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Research Article

Economic Analysis for Setting Appropriate Repair Cycles on the Fixed Materials and Facilities in the Public Rental Housing

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Currently, repair and maintenance cycles that follow the completion of construction facilities lead to the necessitation of subsequent data on the analysis of study and plan for maintenance. As such, an index of evaluation was drafted and a plan of maintenance cycle was computed using the investigation data derived from surveying target housing units in permanent rental environmental conditions, with a minimum age of 20 years, and their maintenance history. Optimal maintenance and replacement methods were proposed based on this data. Economic analysis was conducted through the Risk-Weighted Life Cycle Cost (RWLCC) method in order to determine the cost analysis of maintenance life cycle methods used for repair. Current maintenance cycle methods that have been used for 20 years were also compared with alternative maintenance cycles.

1. Introduction

During the process of rapid economic development and industrialization, cities in South Korea expanded quickly, and demands for collective apartment housing increased at a higher rate than conventional detached houses. Recently, however, with the housing market becoming stagnant owing to the stabilized housing supply and a decrease in population, the market changed to a selective market that is centered on consumers rather than suppliers as it has been in the past [1]. In particular, for apartments sold by private construction companies, when a 10-year warranty period of the construction company expires, it is a general practice for occupants to perform repair works in buildings with long-term repair reserves that have accumulated from the time when the buildings' original tenants moved in, according to Article 47 of the Housing Act. However, for public rental housing, a government-invested institution allocates and executes repair and maintenance expenses [2].

In the case of permanent rental housings among apartment houses, many of them are over 20 years old, and the repair and replacement cycles for facilities in the existing buildings arrive each year, and large-scale repair planning and budget calculations are simultaneously needed [3]. In order to execute such a public budget, the economic efficiency and maintenance plans of building facilities need to be established. However, history data and related documents required for assessment of the repair and replacement cycles of buildings, solutions for repair and maintenance expenses, and data for the establishment of long-term repair plans are insufficient [4]. A problematic result is that adequate facilities with a remaining service life are being demolished and disposed according to uniform replacement criteria [5]. Furthermore, main agents of maintenance in possession of large-scale building assets need to standardize, and develop an efficient system for, the investigation, repair, and replacement process when they design the investigation, repair, and replacement of the facilities for maintenance in the future.

Thus, the present study was conducted to satisfy the need of the study as follows.

First, repair and maintenance cost will be reduced if a method of how to set an appropriate repair period is used in public rental houses. Up until now, history data and related literature have not been sufficient to evaluate the repair and replacement period in buildings and little data is available to establish a measurable solution for repair and maintenance cost as well as a long-term repair plan. Furthermore, although studies on repair cycle have been conducted before, they are only limited to statistical estimation based on a partial repair period. In relation to the calculation of the repair period, there has been an attempt to improve maintenance management that held a large size of building assets but the study achievement has been mediocre due to the lack of problem awareness and immature social and technical conditions.

Second, the validity of establishment on maintenance plans and economic feasibility of public rental houses for efficient execution of public budget can be secured. To do this, it is necessary to perform optimum maintenance on rental apartments and raise asset values through evaluation on economic feasibility regarding repair needed items based on the current status investigation of facilities and analysis results with regard to items to be checked in 20 years of the complete repair period.

In order to achieve the above needs, it is necessary for maintenance management of public rental houses to systematize facility examination, repair, and replacement processes and set an efficient system in place with regard to facility investigation, repair, and replacements for the purpose of future maintenance.

This study reveals the results of an economic evaluation used to select the best repair method by applying the appropriate repair cycle derived from the results of a maintenance (repair/replacement) history survey performed on permanent rental housings 20 years or older (1990~1991). Based on the above activities, it can also identify whether the efficient application of the long-term repair plan for apartments is feasible economically. The final aim of the present study is to develop an economical and efficient maintenance system through measures that optimize existing repair periods used in apartments thereby increasing the service life of apartments.

2. Scope and Method of Study

2.1. Scope of Study. The results of facilities surveys and maintenance (repair/replacement) history surveys for permanent rental housings must be used as the basis for selecting economical, efficient, and appropriate repair and replacement methods. Furthermore, methods to save repair and maintenance expenses required for the management of public rental housings must be presented through a general economic analysis about the application of the appropriate repair cycle and optimal repair method.

The subjects of this study are the facilities of public rental housings 20 years or older. The selection of the target facility in this study was done based on items that required a reset of 20 years of repair period for permanent rental houses in relation to "the Standards on Facilities that Require Establishment of Long-Term Repair Plan, Standard Repair Period, and Repair Rate" by the Korea Land & Housing Corporation (LH).

These facilities can be largely classified into entrance, rooms, bathroom, doors and windows, balcony, and common facilities. The scope of economic analysis will be limited to bathroom (bathroom door, remodeling, floor tiles, and water leakage repair), entrance (floor tiles), doors and windows (entrance door, small room door, main room door, sliding door, and small room window), balcony (floor tiles), and common facilities (shoes cabinet and nonslip). For economic analysis, the RWLCC and MCS methods were applied to determine the repair cost of the conventional method and the optimal repair method for each facility of the public rental housing and to derive the results of the changed repair cycle.

2.2. Study Method. A quantitative evaluation of the economic efficiency of the repair methods for interior and exterior materials of the subject buildings was performed according to the Risk-Weighted Life Cycle Cost (RWLCC) analysis model. The cost of each alternative was calculated with the repair design data for rental houses and the standard estimation data as the basic analysis data [6].

The basic probabilistic RWLCC analysis was reviewed considering the uncertainty (risk) of the variables related to the life cycle cost (LCC) items by applying the Monte Carlo Simulation (MCS) method. The weights in RWLCC model are calculated using the AHP techniques. Then the expected uncertainties were visualized as probability distribution or cost distribution and cumulative distribution. This method is very advantageous for establishing design decision making and maintenance methods according to the repair method for building interior and exterior materials [7].

In addition, for the life cycle inventory analysis as the analysis procedure using the MCS method, the HBLCC program (Road Traffic Technology Institute, Dec. 2006) for which the matrix formula was developed by Heijungs [8] was used. Because this program was developed with a road bridge as the basic model, data related to rental housing repair methods was investigated and inputted for the related input variables and database data for this study.

3. Theoretical Discussion

3.1. Existing Research. This study was conducted to analyze the general economic efficiency of facilities according to the changed repair cycle based on the survey results on the appropriate repair and replacement cycles of interior facilities of permanent rental apartment houses managed by the Korea Land and Housing Corporation (KLHC). Previous studies were researched using keywords such as *apartment house facilities*, *repair cycle*, and *management system and maintenance*. The results are outlined below.

Nah et al. [9] conducted a study on a Web-based apartment house long-term repair planning system. For the longevity of apartment houses across the country, they proposed a Web-based maintenance system that can predict the repair cycle and repair times considering the characteristics of materials for each part of the corresponding apartment complexes using long-term repair plans and allows apartment house managers to automatically manage periodic inspections, diagnoses, and replacements according to a maintenance calendar for each complex. Han et al. conducted a study on long-term repair plans for the maintenance of apartment houses [10]. They suggested the need for establishment of accurate long-term repair plans and accumulation of special repair reserves for occupants of target facilities for maintenance, as well as housing managers, who are the main agents of maintenance activities. Furthermore, they suggested the establishment of a long-term repair plan based on accurate grounds to extend the economic life of buildings by displaying the maximum performance of apartment houses and presented an algorithm for automatic allocation of repair costs to calculate the special repair reserve according to the long-term repair plan.

In a study on repair time settings for apartment houses by construction type, [11] classified facilities into building exterior, building interior, electric facilities, fire hydrants, elevators, intelligent home network facilities, water supply facilities, sanitary facilities, gas facilities, ventilation facilities, heating and hot water supply systems, outdoor subsidiary facilities, and outdoor welfare facilities. The study intended to adjust and improve repair times presented in the standards for establishment of long-term repair plans for apartment housing and present the research results.

Furthermore, Yoo [12] predicted the LCC required for appropriate repair and maintenance of high-rise apartments and estimated the amount of loss from reconstruction by comparing it with the LCC that had been predicted based on the current repair and maintenance expenses.

As a result of investigating previous studies on the repair cycle and methods of apartment housing facilities, there was no study with subjects and methods similar to those of this study, which conducts economic analysis through the LCC analysis of repair method by resetting the appropriate repair cycle for interior facilities among construction facilities.

3.2. Review of Economic Efficiency Evaluation Method. The long-term economic evaluation of the LCC concept that is appropriate for buildings requires quantitative indices for the long-term durability level of the reviewed repair methods. However, data for such quantitative indices is insufficient in South Korea, and it is difficult to apply uniform criteria due to the nature of the building interior and exterior material development process that is continuously developed and improved.

The economic evaluation item is designed to determine economic value by comparing economic levels considering the risk of repair methods; it is not designed to analyze the absolute economic efficiency based on the quantitative service life of the evaluated materials and method. Therefore, relevant comparable data such as LCC analysis are used if such data exist. Along with this standard estimation data for each method, or quotations about the corresponding construction cost, are aggregated and compared.

3.2.1. Calculation of Total RWLCC. When simultaneously considering the weight of each construction step and the risk of repair method for building interior and exterior materials, the weight which is applied after the important step, wherein each economic evaluation item is judged, has a different value for each economic evaluation item. Thus, the weight should be presented as a subset in which the respective weight is applied to each economic evaluation item. Furthermore, regarding the risk of repair method for building interior and exterior materials, the initial investment amount is not a subject of consideration from the aspect of risk. HBLCC program is made by Road Traffic Technology Institute using the matrix formula by Heijungs. Therefore, it is not advisable to apply the risk to all calculation values based on the shared set, as shown in the conventional equation (1). It is instead recommended to calculate the total cost by applying the risk only to the maintenance stage and the demolition and dismantling stage. Consequently, for the total cost calculation, simultaneously considering the weight of each life cycle stage and the risk of repair method for building interior and exterior materials, the following equation is used [6]:

$$\mathrm{RWLCC}_{\mathrm{Tot}} = \frac{\sum \left(C_{\mathrm{INI}} \times W + C_{\mathrm{OMR}} \times WR + C_{\mathrm{DIS}} \times WR\right)}{(1+r)^{t}}, \quad (1)$$

where RWLCC is total life cycle cost considering risk, C_{INI} is initial construction cost, C_{OMR} is current value of maintenance cost, C_{DIS} is dismantling cost, r is discount rate, W is weight of each economic evaluation item, R is risk of repair method for building interior and exterior materials, and t is time.

(a) Application of MCS Method. The MCS (Monte Carlo Simulation) method treats input variables by expert opinion as random variables and sets a probability density distribution for each random variable to review the statistical characteristics of each response value, such as probability density distribution. In the stage for deciding the probability distribution, each probability distribution is determined according to the characteristics of the selected data [8].

When the amount of data is large, normal distribution is applied; otherwise, uniform distribution or triangular distribution is used according to expert judgment. Once this probability distribution is determined, the quantitative uncertainty analysis method MCS is performed.

By applying the MCS method, a basic probabilistic RWLCC analysis considering the uncertainties (risks) of variables related to the LCC cost items becomes possible, and the expected uncertainties during the analysis are visualized as probability distribution, that is, cost distribution and cumulative distribution [13]. Therefore, this method is quite useful for establishing a design decision making and maintenance method according to the application of repair method for building interior and exterior materials.

Furthermore, for the life cycle inventory analysis using the MCS method, the HBLCC program (Road Traffic Technology Institute, Dec. 2006) for which the matrix formula was developed by Heijungs [8] was used. Because this program was developed using a road bridge as the basic model, data related to rental housing repair methods was investigated and

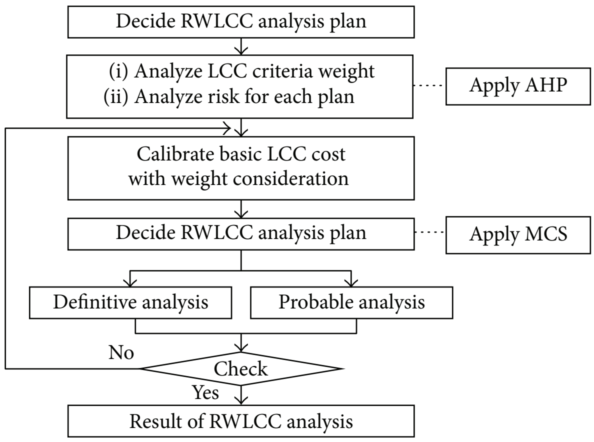


Figure 1: RWLCC evaluation process.

Table 1: Conventional 20-year repair cycle items.

Category	Review items
Interior	
Doors and windows	Front door
	Small room window
	Small room door
	Bathroom door
	Main room door
	Sliding door (inside, outside)
Tiles	Entrance floor tiles
	Bathroom floor tiles
	Bathroom wall tiles
	Balcony floor tiles
Sanitary ware	Wash basin
	Toilet bowl, closet bowl
Furniture	Shoes cabinet
Exterior	
Common facilities	Nonslip
Total number of items	14

inputted for the related input variables and database data in this study.

(b) RWLCC Evaluation Process. For the calculation and probabilistic analysis of RWLCC, the following RWLCC evaluation process in Figure 1 was applied.

3.2.2. Selection of Economic Review Items

(1) Conventional 20-Year Repair Cycle Items. Table 1 lists the 20-year repair cycle items for permanent rental houses related to Schedule 8 (in relation to Article 13) "Facilities that require the establishment of a long-term repair plan, standard repair cycle and repair rate."

Among the items included in this study, a bathtub and aluminum windows were excluded from this economic evaluation because their traditional repair cycle is 25 years, not 20 years. Kitchenware that is currently included in the 20-year repair cycle of KLHC was also excluded, because they were replaced in 2005, 15 years after moving in. Therefore, the economic evaluation according to the changed 20-year repair cycle was performed with 14 items in Table 1.

(2) Changed Repair Cycle Items. The changed repair cycle and economic evaluation items according to "a study on the diagnosis of rental housing facilities and the test and evaluation of repair methods" are listed in Table 2.

Regarding the changed repair cycle, a leakage repair method was added to the 20-year repair cycle items, and the two existing sanitary ware items (wash basin, toilet bowl) and bathroom wall tiles were changed to bathroom remodeling items, resulting in 7 items in the 20-year repair cycle, 5 items in the 25-year repair cycle, 1 item in the 30-year repair cycle, 0 items in the 35-year repair cycle, and 1 item (imitation stone) in the 40-year repair cycle. Therefore, there are 13 items in total. However, imitation stones were excluded from analysis because their need for repair is low considering their repair cycle is 40 years, while the life cycle of rental houses is 50 years, leaving less than 10 years of use after repair. Furthermore, mailboxes were also excluded from analysis because most of them have been repaired in most rental house complexes. Consequently, the final economic evaluation includes 13 items listed in Table 2.

4. Study Results

In this section, quantitative evaluation results for the economic efficiency of the building interior and exterior materials are presented, which was performed according to the RWLCC analysis model, and the cost of each alternative was calculated on the basis of repair design data and standard estimation data. With the calculated cost of each LCC evaluation item, the quantitative and probabilistic RWLCC analysis values were derived using the MCS method and the HBLCC program. The repair cost of the maintenance aspect was calculated on the basis of the repair cycle (20, 25, 30 years, etc.) that had been deducted for each repair item during the RWLCC evaluation period, and the discount rate was set to 0.045.

For the RWLCC economic analysis of facilities, 38 repair methods of 11 evaluation items for bathroom, entrance, balcony, doors and windows, and remodeling were evaluated among the target areas of items that have changed repair cycles in Table 2. Considering the limited space of this paper, the economic evaluation result for front door floor tiles was presented based on the sequence of parts by the number of repair methods and the redundancy of parts. However, the summary of the final RWLCC economic analysis results used the evaluation results for all target parts.

4.1. RWLCC Economic Analysis Results. RWLCC analyses examining the calculation results for the LCC basic cost of front doors are listed in Table 3, and the economic evaluation results for front doors through the quantitative RWLCC analysis using the MCS method are listed in Table 4.

The analysis result of the cost reduction index for each alternative reviewed was Alt-A 45%, Alt-B 34%, Alt-C 27%,

Table 2: Objects of economic evaluation for changed repair cycle items.

Changed repair cycle	Target part	Economic evaluation item	Reviewed method	Remark
20 years	Bathroom	Bathroom door	2	
		Remodeling	6	Including wall tiles and sanitary ware
		Floor tiles	2	
		Leakage repair	2	Added item
20 years	Entrance	Floor tiles	3	
20 years	Furniture	Shoes cabinet	3	
20 years	Common facilities	Nonslip	5	
25 years	Doors and windows	Front door	6	
		Small room door	4	
		Main room door	3	
		Sliding door (inside, outside)	3	
25 years	Balcony	Floor tiles	4	
30 years	Doors and windows	Small room window	3	
Total number of items		13	46	

Table 3: Cost calculation results for LCC evaluation items of front door considering importance.

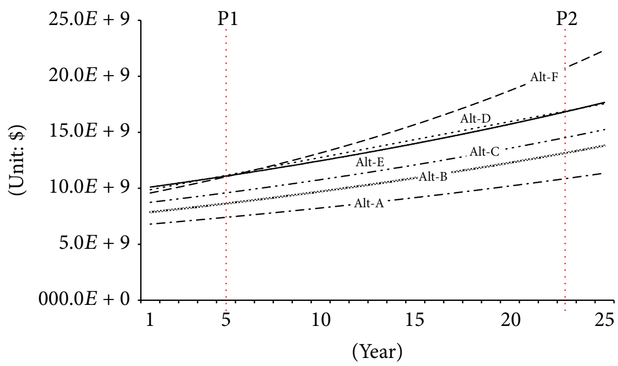
Level-1	Level-2	Analysis results (unit: $)					
		Alt-A	Alt-B	Alt-C	Alt-D	Alt-E	Alt-F (existing)
AE (initial cost)	AE-n01 (design cost)	1,504,976	1,741,242	1,946,508	2,248,530	2,241,069	2,033,340
	AE-n02 (construction cost)	2,652,333	3,068,723	3,430,480	3,962,755	3,949,607	3,583,510
	AE-n03 (management cost)	809,607	936,708	1,047,131	1,209,605	1,205,592	1,093,843
MT (maintenance cost)	MT-n01 (general management cost)	679,706	786,413	879,120	1,015,525	1,012,155	918,336
	MT-n02 (repair cost)	2,206,319	2,552,690	2,853,614	3,296,382	3,285,445	2,980,910
	MT-n03 (daily inspection and diagnosis cost)	328,709	380,313	425,146	491,112	489,483	444,111
		420,058	486,003	543,296	627,594	625,512	567,532
BA (demolition & disposal cost)	BA-n01 (demolition cost)	441,199	510,463	570,639	659,180	656,993	596,095
	BA-n02 (disposal cost)	472,257	546,396	610,808	705,582	703,241	638,056
	Total	9,515,165	11,008,951	12,306,742	14,216,265	14,169,096	12,855,732

Table 4: Economic evaluation result by quantitative RWLCC for front door.

Category	RWLCC analysis result ($)					
	Alt-A	Alt-B	Alt-C	Alt-D	Alt-E	Alt-F (existing)
AE	4,966,916	5,746,673	6,424,120	7,420,890	7,396,268	6,710,692
MT	6,049,484	7,448,710	8,250,814	9,838,452	9,510,216	13,738,294
BA	913,456	1,056,859	1,181,447	1,364,761	1,360,233	1,234,150
RWLCC	11,929,856	14,252,242	15,856,380	18,624,103	18,266,718	21,683,136
CRII	0.45	0.34	0.27	0.14	0.16	0.00
CRI	1.00	1.19	1.33	1.56	1.53	1.82

Alt-E 16%, Alt-D 14%, and Alt-F 0%, in this order. The analysis result of the relative RWLCC index was Alt-F 1.82, Alt-D 1.56, Alt-E 1.53, Alt-C 1.33, Alt-B 1.19, and Alt-A 1.00, in this order. Therefore, Alt-A was the most economical and the conventional method, and Alt-F was most uneconomical, from the RWLCC perspective.

Figure 2 shows the change in the cost curve of front doors estimated with the changed repair cycle of 25 years, which was then analyzed using trend lines. Consequently, the initial cost of Alt-F was slightly lower than those of Alt-D and Alt-E. However, due to the rapid increase of maintenance costs according to interannual variation, it took only about 5 years (P1) for Alt-D and Alt-E to share the same RWLCC cost, and in 25 years, a cost gap of about 15% or more is generated on average. Although Alt-D and Alt-E showed little difference during the maintenance stage, similar trends were observed in most sections, and the cost flow becomes almost identical after about 23 years (P2).



Alt-A: $y = 7E + 09e0.0213x$, $R^2 = 0.9702$
Alt-B: $y = 8E + 09e0.0234x$, $R^2 = 0.9793$
Alt-C: $y = 9E + 09e0.0231x$, $R^2 = 0.9773$
Alt-D: $y = 3E + 08x + 1E + 10$, $R^2 = 0.9779$
Alt-E: $y = 1E + 10e0.0233x$, $R^2 = 0.981$
Alt-F: $y = 9E + 09e0.0353x$, $R^2 = 0.9867$

Figure 2: Changing trends of maintenance cost according to the LCC of front door.

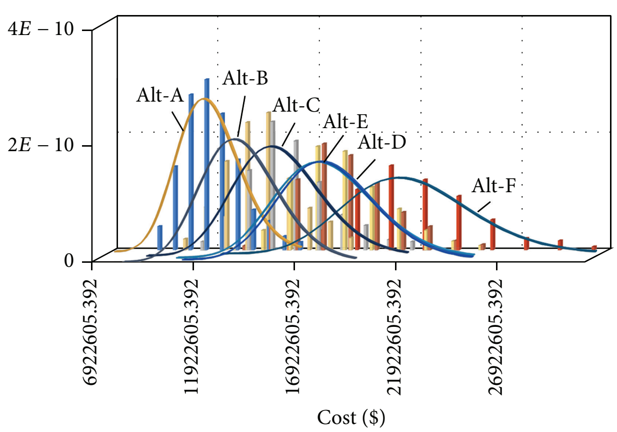


Figure 3: Results of probabilistic RWLCC PDF analysis of front door.

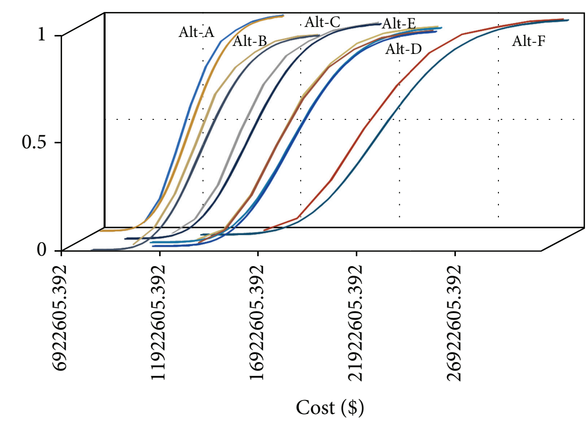


Figure 4: Results of the probabilistic RWLCC CDF analysis of front door.

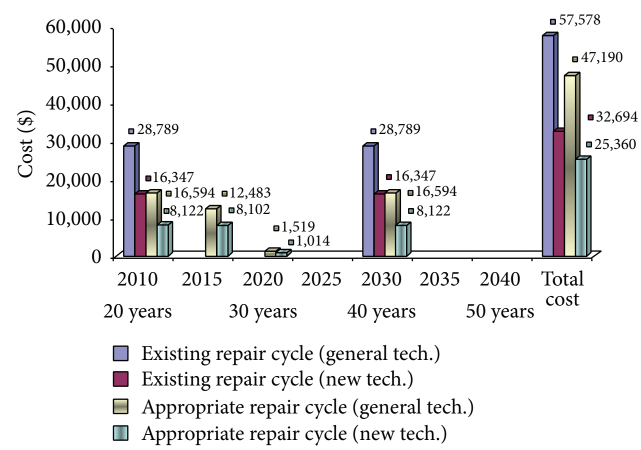


Figure 5: Comparison of replacement cost between conventional repair cycle and the changed repair cycle.

The results of probabilistic cost distribution simulations (repetition of 1,000 times) based on the weight value according to the LCC cost, and risk for probabilistic RWLCC analysis of front doors by the MCS method, are shown in Figures 3 and 4.

The reliability of the overall probabilistic cost distribution was the highest in Alt-A, followed by Alt-B, Alt-C, Alt-E, Alt-D, and Alt-F. Especially for Alt-A, with an average RWLCC cost of 11.9 million dollars, the cost distribution to the left and right is about 5 million dollars based on a 95% confidence level. For Alt-F, with an average RWLCC cost of about 21.7 million dollars, the cost distribution to the left and right is about 7.5 million dollars. This analysis result suggests that when the conventional method Alt-F is applied, the cost may be a minimum of 14.2 million dollars, which is an optimistic estimation. However, it may be as much as 29.2 million dollars. Therefore, the conventional method Alt-F has a higher degree of economic risk compared to its alternatives.

4.2. Summary of Economic Analysis. The analysis results for the repair costs of the conventional 20-year repair cycle and the replacement costs of the changed repair cycle for unit households (based on 43 m^2 apartment house at Beon-dong Complex 3 in Seoul) are summarized in Table 5.

The result of the repair cost analysis revealed that as the repair cycle increased, the overall cost of the changed repair cycle increased by an average of about 15% (25 years 12.3%, 30 years 17.9%) compared to the conventional repair cycle (20 years) in the short term. This is because although the construction cost of each household did not change with the increased repair cycle, the maintenance cost nonetheless increased owing to accelerated degradation for the corresponding period.

4.3. Analysis of Replacement Cost Until the Demolition of Permanent Rental Housing. The results comparing replacement costs according to the elapsed years after move-in, the conventional 20-year repair cycle, and the changed repair cycle are shown in Table 6 and Figure 5.

If the 13 items of building interior and exterior materials were replaced with the conventional 20-year repair cycle

Table 5: Summary of economic evaluation results for changed repair cycle items (11,912 households).

Target part	Evaluation item	Repair cost ($) Conventional repair cycle (20 years) Conventional method	Conventional repair cycle (20 years) Optimal repair method	Changed repair cycle Conventional method	Changed repair cycle Optimal repair method	Changed repair cycle
Bathroom	Bathroom door	9,177,682	9,045,596	9,177,682	9,045,596	20 years
	Remodeling	94,160,923	37,830,237	94,160,923	37,830,237	
	Floor tiles	9,171,350	3,222,461	9,171,350	3,222,461	
	Leakage repair	29,810,096	21,052,841	29,810,096	21,052,841	
Entrance	Floor tiles	7,583,282	1,363,654	7,583,282	1,363,654	20 years
Furniture	Shoes cabinet	10,325,546	3,759,725	10,325,546	3,759,725	20 years
Common facilities	Nonslip	37,436,002	20,472,941	37,436,002	20,472,941	20 years
Subtotal	7	197,664,881	96,747,455	197,664,881	96,747,455	20 years
	Unit household	16,594	8,122	16,594	8,122	
Doors and windows	Front door	19,388,825	10,771,419	21,683,136	11,929,856	25 years
	Small room door	13,946,158	7,240,455	15,565,849	7,697,631	
	Main room door	23,211,581	15,229,820	25,653,258	16,850,550	
	Sliding door (in)	31,763,774	25,203,459	35,714,809	28,210,563	
	Sliding door (out)	33,421,573	25,181,692	39,775,803	27,847,046	
Balcony	Floor tiles	8,689,724	3,587,109	10,305,476	3,972,786	25 years
Subtotal	5	130,421,635	87,213,954	148,698,331	96,508,432	25 years
	Unit household	10,949	7,322	12,483	8,102	
Doors and windows	Small room window	14,848,889	10,767,672	18,097,917	12,080,971	30 years
Subtotal	1	14,848,889	10,767,672	18,097,917	12,080,971	30 years
	Unit household	1,247	904	1,519	1,014	
Total repair cost	13	342,935,405	194,729,081	364,461,129	205,336,858	—
	Unit household	28,789	16,347	30,596	17,238	

Table 6: Comparison of conventional repair cycle and changed repair cycle per unit household (unit: $).

Year		1990	1995	2000	2005	2010	2015	2020	2025	2030	2035	Total replacement cost	Cost reduction rate
Elapsed time after move-in (years)		Initial move-in	5 years	10 years	15 years	20 years	25 years	30 years	35 years	40 years	45 years		
Conventional repair cycle	Conventional method	—	—	—	—	28,789	—	—	—	28,789	—	57,578	
	Optimal method	—	—	—	—	16,347	—	—	—	16,347	—	32,694	43.2%
Changed repair cycle	Conventional method	—	—	—	—	16,594	12,483	1,519	—	16,594	—	47,190	18.0%
	Optimal method	—	—	—	—	8,122	8,102	1,014	—	8,122	—	25,360	56.0%
Cost of conventional repair cycle (20 years)												57,578	
Profit from the changed repair cycle												10,388	
Profit from the application of the optimal method												24,884	
Profit from the simultaneous application of the repair cycle and optimal method												32,218	

Table 7: Comparison of replacement cost according to the change of repair cycle and the application of optimal method (unit: $).

Division	Cost per unit household	Total repair cost	
		Households that passed 20 years (11,912 in total)	Total permanent rental houses (140,078 in total)
Cost of conventional repair cycle (20 years)			
Conventional method	57,578	685,870,810	8,065,430,834
Optimal method	32,694	389,458,158	4,579,795,157
Cost of changed repair cycle			
Conventional method	47,189	562,126,010	6,610,265,886
Optimal method	25,359	302,084,313	3,552,331,013

until the demolition of the building (50 years), about 57,578 dollars is required per household (based on 43 m^2 house). On the other hand, the conventional changed repair cycle saved 10,338 dollars or about 18.0% compared to the conventional repair cycle.

Furthermore, when the optimal method was applied to the conventional repair cycle, 24,884 dollars or 43.2% was saved. In particular, when the changed repair cycle and optimal method were applied simultaneously, a high amount of 32,218 dollars or about 56% of the conventional method was saved.

The expected costs if 13 items of building interior and exterior materials were repaired or replaced until 2040 (50 years after move-in) in permanent rental houses 20 years or older, from 2010 onward (11,912 households in 9 complexes across the country), are shown using the changed repair cycle in Table 7.

The expected replacement cost is presented based on 43 m^2 houses at Beon-dong Complex 3 in Seoul, as compared to 40 m^2, 46 m^2, 53 m^2, and other types of houses. In order to obtain more accurate estimations of 11,912 households, the data for all types of the 11,912 households must be analyzed. However, in this economic analysis, the following method was used to obtain rough estimations.

As a result of the analysis, when the changed repair cycle was applied to permanent rental houses (11,912 in total) 20 years or older in 9 complexes across the country before demolition, a cost of about 123.7 million dollars would be saved by the changed repair cycle, and about 383.8 million dollars would be saved when the optimal repair method was applied to the changed repair cycle.

Furthermore, if all permanent rental houses (140,078 in total) were considered, a cost of about 1,455.1 million dollars would be saved by the changed repair cycle, and about 4,513.0 million dollars would be saved when the optimal repair method was applied to the changed repair cycle.

5. Conclusion

An economic analysis was conducted using the RWLCC method for life cycle cost analysis of repair methods applied to repairs using the resetting result of optimal repair cycles for interior facilities among architectural facilities of apartment houses. The conclusions of this study are outlined below.

(1) As a result of cost analysis based on the changed repair cycle for a 25-year-old front door, it took only 5 years for alternative F to consume the same RWLCC cost as those of alternatives D and E owing to the rapid increase of maintenance costs compared to the initial cost. After 25 years, the cost disparity was at least 15% on average.

(2) Alternative A had a cost distribution of about 5 million dollars to the left and right based on 95% confidence level with about 11.9 million dollars of the average RWLCC cost. On the other hand, alternative F had a cost distribution of about 7.5 million dollars to the left and right based on 95% confidence level with about 21.7 million dollars of the average RWLCC cost.

(3) As a result of the economic analysis involving LCC's application of the optimal repair/replacement methods, when only the repair cycle was considered, the replacement cost of the conventional 20-year repair cycle for 11,912 households in 9 complexes is about 685.9 million dollars, and it was about 562.1 million dollars for the changed repair cycle, resulting in an economic benefit of about 123.7 million dollars (about 18.04%).

(4) When the changed repair cycle and the optimal repair method were applied simultaneously, a smaller replacement cost of about 302.1 million dollars would be spent, resulting in an economic benefit of about 383.8 million dollars (55.95%).

(5) When the data was calculated based on all the current permanent rental houses of KLHC (140,078 households in 126 complexes across the country), the economic benefit owing to the changed repair cycle was roughly 1,455.2 million dollars (about 18.04%).

(6) When the changed repair cycle and the optimal method were applied simultaneously, the total expenditure was about 3,552.3 million dollars, an economic benefit of about 4,513.1 million dollars (about 55.95%).

In the future, the results of this study could be used to select a repair method for the repair and replacement of architectural facilities of rental houses. Test works and monitoring of the repair and replacement method for each part will be performed, and the optimal repair and replacement method that is appropriate for permanent rental house facilities will be applicable through the presentation and use of evaluation criteria considering the penetration, economic efficiency, livability, and usability of rental houses.

Competing Interests

The authors declare that they have no competing interests.

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References

[1] M. Amerigo and J. I. Aragones, "A theoretical and methodological approach to the study of residential satisfaction," *Journal of Environmental Psychology*, vol. 17, no. 1, pp. 47–57, 1997.

[2] Housing Act, Article 47, Long-term Repair Plan, Revised on 2009.

[3] J.-H. Kang, "A Study on the Residential Environments of the Permanent Rental Housings—focused on the Busan area," *Korean Association for Housing Policy Studies, Housing Studies Review*, vol. 23, no. 1, pp. 79–101, 2015.

[4] B.-J. Han, *A study of long-term repair plan for maintenance of apartment housing [M.S. thesis]*, Kyunghee University Graduate School, 2003.

[5] I. M. Shohet and I. Galil, "Decision support system for waterproofing of below-grade structures," *Computer-Aided Civil and Infrastructure Engineering*, vol. 20, no. 3, pp. 206–220, 2005.

[6] S.-M. Choi, S.-K. Oh, and C.-H. Seo, "Construction of evaluation system for selecting an appropriate waterproofing method for the roof of a building," *Canadian Journal of Civil Engineering*, vol. 39, no. 8, pp. 1–11, 2012.

[7] S. Dell'Isola and I. Kirk, *Life Cycle Costing for Design Professionals*, McGraw-Hill, 1981.

[8] R. Heijungs, *Environmental Life Cycle Assessment of Products—Guide and Backgrounds*, CML, Leiden University, Leiden, The Netherlands, 1992.

[9] S.-K. Kim, H.-S. La, and C.-H. Han, "A study on the systemization of the long-term maintenance plan of apartment buildings," *Journal of the Architectural Institute of Korea, Structure & Construction*, vol. 19, no. 1, pp. 111–118, 2003.

[10] B.-J. Han, T.-H. Kim, S.-K. Kim, and C.-H. Han, "A study of long-term repair plan for maintenance of apartment housing," *Korean Journal of Construction Engineering and Management*, pp. 355–358, 2002.

[11] K.-H. Lee, "Preliminary study on the coordination of the repair works' items of the long term repair plan in apartment housing," *Journal of the Korean Housing Association*, vol. 27, no. 4, pp. 13–22, 2016.

[12] S.-I. Yoo, *A study on the prediction of required total costs and avoidable costs of a high-rise apartment building using LCC technique [M.S. thesis]*, Chung-Ang University Graduate School, Seoul, Republic of Korea, 2000.

[13] M. Ehlen and H. Marshall, *The Economics of New-technology Materials: A Case Study of FRP Bridge Decking*, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Md, USA, 1996.