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Selection of the Optimal Waterproofing Methods for the Rooftops of Domestic Multi-Family Housing Projects

Hyun-Seok Moon
(Ph.D. Student, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Sang-Gab Kim
(Ph.D. Candidate, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Hae-Gon Kim
(M.S. Student, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Chang-Taek Hyun
(Professor, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Kyo-Jin Koo
(Associate Professor, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Tae-Hoon Hong
(Assistant Professor, Department of Architectural Engineering, Univ. of Seoul, Seoul, Korea)

Abstract
Various efforts have recently been exerted to reduce the whole life cycle costs of facilities in the construction industry. Moreover, as the domestic (South Korea) construction market is now open and as the value engineering system has been activated, the importance of economic-efficiency assessment through Life Cycle Cost (LCC) analysis has largely increased. Since rooftops are exposed to the atmosphere and are directly affected by rainwater, the waterproof performance of the rooftop largely affects the service life and maintenance cost of a building. This study thus aimed to analyze the economic aspect of the waterproofing method applied to domestic multi-family houses through LCC analysis, and to select the optimal waterproofing method for the rooftops of domestic multi-family houses, taking into account important technological and social impact factors as well as economic considerations.

Keywords
Waterproof, LCC, Sensitivity Analysis, Monte-Carlo Simulation

1. Introduction

The "best value" concept, which has recently been introduced in the building industry, has spread worldwide and has successfully displaced the cost concept. As such, various improvement works aimed at reducing LCC incurred from the design, construction, and maintenance of facilities are being undertaken in many aspects. Moreover, as the domestic construction market is now open and as the value engineering

system has been activated, economic-efficiency evaluation through LCC analysis is becoming increasingly important in the domestic construction industry.

The rooftop is one of the most sensitive parts of a building as it is always exposed to the atmosphere. When it rains or snows, the rainwater or snow is bound to remain on the rooftops of buildings. Furthermore, if waterproofing is not properly done on the rooftop, water will leak to the interior part of the building through the cracks that may emerge in the rooftop owing to the fact that concrete expands or shrinks according to the temperature. This reduces the lifetime of the building and causes large repair and maintenance costs to be incurred. As such, the waterproofing method to be employed on the rooftop can determine, to a certain extent, the repair and maintenance costs of a building.

This study thus aimed to consider the costs of the waterproofing method employed on rooftops through LCC analysis, which is applied to domestic multi-family housing projects. The study also aimed to select the optimal waterproofing method that can be employed on the rooftops of domestic multi-family houses taking into account economic and non-economic factors, especially technological and social considerations.

2. Research Framework

In this study, LCC analysis and economic-efficiency evaluation of the non-exposed waterproofing methods employed by the public sector in charge of domestic multi-family housing projects on the rooftops of domestic multi-family houses were conducted. The methods that were used in the study were as follows.

First, the procedures to be followed in the LCC analysis and economic-efficiency assessment of the waterproofing methods applied to the rooftops of domestic multi-family houses were determined, and an LCC analysis model was developed.

Second, an economic-efficiency assessment of the waterproofing methods applied to the rooftops of domestic multi-family houses was conducted through LCC analysis, and the technological and social factors that must be considered in such analysis, among non-economic factors, were deduced.

Third, in determining the optimal waterproofing method for the rooftops of domestic multi-family houses, economic, technological, and social considerations were taken into account.

3. LCC Analysis Models of Waterproofing Methods Employed on Rooftops

3.1 Analysis Procedure

In this study, the procedure that was used for the LCC analysis of the waterproofing method applied to the rooftops of domestic multi-family houses was analyzed, as follows. An alternative for the analysis was selected, and data on the initial cost, the repair and replacement cost, and the dismantlement cost, the cost items for the LCC analysis, were collected and analyzed. After formulating assumptions regarding the life of the building, the discount rate, etc., LCC analysis was conducted on the two alternatives using the present worth method. To factor the uncertainty of future prices, sensitivity analysis was conducted on the assumptions and the cost items, and the changes in the results of the LCC analysis due to the uncertainty of the data were analyzed. Through consultation with experts, the technological and social impact factors were analyzed, and the optimal waterproofing method to be applied to the rooftops of domestic multi-family houses was determined by comprehensively evaluating all the economic and non-economic factors concerned.

3.2 Development of an LCC Analysis Model

3.2.1 Selection of analysis subject

Waterproofing is aimed at stopping rainwater from leaking into the interior of a building. When selecting a waterproofing method, one must exercise caution in selecting the materials to be used so that the waterproofing would last long, thereby enabling one to save on maintenance costs. In general, waterproofing is classified according to the construction areas and the waterproofing methods employed. The waterproofing methods dealt with in this study are as follows:

Asphalt compound waterproofing method: This method is generally known as "built-up roofing." As its name connotes, it forms a roof that will serve as a waterproof layer. It is generally done by coating a roof with layers of asphalt.

Rubberized bitumen emulsion waterproofing method: This waterproofing method utilizes a high-density rubberized asphalt made of natural and synthetic rubes (neoprene butadiene rubber or styrene butadiene rubber) and asphalt. It has superior temperature susceptibility and elasticity.

Rubberized bitumen sheet waterproofing method: This waterproofing method involves making sheets by attaching asphalt, which nature has improved by mixing polymers like synthetic rubber with the asphalt felts, to the roof. It is weather-resistant and adhesive.

3.2.2 Selection of LCC cost items

To select the cost items for the LCC analysis of rooftop waterproofing methods, the 2006 Construction Cost Data was used, as well as the unit price per ㎡ as of February 2006. The cost items for the LCC analysis were the initial cost, the repair and replacement cost, and the dismantlement cost. Besides these, the energy expenses, taxes, insurances, financial costs, etc. incurred in the construction of the houses were also considered in the LCC analysis. However, since these cost items were not applicable to the analysis subject (the waterproofing method), they were excluded from the study.

3.2.3 Establishment of assumptions

Real discount rate was used to convert the value of money into its value at a given time so as to objectively compare the values of different currencies at different times in the cost analysis, which takes into account various complex factors like the earning rate of the government bond, the market interest rate, the price increase, etc. For the nominal interest rate, which is needed to determine the real discount rate, the treasury bond interests were applied. It was determined that the nominal interest rate was 5.6% on average between January 2000 and February 2006. For the inflation rate, the average consumer price index of 4.5% between January 2000 and February 2006 was applied. For the real discount rate, 1.1% was applied according to the following equation:

$$i = \frac{(1+i_n)}{(1+f)} - 1$$

(i: Real Discount Rate i_n: Nominal Discount Rate f: Inflation Rate)

For purposes of analysis, the life of a domestic multi-family house was set at 50 years in this study, and the following maintenance rates and maintenance periods as shown in Table 1 were applied according to the enforcement regulations of the Housing Act.

Table 1: Maintenance Rates and Periods

Classification	Asphalt Compound Waterproofing		Rubberized Bitumen Emulsion Waterproofing		Rubberized Bitumen Sheet Waterproofing	
	Repair	Replacement	Repair	Replacement	Repair	Replacement
Maintenance Period	8 years	20 years	5 years	15 years	8 years	20 years
Maintenance Rate	10%	100%	10%	100%	20%	100%

3.2.4 LCC analysis

An LCC analysis of the rooftop waterproofing method employed for domestic multi-family houses was conducted based on the cost data secured, the analysis period and discount rates, and the initial cost. The repair/replacement costs for the period of 50 years, and the dismantlement costs, were analyzed after these were converted into their values as of February 2006.

3.2.5 Sensitivity analysis

Although the asphalt compound, rubberized bitumen emulsion, and rubberized bitumen sheet waterproofing methods have been around for 25, 15, and 20 years, respectively, since the life of a domestic multi-family house was assumed to be 50 years in this study, the changes over 50 years in the subject of the sensitivity analysis were considered. The discount rate can be unpredictably changed according to the price increase, etc., and the repair/replacement costs, dismantlement costs, etc. can be changed according to the market price or the development of a new technology or a new waterproofing method. Therefore, sensitivity analysis was performed on the analysis subject considering the analysis period, discount rate, repair/replacement costs, and dismantlement costs. Monte-Carlo simulation (MCS), a statistical-analysis method for uncertainty, was used for this purpose.

3.2.6 Selection of the optimal waterproofing method

The technological and social considerations that must be taken into account in the selection of the optimal method for waterproofing the rooftops of domestic multi-family houses, besides economic factors, were identified after consultation with experts. Then the general optimal waterproofing method was determined through matrix evaluation, giving weight to the technological and social impact factors affecting the efficiency of the method which were identified through the LCC analysis, and to economic efficiency.

4. Case Application of the LCC Analysis Model

4.1 Assessment of Economic Efficiency through LCC Analysis

4.1.1 Collection of data by cost items

The cost items for the LCC analysis of the waterproofing methods employed on the rooftops of domestic multi-family houses were drawn based on the 2006 Construction Cost Data. The cost items by alternatives are arranged in Table 2.

Table 2: Cost Items by Alternatives

(Unit: $/㎡)

Classification (as of USD on February 1, 2006)		Asphalt Compound Waterproofing	Rubberized Bitumen Emulsion Waterproofing	Rubberized Bitumen Sheet Waterproofing
Initial Cost		81.80	59.56	77.47
Maintenance Cost	Partial Replacement	9.47	11.91	9.01
	Entire Replacement	81.80	59.56	77.47
Dismantlement Cost	Dismantlement Cost	22.59	22.35	22.36

4.1.2 Establishment of assumptions

To formulate assumptions for the LCC analysis conducted in this study, the real discount rate was set at 1.1%, using the treasury bond rate and the consumer price index between January 2000 and February 2006 for the purpose, as mentioned in 3.2.3. The life of the domestic multi-family house was set at 50 years.

4.1.3 Integration of the cost

Based on the results of the LCC analysis, which were obtained by converting the cost data by items and assumptions as of February 2006, it was found that the maintenance costs of the rubberized bitumen sheet and the rubberized bitumen emulsion waterproofing methods, whose initial costs were small, were less than those of the asphalt compound waterproofing method. However, as the break-even point of the subject houses will yet occur between 2043~2044, in which year the domestic multi-family houses will have turned 39 or 40 years old, it was found, from an economic perspective, that the asphalt compound waterproofing method is the most efficient waterproofing method for the rooftops of domestic multi-family houses. The LCC analysis result according to the service life change and by year are as shown in Figure 1 and Table 3 repectively.

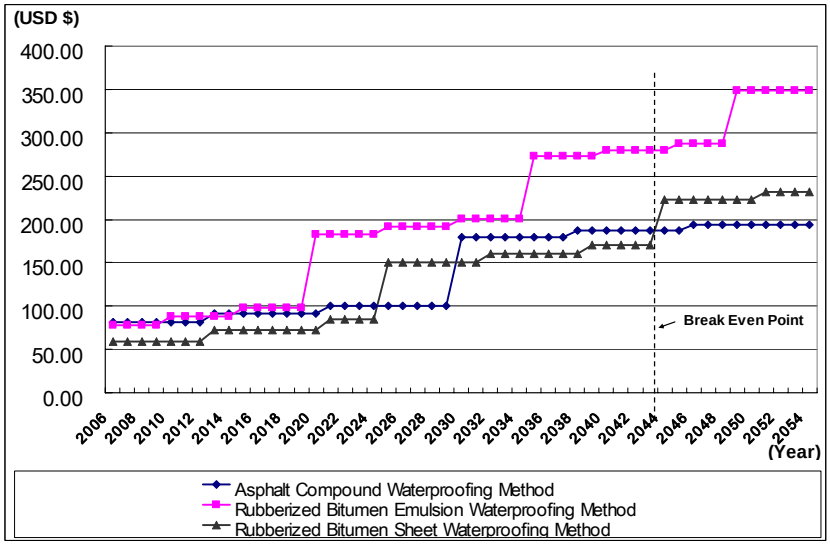

Figure 1: LCC Analysis Result According to the Service Life Change

Table 3: LCC Analysis Results by Year

(Unit: $/㎡, as of USD on February 1, 2006)

Year	Asphalt Compound Waterproofing	Rubberized Bitumen Emulsion Waterproofing	Rubberized Bitumen Sheet Waterproofing	Year	Asphalt Compound Waterproofing	Rubberized Bitumen Emulsion Waterproofing	Rubberized Bitumen Sheet Waterproofing
2006	81.80	77.47	59.56	2031	179.54	200.52	150.22
2007	81.80	77.47	59.56	2032	179.54	200.52	160.75
2008	81.80	77.47	59.56	2033	179.54	200.52	160.75
2009	81.80	77.47	59.56	2034	179.54	200.52	160.75
2010	81.80	88.12	59.56	2035	179.54	272.42	160.75
2011	81.80	88.12	59.56	2036	179.54	272.42	160.75
2012	81.80	88.12	59.56	2037	179.54	272.42	160.75
2013	91.37	88.12	72.52	2038	186.74	272.42	160.75
2014	91.37	88.12	72.52	2039	186.74	272.42	170.40
2015	91.37	98.21	72.52	2040	186.74	280.01	170.40
2016	91.37	98.21	72.52	2041	186.74	280.01	170.40
2017	91.37	98.21	72.52	2042	186.74	280.01	170.40
2018	91.37	98.21	72.52	2043	186.74	280.01	170.40
2019	91.37	98.21	72.52	2044	186.74	280.01	223.28
2020	91.37	182.93	72.52	2045	186.74	287.20	223.28
2021	100.13	182.93	84.40	2046	193.33	287.20	223.28
2022	100.13	182.93	84.40	2047	193.33	287.20	223.28
2023	100.13	182.93	84.40	2048	193.33	287.20	223.28
2024	100.13	182.93	84.40	2049	193.33	348.21	223.28
2025	100.13	191.97	150.22	2050	193.33	348.21	223.28
2026	100.13	191.97	150.22	2051	193.33	348.21	231.74
2027	100.13	191.97	150.22	2052	193.33	348.21	231.74
2028	100.13	191.97	150.22	2053	193.33	348.21	231.74
2029	100.13	191.97	150.22	2054	193.33	348.21	231.74
2030	179.54	200.52	150.22	2055	193.33	348.21	231.74

4.1.4 Sensitivity analysis

To find out the variability of the cost data and assumptions, and of the changes in the analysis results due to uncertainty, sensitive analysis was conducted through MCS. Since the initial costs, repair/replacement costs, and dismantlement costs were determined in the form of equipment or construction contracts, their features resemble the distribution form of the construction business cost. As such, these were assumed in Beta distribution (Spooner et al. 1974), and the variation range was assumed to be ±5%, reflecting the characteristics of the construction market price, which responds sensitively to the internal and external environment.

The analysis period was presumed to be at least 35 years and at most 55 years, reflecting the reconstruction period of current domestic multi-family houses, and this was set as triangular distribution when it was assumed that the reconstruction will be done some time between 40 and 45 years after the houses' construction. Since the discount rate is largely affected by the inflation rate and the interest rate, it was assumed, based on normal distribution, according to the historical data in this study. The variables and ranges that were set for the sensitivity analysis are as shown in Table 4.

Table 4: Setting of Sensitivity Analysis Variables

Classification		Distribution Type	Variation Range
Cost Items	Initial cost	Beta distribution	±5%
	Repair cost	Beta distribution	±5%
	Replacement cost	Beta distribution	±5%

	Dismantlement cost	Beta distribution	±5%
Assumptions	Analysis period	Triangular distribution	35~55 years
	Discount rate	Normal distribution	Standard deviation: 3%

After 50,000 simulation trials were conducted, in which each variable was set according to the Table 4, the results of the sensitivity analysis of the three waterproofing methods were found as shown in Figure 2.

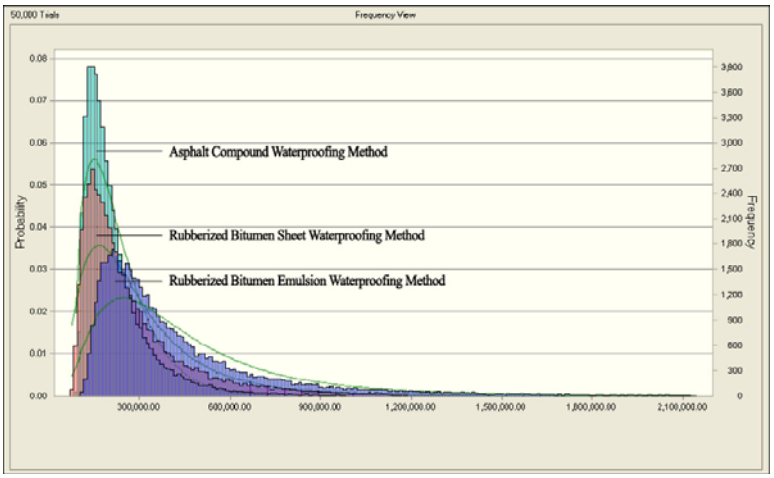

Figure 2: Monte-Carlo Simulation Results

Based on the results of the study, it was found that the rubberized bitumen emulsion and rubberized bitumen sheet waterproofing methods have a higher probability of having higher LCC compared to the asphalt compound waterproofing method.

4.2 Selection of the Optimal Waterproofing Method Considering Technological and Social Factors

4.2.1 Deduction of technological and social factors

It was found from the LCC analysis that the asphalt compound waterproofing method is the most superior waterproofing method for the rooftops of domestic multi-family houses, from an economic perspective. However, as the break-even point of the domestic multi-family houses that are the subject of this study is expected to be reached between 2043 and 2044 still, in which year these houses will have been 39 or 40 years old, if reconstruction will be done when the houses are already around 40 years old, it will be difficult to cite its difference from the asphalt compound and rubberized bitumen sheet waterproofing methods in terms of economic efficiency. Thus, in this study, technological and social factors were considered in the selection of the waterproofing method that is most appropriate for the rooftops of domestic multi-family houses. The analysis was made through consultation with 13 experts on waterproofing methods. It was found that the most important factors to be considered when selecting the waterproofing method to be used for the rooftops of domestic multi-family houses are the protection function of the concrete, the reliability of the waterproofing method, and its field applicability and environment-friendliness.

4.2.2 Comprehensive evaluation of economic efficiency and non-economic factors

To deduce the optimal waterproofing method for the rooftops of domestic multi-family houses, weights for the four deduced impact factors and for economic efficiency, which were identified through the LCC analysis, were given through consultation with interviewees. The results of the research were also considered in the selection of the optimal waterproofing method for the rooftops of domestic multi-family houses, using the matrix evaluation method. Based on the comprehensive evaluation results, the highest

weights were given to economic efficiency and field applicability, and since it was found that the asphalt compound waterproofing method is superior to the rubberized bitumen sheet waterproofing method economically and in terms of the non-economic technological and social factors, as shown in Figure 3, it was concluded that the asphalt compound waterproofing method is the optimal waterproofing method for the rooftops of domestic multi-family houses.

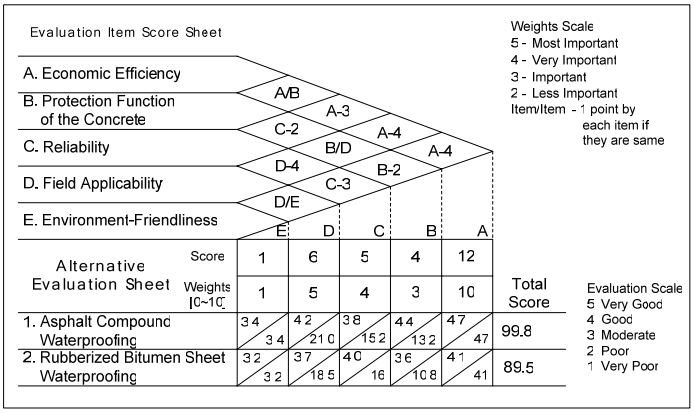

Figure 3: Alternative Evaluation Sheet of Non-Economic Factor

5. Conclusion

Since rooftops are exposed to the atmosphere all the time and are directly affected by rainwater and snow, its waterproof performance may be considered an important factor in determining the life of a building. Therefore, in this study, the economic aspects of the asphalt compound, rubberized bitumen emulsion and rubberized bitumen sheet waterproofing methods, among various waterproofing methods for rooftops, were analyzed, and technological and social impact factors were considered. It was then determined that the asphalt compound waterproofing method is the optimal waterproofing method for the rooftops of domestic multi-family houses.

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