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Article

Optimal model for selection of material with low emission of indoor air pollutants

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Abstract: When the amount of data to be reviewed is large and the properties of the material are complex, it is difficult to make a rational decision in selecting the optimal material. Therefore, in this study, we tried to develop an optimization model that comprehensively considers user requirements, performance and economic feasibility of materials for selecting materials with low emission of indoor air pollutants. To this end, a database was constructed considering the economic feasibility by applying the concept of LCC (Life Cycle Cost) and presenting price range options that can be selected by the user. A genetic algorithm was used to construct a model to derive a material plan that could achieve the target score while satisfying economic feasibility and user requirements. As a result of model verification and verification cases, materials were selected only within the range according to the price range option and user selection criteria for each space and part. The efficiency and effectiveness of this model were confirmed. In this study, reliable results can be presented by presenting a model that can automatically select an algorithm for the optimal preferred material selection problem that is difficult for humans to solve cognitively with database construction and user selection information. Since it can be used in other fields, scalability and usability of this model are expected. In addition, it helps user to reduce the time of the material selection process and the price of materials is also considered, so that it is expected to help improve the economic feasibility of overall construction.

Keywords: material selection; user-choice-based; optimal preferred materials; genetic algorithm; economic feasibility

1. Introduction

The COVID-19 pandemic has led to a reduction in outdoor activities and an increase in the time spent indoors, raising interest in indoor environments. Consequently, the selection of economically feasible low-emission building materials has become important. Practical constraints, such as functional and economic factors, complicate the process of selecting materials in the construction industry, making the prioritisation of various criteria difficult. To address this cognitive challenge, a selection tool for optimal materials is required in scenarios with multiple materials and properties. Thus, the aim of this study was to develop an economic evaluation model for selecting optimal preferred materials based on user choice.

The research methodology is shown in **Figure 1**. This involves constructing a low-emission material database for indoor pollutants, utilising the life cycle cost (LCC) method as an economic evaluation method, and applying a genetic algorithm (GA) as an optimising method. LCC is a calculation method that assesses the total cost of an asset over its life cycle including initial cost, maintenance cost and operating cost. As shown in **Figure 2**, model verification targets new office buildings under the Green

Standard for Energy and Environmental Design (G-SEED) guidelines which certifies the environmental performance of buildings in Korea. The verification procedure considers the economic feasibility, the performance of materials selected for indoor construction, and whether the materials meet the requirements of the G-SEED as described in the G-SEED certification item named '7.1. Application of Indoor Air Pollutant Low-Emitting Material' in '7. Indoor environment' (hereafter referred to as 'G-SEED certification item').

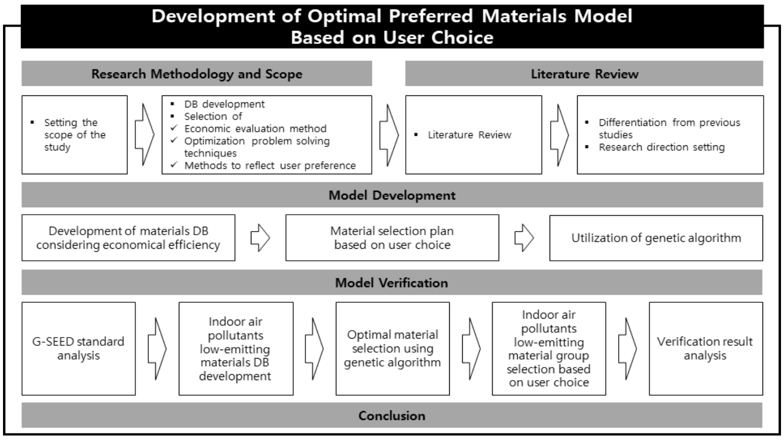


Figure 1. Research process.

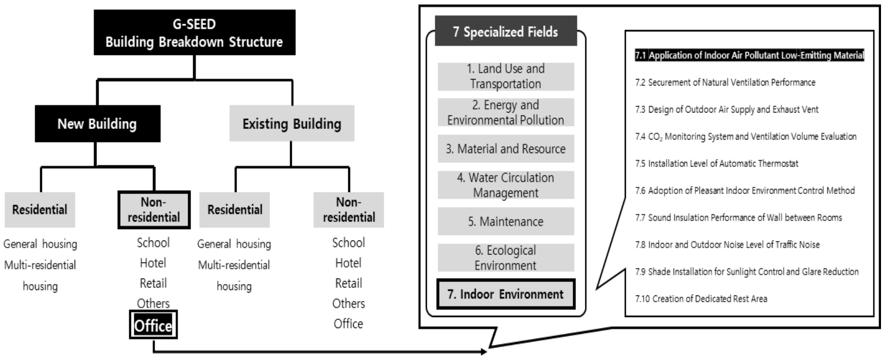


Figure 2. Research verification scope.

2. Literature review

Research areas related to the topic of this study have been explored in several studies. Some studies have presented information document-management prototype systems that can select materials based on index calculations or surveys and manage them efficiently (Kim et al., 2008; Mathiyazhagan et al., 2019; Kwon et al., 2010; etc.). In terms of scoring materials for G-SEED certification, Lee et al. (2014) presented a scoring methodology using an analytical hierarchy process. Hwang et al. (2016), Kim et al. (2015), and Wang and Tae (2018) emphasized the need for green building application technology, certification criteria, and material selection models. Other studies have presented implications for evaluation criteria from social, environmental, and economic viewpoints for the evaluation of green buildings in terms of economic feasibility along with quantitative values (Lee 2014; Lee and Lee, 2017). Kim et al. (2005), Josefin et al. (2019), and Kim et al. (2007) highlighted the importance of using environmentally friendly finishing materials for improving indoor air quality.

Among previous studies, Lee et al. (2014) suggested a new methodology for allocating points for each of the 7 specialized fields of green building certification using the AHP (Analytic Hierarchy Process) pairwise comparison method (which stratifies the evaluation criteria and compares them with each other), but this only mentioned points for each specialized field and couldn't suggest the methodology for detailed point allocation for each specialized field. Lee (2014), Lee and Lee (2017) presented only implications for the evaluation criteria for materials with low emission of indoor air pollutants, but failed to present a practically usable model. In addition, Hwang et al. (2016), Kim et al. (2015), Wang and Tae (2018) not only provided databases for the management of building materials, so that they couldn't play a role in automatically selecting the optimal material using an algorithm. In order to practically apply materials to buildings, it is necessary to be able to select materials intuitively by reflecting user requirements. Therefore, in this study, the concept of life cycle cost was applied to material prices and user requirements were reflected, finally an optimal material selection model using genetic algorithm was presented to differentiate it from previous studies.

3. Model development

3.1. Database and material selection method

The construction industry would benefit immensely from having a material database that considers the complete lifecycle of construction materials. In this study, the present worth method was utilised to calculate the final LCC of materials; the initial price information of the material was set as the initial cost, and replacement and maintenance costs were added later.

Materials can be classified into material groups, that is, sets of similar materials. In this study, various price ranges for material groups were set to allow users to select the final materials within the group corresponding to their preferred price range. Furthermore, orderer requirements and designer intentions are important when selecting materials. However, previous studies in which the current situation of practitioners in charge of material selection was surveyed did not report any standard material selection procedures, guidelines, or direct support tools. Furthermore, most designers ultimately proposed appropriate alternative materials by considering the recommendations of knowledgeable employees of material suppliers. Selecting materials in this manner has certain limitations: the designer cannot acquire detailed information regarding the materials, and the orderer or designer cannot directly select the materials. Thus, a support tool that allows users to directly evaluate the performance of materials during the selection process needs to be developed.

The selection of materials as per user choice refers to the selection of one particular material group among two or more material groups based on user specifications. **Table 1** presents the material selection method based on user choice; this consists of material selection criteria, selection criterion characteristics, and user scores (input values). Material selection criteria (A, B, C, D, and E) are applicable for selecting a preferred material group by comparing material groups a and b. Selection criterion characteristics correspond to characteristics depending on the selection criteria of material groups a and b. For example, selection criterion A is more appropriate when selecting material group, a than material group b, where the selection criterion characteristic is ‘a > b’. Conversely, selection criterion D is more appropriate when selecting material group b than material group a, where the selection criterion characteristic is ‘a < b’. The user score is a value entered by a user depending on material selection criteria and characteristics. Based on the criteria listed in **Table 2**, a user score on a scale of 1 to 5 is assigned by the user considering the material selection criteria and the selection criterion characteristics in a complex manner.

Table 1. User choice method (between material group a and b).

Material selection criteria	**Selection criterion characteristics**	**User score (input)**	
		a	**b**
A (luxury)	a > b	5	2
B (walking sensitivity)	a > b	4	1
C (sound absorption)	a > b	5	3
D (various textures/patterns)	a < b	1	5
E (warmth)	a > b	3	1
Sum		18	12

Table 2. User Score criteria.

User score	**Criteria**
In case of any material considering the selection criteria	
1	is very unnecessary
2	is somewhat unnecessary
3	may or may not be necessary
4	is somewhat necessary
5	is very necessary

For example, **Table 1** presents material selection criterion A, where 5 and 2 points are assigned to material groups a and b, respectively, reflecting user preferences that means a user thought material groups a and b ‘very necessary’ and ‘slightly unnecessary’. Conversely, material selection criterion D is the case where 1 and 5 points are assigned to material groups a and b, respectively, reflecting user preferences that means a user thought material groups a and b ‘very unnecessary’ and ‘very necessary’. Finally, this model enables users to select materials from a database of material groups with high total scores. As summarised in **Table 1**, material groups a and b are assigned a total of 18 and 12 points, respectively; therefore, material group a is selected as the final material group.

Here, the term “necessary” is configured to be selected according to the level of necessity among 1 to 5 points as the criterion for the user to select the material as defined in **Table 2**. At this time, the user selection score is a score that is directly input by a user such as a designer. In the case of the material selection criteria A, for example, if luxury is essential, 5 points can be selected, and if a little is required, 4 points can be selected. In addition, the material selection criteria A to E are not necessarily the only ones, and durability, fire prevention function, and various colour may be added or changed depending on the space where the material is used.

3.2. Models using GA

Comparing individual materials from multiple databases is difficult for users. Thus, an automated comparison of the materials is required. A genetic algorithm is a probabilistic search technique that models the natural phenomena of genetic succession and competition for survival (Lee, 2010). A GA involves selection, crossover, and mutation processes. During the selection process, when an initial group for algorithm execution is created, the fitness of that group for the objective function is evaluated (i.e., whether this group can be used to derive a value close to the target). The algorithm execution is terminated when the stop condition is satisfied, thereby deriving the final value. If the stop condition is not satisfied, the execution is repeated until the condition is satisfied.

Among previous studies related to GA, Sohail (2023) discussed GA and its applications in detail in research fields including computer science, applied mathematics and engineering. Khatri (2023) used GA to develop a model improving an isolated hybrid energy system efficiency.

In general, GA is more advantageous for extracting global solutions in groups than for calculating a single solution (Lim, 2010), and its derived results are probabilistic rather than deterministic. Since there are many types of materials used in this study and the prices of the same type vary, it is difficult for users to compare one by one, so it was judged that it is necessary to automate material comparison. The genetic algorithm was judged to be suitable for a model that needs to derive probabilistic results on a group basis, such as the material selection model proposed in this study. These characteristics were regarded as suitable for the purpose of this study. Thus, this study utilized Evolver 8.1 (Palisade), which constructs an excel-based model and applies a GA.

Figure 3 presents the material selection process using the GA. The database was constructed through space classification using material information, certification case analysis, and LCC analysis. Using this database, the user selects a material group based on the user's choice. Next, when the target score, application/target area, and price range are entered as input values, the first generation is created through a solution set consisting only of material groups selected based on user choice. Here, LCC is calculated using the Present Worth Method as the sum of initial cost, replacement cost, and maintenance cost. For material price information, the base interest rate and inflation rate of the Bank of Korea from 2010 to 2019 were used, and a period of LCC value calculated for the analysis was 40 years.

Next, fitness is evaluated to secure the level above the target score and derive the minimum amount of materials. After the evaluation is completed, it is determined whether the stop condition has been met. If the condition is met (calculated score ≥ target score), the operation is terminated, and the calculated score, optimal amount, and optimal material are output. However, if the stop condition is not met (calculated score < target score), the operation is repeated to generate the next-generation chromosomes. This process generates new child chromosomes via selection, crossover, and mutation, thereby replacing the current solution set with a new solution set. Fitness is re-evaluated using the replaced solution set, and this process is repeated until the stop condition is satisfied. When using the GA in this study, the ranking selection method and uniform crossover were utilised as the selection and crossover methods, respectively.

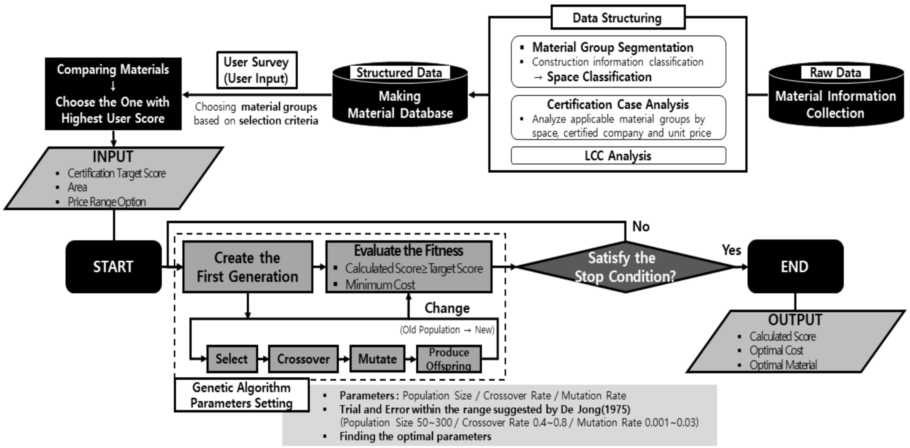


Figure 3. Material selection process.

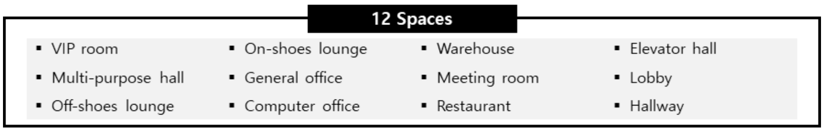
The parameters that affect the derivation of the optimal values of the GA include population size, crossover rate, and mutation rate. One parameter is fixed and the other two parameters are varied during repeated trials to determine the optimal parameters. In this case, the variable ranges proposed in previous studies can be utilised for repeated trials. De Jong (1975) typically presented a population size of 50–300, crossover rate of 0.4–0.8, and mutation rate of 0.001–0.03 as optimal parameter ranges, which were used while setting the parameters for repeated trials in this study.

An actual office building was considered for repeated trials to determine the optimal parameters. In this case, the lowest final cost was derived under the conditions of a population size of 300, crossover rate of 0.5, and mutation rate of 0.01, which were used as parameters for further verification. As a result of applying GA to the actual building to set the stop condition (the condition for stopping the genetic algorithm calculation and outputting the optimum value), the optimum value was outputted from 1.5 million generation. Thus, in this study, 1.5 million generation was set as the stop condition, allowing the calculation to be terminated and the optimum values to be output after the passage of the corresponding generation.

4. Model verification

For model verification, three office buildings (two privately owned buildings and one public building) were selected and the G-SEED certification criteria were applied. Objectivity was secured by conducting verification and model development for buildings that obtained green building certification. In addition, in the process of developing a material database with low emission of indoor air pollutants, in order to identify materials actually used in past cases, a vast amount (total: 9231 cases, average: 769 cases) of material database was established for 12 rooms (**Figure 4**) and areas for a total of 11 buildings, and quantitativeness was also secured.

The G-SEED requires heavy workload and time, as well as an understanding of various fields during the process of obtaining certification, causing difficulties in practice and preventing efficient selection of materials because of the multitudinous requirements of owners or the lack of a high-quality material selection system during the process of selecting materials (Kim, 2009). Thus, there is a need for a material selection tool that satisfies user requirements, material performance, and price constraints, as well as the target certification score.



12 Spaces

- VIP room
- Multi-purpose hall
- Off-shoes lounge
- On-shoes lounge
- General office
- Computer office
- Warehouse
- Meeting room
- Restaurant
- Elevator hall
- Lobby
- Hallway

Figure 4. Space classification.

4.1. Analysis of G-SEED certification evaluation criteria

Building materials emit pollutants such as formaldehyde and volatile organic compounds indoors. The G-SEED is employed to evaluate these materials from the viewpoint of indoor air environment. Therefore, the evaluation method and calculation criteria in this study were developed by referring to the G-SEED manual. Indoor air quality was assessed based on the use of low-emission building materials. Their scores were calculated and are presented in **Table 3**.

Table 3. Standard of "application of indoor air pollutants low-emitting products".

Category	**Application site**	**Points**		
		Wall	**Ceiling**	**Floor**
Finishing materials	Indoor air pollutant low-emission products applied to the site (wall, ceiling, floor)'s surface are suitable for standards	2	1	1
Adhesive		1	1	1
Other interior materials		2	2	1
Score calculation	Sum {Points for Each Application Site} ÷ (Number of Floors × 4)			

In **Table 3**, points 1 and 2 are calculated in such a way that points are obtained for each part (wall, ceiling, floor) if the material is satisfied, and no score is obtained if it is not satisfied. For example, in the wall area, if the final finishing material meets the indoor air pollutant low emission standard, 2 points are obtained, and if not, 2 points are not obtained.

4.2. Development of database of low-emission building materials

After the certification examination criteria were analysed, a database of low-emission building materials was developed based on the analysis results. Crucial material information, such as material specifications, units, prices, uses, and the eco-label certification status of materials, was obtained in reference to 'Environment-Friendly Construction Material Information' and 'Current Status of Eco-label Certified Products' issued by Korea Environmental Industry & Technology Institute. The materials must be classified into specific groups to facilitate the analysis of client requirements for selecting optimal preferred materials, utilisation of the GA, and calculation of cost. Indoor floor decoration materials were subdivided into wooden flooring, waterproofing materials for floors, vinyl sheets, vinyl tiles, conductive tiles, and carpet tiles. The wall and ceiling finishing materials were subdivided into wall boards, gypsum boards, ceiling boards, and tex materials. Furthermore, given that finishing materials, adhesives, and interior (finishing) materials utilised in buildings vary depending on the areas to which these materials are applied, or the space for each room, there is a need for the classification of material groups based on the office spaces in which they can be installed. Office spaces were classified into 12 types based on the concepts provided by the Construction Information Classification System (2007), as shown in **Figure 4** (only showing the category of VIP room among 12 spaces).

Similar materials are typically applied to similar spaces and areas in office buildings, and material selection using similar cases in the past benefits the design process. To implement the material selection model effectively, materials should be selected within the material group that has been applied in the past. Thus, this study analysed the grading scales, scores, materials, and area of actual certification cases (two private and nine public cases) related to the G-SEED to build up a material database for 12 living spaces, which comprise only the material groups that have been applied previously. For example, **Table 4** lists the types of material groups applied to the VIP room.

Table 4. Types of material group applied in VIP room.

Category	Site	Division	Applied material group
VIP room	Floor	Finishing materials	Carpet tile/vinyl tile
		Other interior materials	Double floor material
	Wall	Finishing materials	Paint
		Other interior materials	Plaster board
	Ceiling	Finishing materials	Fibre insulation boards/paint
		Other interior materials	Plaster board

Furthermore, according to the analysis results on manufacturers and applicable areas by material groups, materials manufactured by major companies were mainly utilized in product groups, such as paint, raised floor materials, vinyl sheets, vinyl tiles, conductive tiles, carpet tiles, gypsum boards, and tex materials, which form a large part of each material group. The prices of materials supplied by these companies were close to the average ones, and products that had extremely high or low prices were not used. In this respect, this study set the low-price, middle-(average-) price, and high-price as 20% (10%–35% range), 50% (35%–65% range), and 80% (65%–90% range), respectively, for the unit prices of all data, thereby providing options for material unit prices. Thus, a user is allowed to select a price option before selecting a material, and the model is configured to propose the most feasible materials while meeting the target score among materials within the price range.

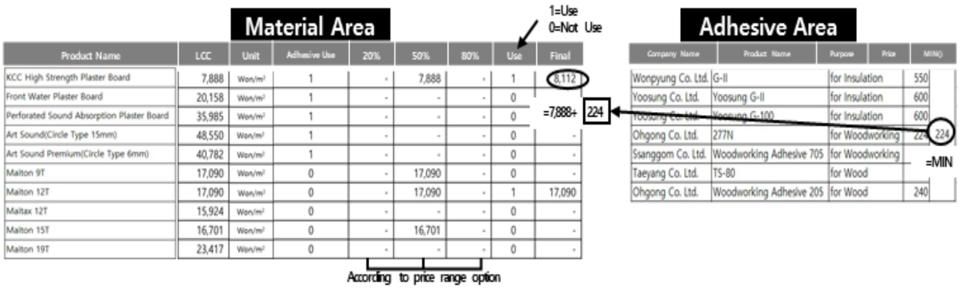
A material database was constructed by extracting products eligible with respect to the G-SEED certification item from among the collected materials and classifying them according to the areas in which they can be applied. In this case, the information on the material price is determined according to the Bank of Korea's base and inflation rates from 2010 to 2019, and the price is replaced by the LCC value calculated for an analysis period of 40 years. The units (including m^2, L, and KG) marked differently for each material were consistently converted into area (m^2) based on detailed material information and specifications to facilitate price comparison between materials.

4.3. Selection of low-emission building materials based on user choice

This study utilised a material database based on building space classification, as shown in **Figure 3**, and allowed users to select a material group depending on its performance for each space or the owner’s requirements. Our proposed model was configured to enable a user to input a score in a tabular form consisting of material selection criteria, selection criterion characteristics, and user scores to select the material group with the highest total score for the building.

The model requires the calculation of the certification score and material cost reflecting user options. However, calculating these values in this model based on numerous databases may be difficult for users. Therefore, a tool that enables the user to obtain the certification score and material cost through an automated calculation process is required.

Figure 5 shows a schematic diagram of the material selection and calculation procedures for a typical office space. The input values required for the material selection procedure include the target and applicable areas for each space and section of the floor to which the material will be applied, the price range, and the target score in the certification process. Here, the target area means the area required for certification. The user can select the materials and calculate the score and cost using this model. To facilitate the cost calculation for target products and the utilisation of GA variables, 1 (used) and 0 (unused) were assigned to the cases depending on whether each material was applied.



Material Area

Product Name	LCC	Unit	Adhesive Use	20%	50%	80%	Use	Final
KCC High Strength Plaster Board	7,888	Won/m²	1	-	7,888	-	1	8,112
Front Water Plaster Board	20,158	Won/m²	1	-	-	-	0	
Perforated Sound Absorption Plaster Board	35,985	Won/m²	1	-	-	-	0	
Art Sound(Circle Type 15mm)	48,550	Won/m²	1	-	-	-	0	-
Art Sound Premium(Circle Type 6mm)	40,782	Won/m²	1	-	-	-	0	-
Malton 9T	17,090	Won/m²	0	-	17,090	-	0	-
Malton 12T	17,090	Won/m²	0	-	17,090	-	1	17,090
Maltax 12T	15,924	Won/m²	0	-	-	-	0	-
Malton 15T	16,701	Won/m²	0	-	16,701	-	0	-
Malton 19T	23,417	Won/m²	0	-	-	-	0	-

Adhesive Area

Company Name	Product Name	Purpose	Price	MIN()
Wonpyung Co. Ltd.	G-II	for Insulation	550	
Yoosung Co. Ltd.	Yoosung G-II	for Insulation	600	
Yoosung Co. Ltd.	Yoosung G-100	for Insulation	600	
Ohgong Co. Ltd.	277N	for Woodworking	224	224
Ssanggom Co. Ltd.	Woodworking Adhesive 705	for Woodworking		
Taeyang Co. Ltd.	TS-80	for Wood		
Ohgong Co. Ltd.	Woodworking Adhesive 205	for Wood	240	

Figure 5. Material selection and amount calculation process.

In addition, 20%, 50%, and 80% of the unit prices entered by the user, depending on the price range, fall within the ranges of 10%–35% 35%–65%, and 65%–90% of the unit prices in each material group, respectively. Thus, only the unit price corresponding to the option entered by the user is activated in the material selection process, in which the final material price is ‘0’ if the usage value of a material is ‘0’. In contrast, if the usage value of a material is ‘1’, the final material price equals the sum of the LCC unit price and the adhesive unit price or the LCC unit price alone, depending on the usage of the adhesive.

For example, if a user selects 50% as the price range for a typical office space, only 50% of the unit price is activated in the material selection process and only 50% is used to display the final price. This model aims to assist the user in selecting a material at the minimum cost within the price range selected by the user. Thus, if an adhesive is typically inexpensive and the price difference between the products is insignificant, the applicable unit price is determined based on the product with the lowest LCC unit price among adhesives with the same usage.

Once the material is selected through the function constructed in the model and GA, and the final output value is determined, as shown in **Figure 6**. As the left part of **Figure 6** illustrates, the certification score for each applicable floor is a factor used to calculate the final score, which is determined for the floor area based on the certification criteria. The material selection status by living space, as shown on the right side of **Figure 6**, represents the status for calculating the final price, displaying the number and cost of materials for each room.

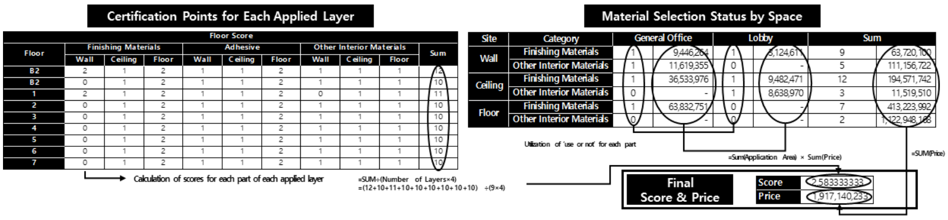


Figure 6. Material selection output.

4.4. Model verification results

Three real office buildings were considered to verify the material-selection model. Input values were selected based on each building's information, and each case was analysed based on the user selection criteria. The analysis results obtained before and after model utilisation were compared for each price range (20%, 50%, and 80%) to derive the results shown in **Table 5**.

Table 5. Summary table of model regression coefficient.

Category	Price range Option	Score target	Score calculated	Number of generations	Original cost (unit: 1000 Won)	Optimal cost (unit: 1000 Won)	Cost increase/decrease rate
	20%	3	3	845,130		177,522	(↓) 15.8%
Case A (private)	50%	3	3	1,420,991	210,801	283,127	(↑) 34.3%
	80%	3	3	1,370,804		386,829	(↑) 83.5%
	20%	2.63	2.71	1,426,523		198,628	(↓) 35.4%
Case B (public)	50%	2.63	2.71	1,476,487	307,363	302,601	(↓) 1.6%
	80%	2.63	2.71	1,330,027		412,079	(↑) 34.1%
	20%	3	3	1,051,952		127,651	(↓) 29.7%
Case C (private)	50%	3	3	1,084,940	181,532	200,050	(↑) 10.2%
	80%	3	3	1,480,227		290,205	(↑) 59.9%

The results of the detailed material selection status also indicate that higher-priced materials were selected as the price range increased, leading to an increase in the final price. This result suggests that user satisfaction can be low because of low performance when the 20% price range is selected (this selection is applicable to the case where the material price is prioritised). In contrast, the price-to-performance ratio can be extremely high when the 80% price range option is selected (this selection is applicable when the performance of materials is prioritised). Meanwhile, a 50% price range can be selected when the both price and performance of the material are prioritised by a user when a product with an average price among material groups is selected. GA is a search technique that uses information on the fitness evaluation of the objective function, and the more likely it is to reach the optimal solution as it operates a large number of populations. In this study, we made a vast amount of material database and by utilizing GA, it is possible to derive intended results (material selection according to the user price range option) using information only from simple fitness evaluation (calculated score ≥ target score).

5. Conclusion

The purpose of this study was to develop a material selection model that complexly considers user requirements, material functionality and economic feasibility. To this end, based on the user selection-based materials database, the concept of life cycle cost was considered, and a model that satisfied the target score was developed by considering price range options using genetic algorithms as a material selection tool.

For model verification, three cases of actual G-SEED certified office buildings were targeted. As a result of verification, in all three cases, the materials were selected according to the user material group selection criteria for each space and part presented in this study. In addition, materials were selected only within the range according to the price range option entered by the user, and the amount of the selected material increased as the value of the price range option increased.

Therefore, this model is effective in selecting materials that meet the target score of G-SEED while satisfying user requirements and considering user price range option. Also, it is expected to help improve the economic feasibility of construction by considering the range of material unit prices. This model can be modified to suit the user's requirements, such as changing data to other types or changing the range of price options, so that it is expected to be expanded and utilized in other fields than the construction field.

The factor that most affects the efficient use of this model is the user’s input of sincere requirements (scores) and selection of price range options. When implementing the model, if the user inputs the price range options he or she actually wants and assigns scores accurately and intuitively, the feasibility of this model can be strengthened and practical results can be obtained.

However, this study has limitations in that it did not consider factors such as manufacturers, follow-up quality control in the material selection criteria and the consideration of uncertified materials, so it is necessary to supplement through future research

Author contributions: Conceptualization, BSK; methodology, BSK; software, SMK; validation, SMK and BSK; formal analysis, SMK; investigation, SMK; writing—original draft preparation, SMK; writing—review and editing, SMK and BSK; visualization, SMK; supervision, BSK; project administration, BSK. All authors have read and agreed to the published version of the manuscript.

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