolition of interior/exterior structures depending on owner requests and the repair and reinforcement of existing structures depending on their durability, accurate cost estimation is difficult. To accurately estimate the cost of a renovation project, the cost needs to be predicted based on expected risk factors.

This paper proposes a risk-based estimation process model that can secure the reliability and transparency of cost estimation by reflecting the uncertainties of high-rise residential renovation projects. The proposed method features an improved cost estimation process for residential buildings based on a method of quantifying critical risk factors using a sustainable cost data management program.

As a first step, the current cost estimation process was examined, and preceding research on risk-based cost estimation was reviewed. Current estimation practices of new construction and renovation projects were collected from experienced estimators and scrutinized. In addition, recent academic journal papers and research reports on risk-based cost estimation published were analyzed. Second, risk factors affecting the renovation cost were derived and classified. Graphic brainstorming tools such as cause–effect diagrams were used to derive many risk factors, which were then examined through expert interviews and a questionnaire survey. Third, a framework for the risk-based cost estimation process model was developed by mapping the current cost estimation processes. The databases (DBs) and various matrices required for this framework were also proposed. Finally, a system algorithm was developed to implement this framework in a practical form, and the feasibility of the research was examined through an application to a case study.

2. Preliminary Research

In general, the estimation process is based on the unit cost; this reflects owner requirements such as floor area expansion, new construction of car parking space, facility equipment replacement, and upgrade of interior finishing. Unfortunately, current estimations for renovation projects do not have a systematic approach to consider uncertainties (e.g., state of the existing building) even though there are much wider and various uncertainties in a renovation project than in a new construction project (AACE 1999, Kirkham 2007). The cost estimation results cannot be ensured to be reliable if the accumulated performance data of the project are insufficient. Furthermore, in the case of a lump sum contract, inaccurate cost estimation at the initial stage often causes a dispute when the renovation project is completed. Therefore, a risk-based cost estimation process that considers uncertainties will enhance the reliability of renovation cost estimations and can be utilized to select rational alternatives when making decisions in the design and construction stages (NevadDOT 2012).

There have been many attempts to reflect uncertainties in the cost estimation for buildings. Representative examples include the application of simulation methods using an artificial neural network, genetic algorithm, or case-based reasoning (Li 1995, Feng 1997, Kim 2005, Kim 2010, Ji et al. 2012). In cases where experience and historical data are not sufficiently available, a recent trend has been to apply a qualitative method such as fuzzy theory rather than a quantitative method based on probability and statistics. However, there have been few holistic and robust approaches to cost estimation that are specialized for renovation and thus effectively reflect the characteristics of renovation projects. Because of their data-driven characteristic, the current cost estimation methods are not suitable for the decision-making of a renovation project in its initial stage.

Compared to new construction, renovation projects are more dependent on the risk factors. Due to existing building constraints, factors such as the reduced concrete strength, material loss, and rebar corrosion directly impact the cost of the building renovation. Delayed decision-making by multiple owners and the excessive demands of residents also indirectly affect the project. In order to derive cost-related influential factors for a renovation project, a series of workshops and questionnaire surveys was conducted to elicit the critical factors for estimating the renovation projects. Many papers in the literature, tools, and techniques were also reviewed to determine the factors. (For details, see Lee & Cha 2016.) In total, 54 risk factors were derived. Among them, the 15 most significant items were selected and classified into five categories (see Appendix 1).

3. Algorithm for the Risk-embedded Renovation Cost Estimation Process Model (RCEPM)

3.1 Overview of the RCEPM

The proposed cost estimation process aims to predict the cost while considering the characteristics and uncertainties of a renovation project, which are neglected in conventional methods. As mentioned earlier, the driving principle of the risk-based cost estimation model is to graft existing historical data onto the probability concept to consider uncertainties. However, when an existing simulation model is implemented, an enormous amount of historical data should be collected, and much time and effort are needed to set up correlations between variables for the simulation model.

Hence, this study utilized the rough estimation method to establish a new model for renovation projects. In the proposed method, the owner’s requirements and project characteristics are regarded as input information for assessing the risk factors noted in the previous section, and the assessment
results are converted to probabilistic values in order to quantify the values at risk for the uncertainties of cost estimation.

One advantage of this method is that it is easily applicable to practical work because it uses the standard costs calculated by existing estimation methods as basic information. The conventional method estimates the total cost deterministically by applying the cost of a unit area for each work package based on the owner’s requirements. In contrast, the proposed model receives feedback about the identified risk factors including project characteristics and predicts cost in a probabilistic manner. Consequently, the latter approach can obtain reliable results because uncertainties regarding renovation project characteristics and other risk factors are reflected, unlike the conventional method.

![Fig.1. Algorithm for the RCEPM](image)

Fig.1. presents the algorithm of the proposed risk-embedded renovation cost estimation process model (RCEPM). This model consists of three phases. Phase 1 analyzes the basic information of the renovation project and owner’s requirements to calculate the cost basis (approximate cost). This phase utilizes basic information about the renovation project, such as the building purpose, location, land area, building area, total floor area, construction year, and design information obtained from site inspection. The results of phase 1 are used to determine the cost basis from the current construction unit cost. In phase 2, the determined unit cost is utilized as cost information, which is the basis of risk-based cost estimation. Especially, the core objective of this phase is to conduct three-point estimation and predict the difference from the cost basis calculated in phase 1. This difference is obtained as the value at risk (VaR). In phase 3, risk factors that may influence the project are analyzed based on the cost (unit cost) to reflect the renovation method determined in phase 2 and thus the risk characteristics of the project for cost estimation. For this purpose, the mean and standard deviation of the VaR calculated in phase 2 are transformed to determine the final version of cost estimates (denoted as VaR).

As shown in Fig.1., a total of three DBs are utilized. One is the industry average cost DB. This DB is updated mainly by public organizations on a periodical basis; relevant cost items need to be checked during the process. The second is the standard unit cost DB. The degree of deviation from the industry average is identified according to the characteristics of the project. The third is the risk-cost impact DB. This DB is managed by quantifying risk factors that are found and quantifying the risk influence according to the risk factors and work packages. If these DBs are continuously managed and data are accumulated through such a risk-based cost estimation process, more reliable estimates can be produced. The three phases of RCEPM are described in detail below.

### 3.2 Three Phases of RCEPM

The first phase of the RCEPM is a basic estimation stage based on the owner requirements and project characteristics. As shown in Fig.1., in order to produce a basic cost estimate, not only the basic information of the renovation (e.g., building purpose, project location, land area, building area, floor area, and building age) but also the requirements for vertical/horizontal expansion, parking lot expansion, additional elevators, and/or energy efficiency equipment should be checked. Table 1 shows a partial example of results of the 1st phase of the model.

![Table 1. Preliminary Estimation: Phase 1&2 (Partial)](image)

A standardized cost breakdown structure (CBS) is used for basic estimation. It consists of eight work packages on level 1 and 23 work packages on level 2. The total cost of renovation can be calculated as follows:

$$Total\ Cost = \sum_{i=1}^{23} W_{P_i}$$

Here, $W_{P_i} = Q_i \times U_{C_i}$, where $W_{P_i}$ is the cost of work package $i$, $(i = 1, 2, 3, \ldots, 23)$, $Q_i$ is the quantity of $W_{P_i}$, and $U_{C_i}$ is the unit cost of $W_{P_i}$.

As indicated in Table 1., each work package has a different unit and unit cost. The far right column titled "Renovation correction index" is utilized to adjust the standard unit cost based on the project characteristics. Because renovation has unique characteristics that are not found in new construction, basic historical data cannot be used without modification. Consequently,
the weights of the new construction cost information need to be changed to reflect the cost increase/decrease compared with the standard unit cost when the project characteristics and owner’s requirements are considered. For example, when a project site is located in a downtown area, an additional noise-related cost can occur compared to that in a suburban area. For this reason, a weight of 1.2 was applied to demolition work conducted in a downtown area for realistic cost estimation. This system was implemented to compensate for the present situation where no standard unit cost system has been established for a renovation project. When sufficient renovation history data have been accumulated in the future, such a process will no longer be needed. As a result, the standard unit cost for the cost estimation in phase 1 can be obtained by referring to the current construction unit cost DB, as shown in Fig.1.

In phase 2, the uniqueness of the target project is reflected, and the anticipated cost increase/decrease, which is also referred to as the value at risk (VaR), is allocated to 23 work packages by three-point cost estimation. The cost estimation of a renovation project generally needs to include a comprehensive assessment of various risk factors that are likely to occur during renovation work. Such risk factors include the density and distance between neighboring buildings, easy entry of equipment into the building, ease of securing the work place, structural safety (crack, detachment, concrete deterioration, etc.), and the foundation. In this stage, the staff in charge of cost estimation is requested to classify the renovation cost of each work package into three categories corresponding to optimistic, most likely, and pessimistic situations. Calculating the three values involves a process of inputting a degree of cost increase or decrease for each of the three scenarios with the standard cost of the work package set to 100%.

When such a process is completed, the contingency of each work package can be expressed as a probability distribution by applying the three-point estimation method. It is noteworthy that this method assumes a normal probability distribution in the Program Evaluation Review Technique (PERT) technique (PMI 2013). In other words, the expected VaR of the ith work package is converted to a probabilistic value with the following mean and standard deviation:

\[
\mu(\text{VaR}_i) = \frac{O_i + 4M_i + P_i}{6} \times C_i \% \tag{2}
\]

\[
\sigma(\text{VaR}_i) = \frac{O_i - P_i}{6} \times C_i \% \tag{3}
\]

where \( O_i, M_i, P_i, \) and \( C_i \) are the optimistic value, most likely value, pessimistic value, and contingency, respectively, of \( WP_i \).

Consequently, a confidence interval can be designated from the probability distribution to calculate the total cost. For example, in the case of demolition work for \( WP_i \), if the three-point estimation calculates the optimistic, most likely, and pessimistic values as 0.703, 1.070 and 1.155, respectively, Eqs. (2) and (3) calculate the mean and standard deviation of the contingency allocated to this WP as 1.023 and 0.075, respectively. Likewise, the probability and standard deviation of the contingency for all 23 WPs can be obtained to convert the definitive renovation cost into a probabilistic value. Finally, phase 3 considers risk factors that increase or decrease the renovation cost, as explained in Section 2. In order to effectively understand the influential factors of a renovation project, a risk–cost matrix was developed in this study. This matrix is a table that quantifies the effects of 15 risk factors in 23 work packages (see Table 2.).

The quantified results from the matrix are used to adjust the mean and standard deviation of the VaR calculated by the three-point estimation in phase 3. Table 2. presents an example of the risk–cost matrix. It clearly shows the degree of each risk item’s effect on the increase in cost of each WP. For instance, the effect of risk \( A_1 \) on the contingency cost increase of demolition work is expressed as 4% (\( A_1/WP_i = 0.04 \)). The matrix in Table 2. is based on the opinions of some experts on cost estimation who participated in this study and thus needs to be constantly updated. More details are discussed in Section 5.

3.3 Determining the Value at Risk by Combining Probability and the Fuzzy Set Theory

As indicated in Table 2., the remodeling cost factors (RCFs) influence the cost increase of a renovation project. However, such risks should be assessed for whether or not they will occur during the renovation project. Thus, the likelihood of each of the 15 risk items needs to be identified. The fuzzy arithmetic method was adopted as an effective solution (Elbarkouky 2016). To simplify the defuzzification process, the likelihood of each risk item was divided into five cases: strongly agree, agree, neutral, disagree, and strongly disagree. Those five categories were then defuzzified to be quantified as 100%, 75%, 50%, 25%, and 0%, respectively. In other words, the likelihood of a particular risk item in the project was quantified, and the influence levels of 23 WPs of the risk–cost matrix on the cost were adjusted. During this process, the mean and standard deviation calculated in phase 2 were adjusted according to the project risks. Such a conversion process was quantified as follows. For the sake of convenience, the conversion ratio (CR) was defined as an index indicating the degree of conversion. The following equations can be used to determine the converted mean (\( \mu' \)) and standard deviation (\( \sigma' \)):

\[
\mu'(\text{VaR}_i) = \mu(\text{VaR}_i) \times CR_i \tag{4}
\]

\[
\sigma'(\text{VaR}_i) = \sigma(\text{VaR}_i) \times CR_i \tag{5}
\]

The conversion ratio \( CR_i \) can be calculated as follows:

\[
CR_i = \Pi_{j=1}^{15}(1 + P_{ij} \times F_j) \tag{6}
\]

where \( P_{ij} \) is the risk–cost index of \( ij \), \( F_j \) is the risk evaluation defuzzification index, \( i \) is the WP, and \( j \) is the risk factor.

If the evaluation results of 15 renovation risks are as given in Table 3., the risk-reflecting \( CR_i \) for the demolition WP of the project can be obtained as given

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in Tables 2 and 3.

\[ CR_1 = (1 + 0.04 \times 1) \times (1 + 0.07 \times 0.75) \times (1 + 0.04 \times 0.25) = 1.484 \times 1.023 = 1.510 \]  

(7)

Consequently, the mean and standard deviation for the contingency of WP1 in the project are finally converted as follows:

\[ \mu'(VaR_{R1}) = 1.484 \times 102.3\% = 151.8\% \]  

(8)

\[ \sigma'(VaR_{R1}) = 1.484 \times 7.5\% = 11.18\% \]  

(9)

As noted previously, the mean and standard deviation of a cost that reflects the risk factors for 23 WPs in total can be obtained by utilizing a final conversion index. The mean and standard deviation for the VaR of the project are modified through probability distribution; the modified values can then be utilized to calculate the cost of a renovation project based on reliability. The probability distribution for the contingency of this project can be obtained as follows:

\[ \mu(VaR_{Total}) = \sum_{i=1}^{23} \mu'(VaR_i) \]  

(10)

\[ \sigma(VaR_{Total}) = \sqrt{\sum_{i=1}^{23} \sigma'(VaR_i)^2} \]  

(11)

Table 4. presents an example probabilistic computation of the VaRs of the final renovation project for a certain project consisting of 23 work packages. The mean and standard deviation, which were the probability distribution for the 23 WPs in total, were evaluated by the fuzzy arithmetic method according to 15 risk–cost relationship matrices and modified by CR values. This modification was conducted by multiplying CR values with the original contingency values allocated to each WP. As shown on the bottom row, the original contingency value was 197,430,000, which corresponds to 10% of 1,974,300,000 calculated in phase 1. However, the three-point estimation and risk evaluation modified the original value to a mean of 287,061,186 and standard deviation of 6,485,747 (see Table 4).

When a renovation cost is calculated by using such a mean and standard deviation, the risks can be considered in the estimation. In addition, a VaR can be sensibly predicted by using the simulation program @RISK or applying the normal distribution conversion formula according to different degrees of reliability. Although the research assumed the use of three-point estimation with the PERT technique, it is noteworthy that the distribution should be encoded when a sufficient data set has been achieved. The cost depending on the reliability can be calculated with the following normal distribution formula:

\[ \text{Renovation Cost} = \text{Initial Cost} + [\mu(VaR_{Total}) + z \times \sigma(VaR_{Total})] \]  

(12)

Fig.2. presents the variation in the cost estimation according to the confidence level (0.5 - 0.99). Therefore, the cost is effectively estimated considering the level of risk exposure. The outcome of this model provides a probability-linked estimation for a particular project.

4. Application of the RCEPM

4.1 Case Study Overview

A pilot-test project was configured to verify the proposed RCEPM. A renovation project with design drawings and approximate and real cost statements was selected for the case study (see Fig.3.). The case study
was a 10-block apartment complex on Jeju Island. The apartment complex was built in 1993 and consisted of 400 units in total; half had an area of 35 m$^2$ each, and the other half had an area of 40 m$^2$ each. The walls of the building were structural, and each unit had an individual heating system using gas. Because the unit plan was very small, it was assumed that the renovation involved vertical/horizontal plane expansions, elevators, stairways, and additional parking space.

4.2 Application to the Case Study

In the first phase (seen in Fig.1.), a preliminary estimation was conducted by surveying the owner’s renovation requirements and basic information about the renovation project. As basic information of the project, the location, land area, building area, total floor area, and construction year were inspected. In addition, the requirements of the virtual owners for the renovation were outlined. In particular, the owners were assumed to have demanded the construction of an underground parking lot and additional elevators so that the apartment building would be changed into a staircase type with more car parking capacity. The owners were assumed to also want a new and renewable energy system to reduce maintenance fees. Based on such requirements, three alternatives were proposed, as shown in Fig.3.

These alternatives were based on the basic information of the project and the owner requirements. The rough renovation cost could be calculated by using those alternatives and historical cost data. Because all three alternatives required similar amounts of demolition and additional construction, they produced similar costs. The industry average cost and quantity were calculated for each of the 23 WPs, and the final cost estimation was produced based on the calculations as seen in Table 1. The total estimated cost was KRW 1,973,400,000.

After the rough estimation, a three-point estimation was performed by considering the project characteristics corresponding to phase 2 (seen in Fig.1.). For this process, a field inspection was performed, and the detailed characteristics of the project and owner requirements were surveyed to determine considerations when selecting the construction method. In addition, experts were interviewed to help make a final decision on the most appropriate construction method. Based on the results, the crushing method using breakers was preferred for demolition work rather than manpower. The micro-pile method was found to be more suitable for basic reinforcement work than the conventional pile driving method. For seismic reinforcement work, the existing steel bracing method was replaced with the steel wall enforcement method. The selected methods were applied to the renovation alternatives to estimate the costs. By using Eqs. (2) and (3), the contingencies could be estimated for all 23 WPs. Table 5. presents the mean and standard deviation of the contingency increase/decrease for each WP of Alternative 1 according to the three-point estimation.

After the work methods were incorporated into the cost estimation, phase 3 (“fuzzy arithmetic evaluation” in Fig.1.) was performed by evaluating the risk factors of the case study. In this manner, the probability distribution for the contingency of each WP could be modified. In other words, the quantitative evaluation of the 15 risk factors (as seen in Table 3.) could be used
to modify the mean and standard deviation of each WP for a more realistic cost estimation of the renovation project. Table 6. presents how the risk evaluation of the case study modified the mean and standard deviation of the contingency for each alternative. This table also presents the cost estimation calculated with 95% reliability by the @RISK program for each alternative.

### 4.3 Results of the Case Study

The RCEPM was applied to a pilot-test renovation project in order to perform the proposed algorithm. Each renovation alternative clearly showed a change in the estimated cost for each phase. The initial rough estimation was based on the conventional methods without considering project characteristics. For this reason, the estimated cost was less than the actual cost. When suitable construction methods were determined and considered, the project characteristics could be reflected in the estimated cost, which became closer to the reality of the project case. The final phase applied risk factors to calculate the range of expected costs and thus enhance the reliability of the cost estimation.

As indicated in Table 6., when risks were incorporated into the cost estimation, the three alternatives produced different cost estimates, even though the initial estimations using the standard unit costs were the same. In other words, when the cost estimation reflected risk factors with 95% reliability, Alternatives 2 and 3 required additional costs of KRW 35,050,000 (=2,315,780,000-2,280,730,000) and KRW 297,061,186, respectively, compared with Alt. 1.

Thus, in the case of renovation projects with potential risk, owners should not depend on definitive values to make a decision but should consider uncertainties by incorporating risk factors into the cost estimation of each alternative. Although the virtual case study project was used instead of a real case, the applicability of the proposed method was verified clearly enough to confirm that RCEPM can be successfully implemented.

### 4.4 RCEPM Limitations

There are several shortcomings in expanding its application to real-life projects. First, the cost data reliability should be improved and the data gathering process should be well established. It is widely accepted that cost estimation is a data-driven process. Most of the data in the system are based on the assumptions. The databases of the system should be well managed and constantly updated in order to ensure the reliability of the results.

Second, the contents of risk items (in Appendix 1) in this study are still primitive. The identified risk factors in this study play an important role in obtaining the risk-based estimation results. As such, the risk-cost relationship should be thoroughly monitored in terms of whether any falsifiable data results can be obtained. The soundness of the results is recognizably dependent on the robustness of the risk-cost quantification endeavors. For example, the fuzzy defuzzification in this study assumes that the fuzzy numbers are generated with a five-scale approach. It is accepted that real fuzzy functions are differentiated in terms of the risk profiles and circumstances of the project.

Finally, there is a large gap between estimated cost and cost at completion. Therefore, it is useful to feed historical data of completed real renovation projects back to the renovation estimation system. More accurate cost estimation can be made possible by adding real cost information according to completed work packages to the existing cost items. Furthermore, the DB of costs according to the renovation method must be updated when a new method is developed. Updating variations in cost according to the remodeling method will enable more accurate cost estimation.

### 5. Discussion and Conclusion

The proposed RCEPM model consists of preliminary estimation (phase 1), three-point estimation reflecting the characteristics of a renovation project (phase 2), and fuzzy arithmetic evaluation (phase 3). As noted in Section 3, each phase should utilize its corresponding DB: industry average cost, standard unit cost, and cost-risk impact. The information of these DBs needs to be updated based on historical data after each renovation project is completed. In this manner, the accuracy of the cost estimation can be improved.

The renovation project introduced earlier had a complicated ownership involving 400 owners. In this case, the renovation project could not proceed without certainty regarding the total project cost. There was also concern over the cost generated by each item (e.g., underground parking lot, elevator) and whether full-
scale or partial-scale renovation should be performed. The application of the proposed RCEPM to the above case resulted in the following feedback. First, compared with deterministic estimation, the cost range could be identified, which provided confidence in decision-making. The cost could be estimated for various alternatives, so they could be quickly examined. As uncertainties were identified, communication between stakeholders became much smoother.

Although RCEPM was applied to an illustrative case, its applicability was successfully verified. If the DBs and user interfaces can be improved through systematization, the proposed RCEPM will be highly useful for risk-based cost estimation of renovation projects for high-rise residential buildings. At present, this system is being verified through actual operations, and the accuracy of the prediction system needs to be improved by upgrading the user interface and accumulating information on project cases.

The current cost estimation process for renovation projects can hardly be distinguished from that of new construction projects and does not reflect the characteristics of individual renovation projects. For this reason, it is difficult for owners who are planning renovation projects to make sound decisions. The results of this study will help with reliable renovation cost estimation and thus facilitate the decision-making of owners. Renovation-oriented estimation companies, construction companies, and construction managers can benefit from the proposed model by reflecting the uncertainties of renovation projects and thus successfully implement the renovation projects by analyzing the project risk factors.

### Appendix 1. Critical Risk Factors for High-rise Residential Building Renovation Costs.

| Category                      | Risk Factor                              | Description                                                                                      |
|-------------------------------|------------------------------------------|-------------------------------------------------------------------------------------------------|
| A. Construction Execution Plan| A1. Poor project execution strategic plan| Does an excessive cost increase occur due to the lack of a strategic plan for the renovation project? Is scrupulous attention have to be paid to the organization, budget allocation, and calculation of construction period? |
|                               | A2. Poor cost/schedule management plan   | Is it necessary for the management stage to establish a control system as well as cost/period plans? |
|                               | A3. Building utilization plan during construction stage | Does the use of the existing building have a great effect on the construction cost? Can renovation be carried out while tenants still reside in the building? How about after full evacuation of the building? |
|                               | A4. Poor review on design/construction document | Poor review on design and construction documents can cause reconstruction and low productivity. Is that a cause of the cost increases? |
| B. Existing Building Risk     | B1. Alteration history during building usage | In the case of old buildings, past changes in use can increase the cost. Has the building ever been used as an office or warehouse apart from housing? |
|                               | B2. Data shortage for existing building  | The utilization of design drawings, structural drawings, facility maps, and other information of the existing building greatly increase the cost? |
|                               | B3. Difficulty with onsite inspection    | Is it easy to carry out a preliminary onsite investigation? Is it difficult to accurately calculate the renovation scope and cost estimate? |
| C. Personnel Risk             | C1. Delayed owner's decision-making      | Is the design draft of the renovation frequently modified by delayed decision-making? Or, are there many influential factors that can delay decision-making? |
|                               | C2. Unclear owner requirements           | Are the owner's requirements (e.g., parking space extension, plane expansion, eco-friendliness) clear? |
|                               | C3. Deficient communication among project stakeholders | Is communication among project stakeholders smooth? In other words, does deficient communication cause trouble for the project? |
| D. Public Relations Risk      | D1. Difficulty with regulatory approval & permission | Is it difficult to obtain approval and permission for a project or other construction-related permission from the competent authority? Are frequent public complaints anticipated because they cannot be quickly responded to? |
|                               | D2. Insufficient plan for public complaints | Is there any special characteristic of the project site to be considered (e.g., workers are hard to find, night work is impossible)? |
|                               | D3. Poor response to local issues        | Does the unstable structural strength of the existing building require separate structural reinforcement? |
| E. Deterioration Risk          | E1. Difficulty with establishing the remodeling scope due to building age | Is the renovation scope hard to establish because of the building age? |
|                               | E2. Unstable structural strength of the existing building | Does the unstable structural strength of the existing building require separate structural reinforcement? |

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