# Effect of Delivery Methods on Design Performance in Multifamily Housing Projects

ChangTaek Hyun, M.ASCE[1]; KyuMan Cho[2]; KyoJin Koo[3]; TaeHoon Hong, A.M.ASCE[4]; and HyunSeok Moon[5]

**Abstract:** Existing studies on the performance evaluation by the delivery method generally indicate that the design build (DB) method is superior to the design-bid-build (DBB) method in terms of construction duration, cost, and quality. As opposed to the performance of construction duration and cost, where quantitative evaluation is relatively possible, most performance evaluations of quality are based on interviews with the owners. Therefore, this paper aimed at evaluating the level of design performance to conduct a quantitative evaluation on the performance of quality. To achieve this goal, this paper analyzed the impact of delivery methods on design performance in terms of the quantitative evaluation based on the case studies analyzing construction drawings and specifications of public multifamily housing projects delivered through the DB and DBB methods since 2000. The Delphi and analytic hierarchy process methods were used to develop objective standards and contents for evaluating the design performance. An analysis of variance test was conducted to analyze which delivery methods would have an effect on the design performance. Construction industry practitioners can use the results of this study in selecting a delivery method appropriate to the project characteristics.

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## Introduction

The demand on building construction has been becoming increasingly more complicated, more varied, and bigger. Technology-intensive construction projects rather than simple labor-intensive projects are increasing in number. With the further diversification of demand from owners and consumers in various social levels, many countries are devoting considerable effort to coping with such a demand by developing innovative delivery methods such as design-build (DB), construction management (CM), at risk, the A+B method, or warranty method. They also put an equal amount of effort into performing pilot projects to develop and complement such various delivery methods, consistently analyzing the performance of each delivery method, analyzing advantages and disadvantages of the delivery methods, and developing a delivery method most appropriate for every project.

Generally, the project performance can be measured in terms of construction duration, construction cost, quality, the level of the owner's satisfaction, etc., among other factors. These items can then be divided further into the performance evaluation of quantitative aspects such as construction duration, construction cost, and intensity, and that of qualitative aspects such as quality and the level of the owner's satisfaction. The results of such evaluations show that the DB method is more effective than the design-bid-build (DBB) method in terms of construction durations, construction cost, and quality (Bennett et al. 1996; Chan et al. 2002; Konchar and Sanvido 1998; Songer and Molenaar 1997).

The quantitative evaluation, which deals with construction duration and construction cost, usually derives from the results based on objectively statistical analysis methods, and thus has a relatively high confidence interval (CI). On the other hand, the qualitative performance evaluation on quality and the level of the owner's satisfaction is often based on questionnaires and interviews, which rarely produce results with a high CI. Such qualitative performance analyses based on the questionnaires and interviews may not reveal how much difference by the delivery method there will be among similar facilities and measures only the level of the owner's satisfaction on the facilities (MOCT 2006).

Therefore, this study departed from existing qualitative analytical methods, and evaluates the level of design performance more quantitatively through case study by: (1) analyzing the design documents of the projects delivered by traditional DBB and DB methods; and (2) evaluating the extent of their differences that the level of design performance of public multifamily housing projects would be in reality depending on each delivery method.

[1]Professor, Dept. of Architectural Engineering, Univ. of Seoul, Seoul 130-743, Korea.

[2]Ph.D. Candidate, Dept. of Architectural Engineering, Univ. of Seoul, Seoul 130-743, Korea.

[3]Associate Professor, Dept. of Architectural Engineering, Univ. of Seoul, Seoul 130-743, Korea.

[4]Assistant Professor, Dept. of Architectural Engineering, Univ. of Seoul, Seoul 130-743, Korea (corresponding author). E-mail: hong7@uos.ac.kr

[5]Ph.D. Student, Dept. of Architectural Engineering, Univ. of Seoul, Seoul 130-743, Korea.

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## Literature Review of Performance Evaluation

Several studies have been conducted to evaluate the performance of facilities according to the delivery methods. In the study by Bennett et al. (1996), this study compared DB, DBB, and managed projects with respect to cost, quality, and time to figure out their performance. They also conducted questionnaire surveys among owners and project participants and, at the same time, carried out case studies (Bennett et al. 1996).

Songer and Molenaar (1997) analyzed the characteristics of a project for the success of the DB method and presented the standards of a successful project through a performance evaluation by delivery methods such as budget, schedule, the high quality of workmanship, meeting specifications, conforming to user's expectation, and minimizing construction aggravation. This study evaluated the performance of each delivery method using mostly qualitative evaluation standards based on the opinion collected from the owners on each delivery method by means of questionnaires with public-sector design-build personnel. With the result of the surveys, the successful factors in selecting an effective delivery method were presented (Songer and Molenaar 1997).

In the study conducted by Konchar and Sanvido (1998), according to the DB, DBB, and CM at risk methods, the standards for evaluating the project performance were generally analyzed by three aspects using questionnaires on: (1) cost; (2) schedule; and (3) quality. The cost was further divided into unit cost, cost growth, and intensity. The schedule was divided into construction speed, delivery speed, and schedule growth. The quality was divided into turnover quality, system quality, and process equipment quality. The performance evaluation on cost and schedule was based on quantitative evaluation standards, whereas that on quality was based on the scale method in which the level of the owner's satisfaction was evaluated in the scale degree of high, mid, and low via surveys (Konchar and Sanvido 1998).

The study conducted by Chan et al. (2002) summarized the contents with regard to the results of the aforementioned studies more systematically. This study developed successful factors in the DB method by means of the performance evaluation on such delivery methods. The study analyzed other existing studies on performance evaluation of various delivery methods for the last 10 years. The standards for the performance evaluation by the delivery method implemented by 20 existing studies presented in the study were generally categorized in terms of objective and subjective measures. Similar to the study conducted by Konchar and Sanvido (1998), the study put time, cost, and the cost increase ratio as the objective measures and quality, the level of the owner's satisfaction, productivity, and aesthetics as the subjective measures (Chan et al. 2002).

The study conducted by Debella and Ries (2006) evaluated the performance of educational facilities depending on the different delivery methods. Quantitative and qualitative variables were used for analyzing the performance of construction delivery systems. As for the quantitative evaluation standards, the study used construction speed, unit cost, cost growth, construction schedule growth, percentage change order, and the number of litigation cases. In addition, in order to measure the owner's acknowledgment in delivery methods, the study implemented qualitative methods using questionnaires and analyzed punch list length, the level of administrative burden, and litigation tests (Debella and Ries 2006).

As such, an evaluation on the performance of delivery methods has usually been performed by dividing the standards into quantitative aspects (construction cost and construction duration) and qualitative aspects (quality, level of satisfaction, and productivity). In addition, most studies have evaluated the performance of quality based on the final product of a given project. However, it is difficult to measure how much difference in quality would occur depending on the delivery method. The level of the owner's satisfaction and defect can be evaluated only after the owner has occupied the facilities. Therefore, the result of the evaluation on the performance of quality using such evaluation standards is not only due to the differences of the delivery method but also to project participants, in particular, errors and mistakes by contractors.

Meanwhile, the DB method, in which one company takes the responsibility of the design and construction, lets the contractor participate in the project from its early phases (i.e., predesign and conceptual design). The personnel who handle the design in the DB method are different from the ones in the same phase of the DBB method. Any approach to the given project is different from the planning phase of the project depending on the delivery method, which also causes significant differences in the constructed facilities. Thus, in order to evaluate the differences by delivery methods, it is recommended that the design performance be evaluated; that is, the quality of delivery methods based on the product for the design phases.

Therefore, the objective of the study is to evaluate the differences in design performance depending on the actual delivery methods not through the quality evaluation in terms of qualitative aspects in which the level of satisfaction of the final product is measured, but through the comprehensive analysis based on design drawings and specifications.

## Research Framework for Evaluating Design Performance Level

In evaluating the design performance level, this study did not consider the design drawings of public multifamily housing projects that had already been constructed, most of which were already 5 years old, but the design drawings of public multifamily housing projects that are currently being constructed and whose construction began in 2000 in order to reflect the recent trends. Fig. 1 shows the research framework used in evaluating the design performance level of the delivery methods.

First, the preliminary evaluation standard (PES), which was classified by large, mid, and small category in terms of an evaluation standard for design performance level, was established. In the analysis of the relevant laws for the evaluation of the design plan in the DB and DBB methods, six large categories were presented. In addition, for developing the contents of: (1) a midcategory under the large category; and (2) a small category aimed at evaluating the midcategory, we analyzed the specific standards under the relevant laws and the design documents of public multifamily housing projects. Second, the Delphi method was implemented to evaluate the appropriateness of the PES developed, and to finalize it. The Delphi method was processed in three rounds. In the first Delphi round, the appropriateness of each evaluation item on PES was verified. In the second Delphi round, the analytic hierarchy process (AHP) method, a method of quantifying the subjective opinions of experts, was implemented to assign weights to each evaluation item. In the third Delphi round, the rating criteria were developed based on the results obtained from the first and second Delphi rounds. For the specific application of the contents and methods of Delphi and AHP, refer to the following sections from Step 2-1 to Step 2-3. Third, a case study was



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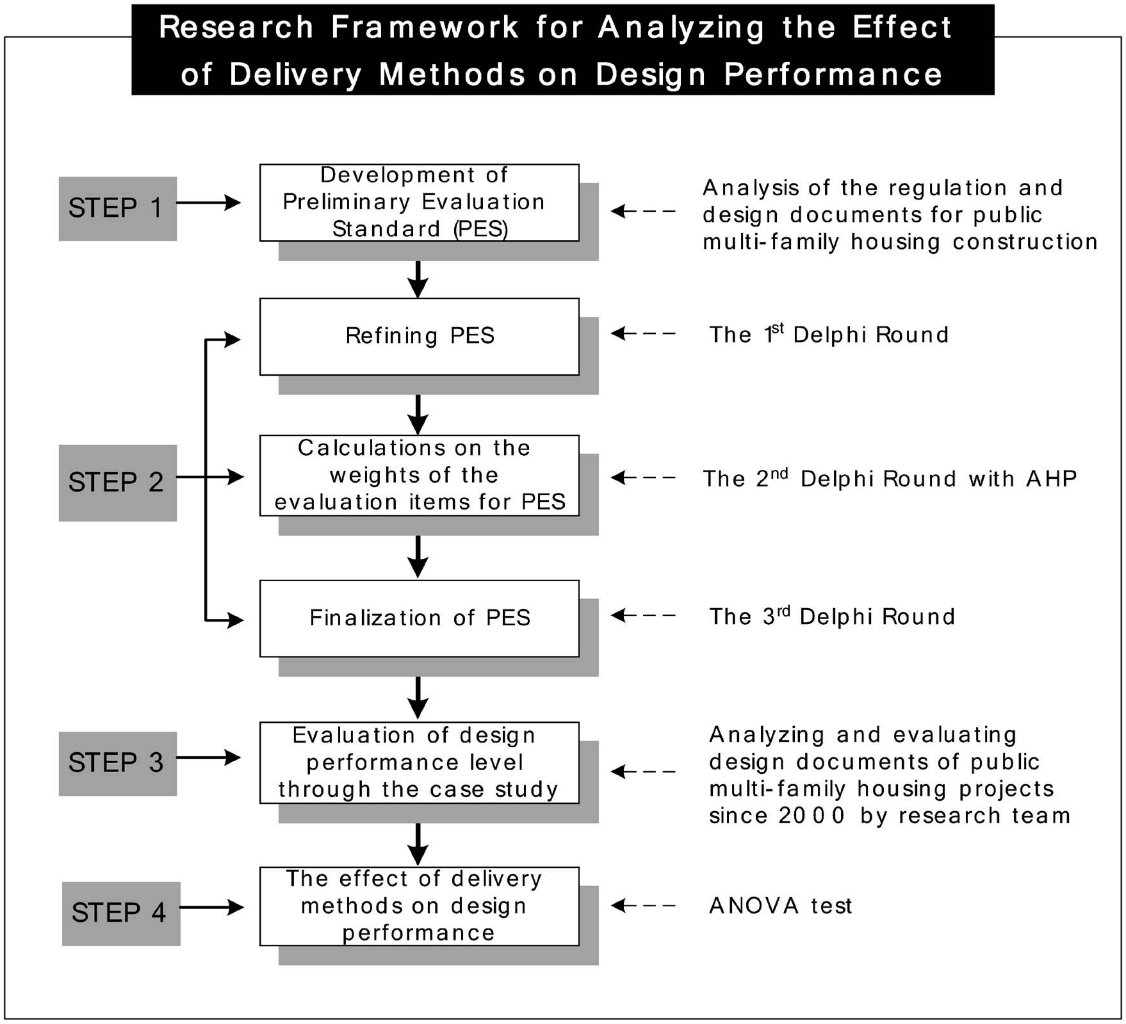


**Fig. 1.** Research framework

conducted using the design documents of ongoing public multifamily housing projects that were begun in 2000, and the level of these projects' design performance was evaluated, using the evaluation standards developed by the Delphi method, depending on the delivery methods used.

Finally, this study conducted an analysis of variance (ANOVA) test to determine whether the design performance levels can indeed be attributed to the delivery methods that were used or to other factors. Through these aforementioned four stages of the evaluation method, the effect of the delivery methods on the design performance level of public multifamily housing projects was determined.

## Development of Evaluation Standards for Evaluating Design Performance Level

### *Step 1: Development of Preliminary Evaluation Standards*

In order to evaluate the level of design performance of public multifamily housing projects based on the delivery methods, this study analyzed Korea's laws and systems for evaluating the design plans of the public sector. The reason for such an analysis is that Korea's standards on evaluating the design plans for public multifamily housing projects are well established since the country is currently experiencing a construction boom involving public multifamily housing projects of more than 20 stories.

The regulations for evaluating the design plans for public multifamily housing projects through design competitions in Korea include: (1) "Regulations for the Enforcement of the Construction Technology and Management Laws, Annexed List 7"; (2) the design evaluation indices of the "Regulations for the Operation in Relation to the Development of Construction Technology and Management Laws, Annexed List 4"; and (3) the standards on producing a design evaluation report of the "Regulations for the Operation in Relation to the Development of Construction Technology and Management Laws, Annexed List 5," all of which are design evaluation standards for the DBB and DB methods.

The main contents of the Annexed List 7, which are the regulations for evaluating the design plans for public multifamily housing projects delivered by the DBB, include: (1) the suitability of a complex planning to the environment; (2) the quality of the project planning; (3) the technology and safety of the structural and the construction plan; (4) harmony with the surrounding environment; and (5) economic ability. Otherwise, the design evaluation of a public multifamily housing project delivered by the DB method is conducted based on planability, constructability, maintainability and operability, safety, economic ability, and environ-



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**Table 1.** Preliminary Evaluation Standard for Analyzing Design Performance

| Large category | Midcategory | Small category |
|---|---|---|
| Planability/comfortability | Ecological floor space ratio | A green tract of land (%), water space, green way, afforestation of retaining wall, program parking |
| | Main building characteristics | Side design, side pitch of building, arrangement angle of main building (sunshine right), household specialization, view in house |
| | Parking lot plan | Number of parked cars per household (%), ratio of underground parking lot (%), integration of underground parking lot and main building |
| | Harmony with surrounding environments | Exterior design of lower floors, uniqueness of exterior amenities, consideration of topology, aesthetics |
| | Consideration on the path of flow | Ratio of the first-floor piloti, vista, and pedestrian axis, separation of vehicle and passenger passageways, emergency vehicle flow |
| Usability | Flexible space | Variable walls, extendible balcony, open window |
| | Specialization of unit-household | Acquiring storage, installing vestibular room and secondary kitchen |
| | Sunshine and ventilation | Number of bays, length of building facade |
| | Utility | Number of bathrooms, bathroom attached to bay, ratio of balcony floor space (%), appropriateness of dry room |
| Quality/constructability | Analysis on the level of finishing material | Living room, bedroom, kitchen, bathroom, entrance, balcony, mechanical and electric equipment |
| | Number of cases introducing process-streamlined methods | Structure, finishing, construction schedule reduction |
| | Survey of customer satisfaction | Survey of the occupants' satisfaction with the house |
| Maintainability/operability | Easability of maintenance, repair, checkup, and inspection | Main shaft prefabrication, installation of the entrance for bringing in/out of equipment, extensible balcony, exclusive heating and plumbing facility, system furniture |
| | Energy-saving plan | Consolidation of external insulating function, using high-efficient device, electricity plan |
| | Number of cases reflecting maintenance considerations in design | Automatic backwash device, etc. |
| Safety | Safety plan during construction | Structuring a safety management organization, safety training and inspection plan |
| | Fire plan | Crime and fire prevention |
| Environmental-ability | Environmental plan during construction | Plans to process noise/vibration, diffusion prevention of scattered dust, plans to reduce water pollution |
| | Noise plan | Noise prevention of residential building/external |

mental ability according to Annexed lists 4 and 5. That is, items included in the evaluation of the design plans are similar regardless of whether it is a DB-delivered or DBB-delivered project, and irrespective of the delivery method, the above items are deemed important elements.

In addition to the analysis of such regulations and laws, the evaluation items were developed to effectively measure the level of design performance of public multifamily housing projects by analyzing the content of existing design drawings as shown in Table 1. As shown in Table 1, the research team developed 19 midcategories based on the actual design drawings of public multifamily housing projects to evaluate six large categories, which include "planability/comfortability," "usability," "quality/constructability," "maintainability/operability," "safety," and "environmental ability."

As for the midcategory for the "planability/comfortability," five items were considered in this study (i.e., ecological floor space ratio, main building characteristics, parking lot plan, harmony with surrounding environments, and consideration on the path of flow). The midcategory for the "environmental ability" is composed of "environmental plan during construction" and "noise plan" (refer to Table 1). In addition, a small category was developed to evaluate each midcategory by applying the same method used in developing the midcategory. For instance, the small categories for evaluating a midcategory, "main building characteristics," are composed of "side design," "side pitch of building," "arrangement angle of main building (sunshine right)," "household specialization," and "view in house" (refer to Table 1).

### Step 2-1: Developing PES Using Delphi Method

The PES developed by the research team in Step 1 was based on relevant laws and actual design drawings. The Delphi method was used to evaluate and finalize the developed evaluation standard objectively. The following is a brief overview of the Delphi method.

#### Delphi Method: Brief Overview

The concept of the Delphi method was first developed by the U.S. defense industry, and its name was originated from the name of a research study conducted by the United States Air Force's Rand Corporation in the early 1950s, which considered the opinion of experts (Robinson 1991). The Delphi method has been widely used in complicated areas where an agreement must be made from uncertain situations. It is a highly formalized communica-



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**Table 2.** Panelists for Delphi Method

| Number | Position | Sector | Experience (years) | Special areas | Qualification |
|---|---|---|---|---|---|
| 1 | Professor | Academic | 25 | Construction management | Ph.D., AVS[a] |
| 2 | Professor | Academic | 15 | Construction management | Ph.D. |
| 3 | Managing director | Private | 23 | Construction management | M.S., P.E.[b] |
| 4 | President | Private | 31 | Value engineering | M.S., P.E.[b], CVS[c] |
| 5 | Director | Private | 16 | Architectural engineering | M.S., Architects |
| 6 | Chief manager | Public | 24 | Architectural engineering | Architects, CVS[c] |
| 7 | Chief manager | Public | 28 | Architectural engineering | M.S., Architects |

[a]AVS=associate value specialist.

[b]P.E.=professional engineer.

[c]CVS=certified value specialist.



tion method devised to extract much unbiased information from experts in various fields (Chan et al. 2001). The Delphi method can offer additional gains in a crucial situation where a field of uncertainty or in which experts disagree with one another should be defined (Robinson 1991). Furthermore, as the viewpoint of a group can become more accurate than that of any individual in the Delphi method, the success of its implementation depends on the careful selection of the panelist (Goldstein 1975). Therefore, the Delphi method was used in this study to revise and finalize the evaluation items on design performance of public multifamily housing projects by delivery methods, which were developed in Step 1.

### First Delphi Round for Refining PES

A successful application of the Delphi method requires extensive experience and knowledge as it necessitates an efficient evaluation of various alternatives, which makes the panel selection process of experts crucial. Therefore, this study selected the panel of experts from various fields (academic, public, and private sectors) who have over 15 years of experience in the field of multifamily housing projects. Based on such criteria, the study finally selected seven experts with a mean number of years of experience of about 23. Table 2 shows detailed information on the participating experts.

The experts conducted the Delphi analysis using the following process. In the first round, the experts verified the evaluation items developed by the research team to evaluate the level of design performance. In the second round, they calculated and applied weighted values for large, and midcategories by each evaluation item using the AHP method, which will be explained in Step 2-2. In the third round, they exchanged opinions with one another to verify and finalize each evaluation item, and developed evaluation contents and the rating criteria to evaluate the evaluation items of each large, mid, and small category.

In the analysis of the first Delphi round, the experts generally agreed on the PES of the large categories developed by the research team. However, they suggested that a revision was necessary for the midcategories, according to which the panel discussed and determined the issues to be refined. Moreover, the panel performed revisions and complements on the small category of each midcategory.

Table 3 shows the large, mid, and small categories of the evaluation standard extracted and revised through the process explained in the previous sections. Taking a look at the revised Table 4, the large category, "planability/comfortability," is evaluated by four midcategories such as "main building characteristics," "harmony with surrounding environment," "parking lot plan," and "consideration on the path of flow," whereas "usability" now focuses on "sunshine and ventilation," "flexible space," "specialization of unit-household," and "utility." "Quality" now concentrates "analysis on the level of finishing material and facility." In case of "maintainability/operability," the "maintenance and repair" and "energy-saving plan" were considered as midcategories (refer to Table 3).

## *Step 2-2: Second Delphi Round for Weights Calculation with AHP Method*

In the second Delphi round, the AHP was used to develop weighted values using the evaluation items of the PES revised at the first Delphi round. The following is a brief overview of the AHP method.

### AHP Method: Brief Overview

The AHP method was first suggested by Satty (1980) and was a new methodology developed to deal with economic, technical, and social issues that are complicated and pose a high level of uncertainty. One major advantage of AHP is that it can convert elements that are intangible and difficult to quantify into quantified and tangible values by using systematic approaches. To help in the decision making on these complicated issues, the AHP considers the tradeoffs and evaluates the level of relative importance among various factors related to the issues using pairwise comparison (Khasnabis et al. 2002; Shapira and Goldenberg 2005). Due to such advantages, as described in the study by Shapira and Goldenberg (2005), the AHP method was applied to evaluate those that are complicated and hard to quantify such as advanced technologies, processes, materials evaluation, contractor selection, procurement selection, alternative dispute resolution, etc. Therefore, the AHP method was used to calculate the level of relative importance of the items in the large, mid, and small categories revised at the first Delphi round.

### Calculation on Weights of Evaluation Items

According to the study by Saaty (1980 and 1990), a mathematical methodology to calculate the weights in the AHP method is considerably simple. As shown in Fig. 2, the weight of each item was calculated using the weights calculation concept developed by Dell'losa and Kirk (2003). Fig. 2 is an example of the weights calculation process on six evaluation items of the large categories, which were evaluated by an expert.

The experts were asked to check items that are more important than the other items in the questionnaire, evaluating both in the large and midcategories. The scales by which they checked the



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**Table 3.** Revised Preliminary Evaluation Standard by First Delphi Round

| Large category | Midcategory | Small category |
|---|---|---|
| Planability/comfortability | Main building characteristics | Arrangement angle of main building (sunshine right), specialization of the highest and first floor household, side pitch of building, front/back side design changes, side design changes |
| | Harmony with surrounding environments | Exterior design of lower floors, uniqueness of exterior amenities, consideration of topology, skyline changes |
| | Parking lot plan | Number of parked cars per household (%), ratio of underground parking lot (%), integration of underground parking lot and main building |
| | Consideration on the path of flow | Ratio of the first-floor piloti, vista, and pedestrian axis |
| Usability | Sunshine and ventilation | Number of bays, length of building facade |
| | Flexible space | Variable walls, extendible balcony, open window |
| | Specialization of unit-household | Acquiring storage, installing vestibular room, and secondary kitchen |
| | Utility | Number of bathrooms, bathroom attached to bay, ratio of balcony floor space (%), appropriateness of dry room |
| Quality | Analysis on the level of finishing material | Living room, bedroom, kitchen, bathroom, entrance, balcony |
| | Analysis on the level of facility | Floor noise, plumbing noise, mechanical, electric, information, and communication |
| Maintainability/operability | Maintenance and repair | Main shaft prefabrication, extensibility potential |
| | Energy-saving plan | Exterior windows, insulating performance, automatic temperature control by room, ventilation of underground parking lot |
| Safety/constructability | Safety plan during construction | Structuring a safety management organization, safety training and inspection plan |
| | Fire plan | Separation of vehicle and passenger passageways, emergency vehicle flow |
| Environmental ability | Environmental plan during construction | Plans to process noise/vibration, diffusion prevention of scattered dust, plans to reduce water pollution |
| | Ecological floor space ratio | A green tract of land (%), water space, green way, afforestation of retaining wall, program parking |

**Table 4.** Weight of Evaluation Items for Measuring Level of Design Performance

| | | Weight | |
|---|---|---|---|
| Large category | Midcategory | Large category | Midcategory |
| Planability/comfortability | Main building characteristics | 30 | 8 |
| | Harmony with surrounding environments | | 10 |
| | Parking lot plan | | 8 |
| | Consideration on the path of flow | | 4 |
| Usability | Sunshine and ventilation | 30 | 10 |
| | Flexible space | | 6 |
| | Specialization of unit-household | | 7 |
| | Utility | | 7 |
| Quality | Analysis on the level of finishing material | 10 | 6 |
| | Analysis on the level of facility | | 4 |
| Maintainability/operability | Maintenance and repair | 10 | 4 |
| | Energy-saving plan | | 6 |
| Safety/constructability | Safety plan during construction | 10 | 4 |
| | Fire plan | | 6 |
| Environmental ability | Environmental plan during construction | 10 | 2 |
| | Ecological floor space ratio | | 8 |
| Total | | 100 | 100 |



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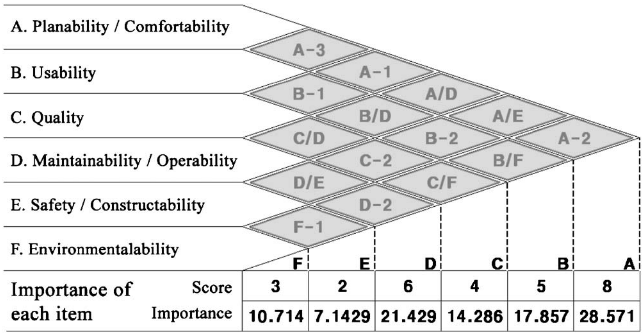


**Fig. 2.** Analysis sheet for AHP

level of importance were four in total (very important: three scores, important: two scores, slightly important: one score, and same: one score. For example, as shown in Fig. 2, if the experts are asked to look at the two items, "A. planability/comfortability" and "B. usability"

1. If the experts judge that A is much more important than B, it is marked A-3;
2. If the experts judge that A is more important than B, it is marked A-2;
3. If the experts judge that A is slightly more important than B, it is marked A-1; and
4. If the experts judge that A is equal to B, it is marked A/B.

Based on this method, the experts will conduct a pairwise comparison on the evaluation items and then mark all the shaded areas in Fig. 2. After marking all the shaded areas, they will calculate the scores for the items based on the following standards:

1. If the mark made is A-3 as above, A is given three points;
2. If the mark made is A-2 as above, A is given two points;
3. If the mark made is A-1 as above, A is given one point; and
4. If the mark made is A/B as above, A and B are given one point each.

Therefore, if the experts think that A is "very important" compared with B, he or she writes down "A-3" on the shaded part. In the case of a comparison between "A. planability/comfortability" and "D. maintainability/constructability" if the expert thinks that, A is the "same" as D, he or she writes down A/D. As shown in the lower part of Fig. 2, if the expert checks the level of importance by item, the number of checked items is calculated and shown as the "score" result of the level of importance of the items evaluated. Once the total scores of each item (i.e., $8=3+1+1+1+2$ for "A. planability/comfortability") is divided by the total sum of the scores (i.e., $28=3+2+6+4+5+8$), the level of importance by item in the lowest part of Fig. 2 is calculated (i.e., $0.2857=8/28$ for "A. planability/comfortability"). Finally, the weights of each item were calculated through the mean value of the level of importance by the item obtained from the seven experts.

As shown in Fig. 3, the AHP analysis of the scores shows that the scores of the six evaluation items comprising the large categories were 30% for "planability/comfortability," 30% for "usability," 10% for "quality," 10% for "maintainability/operability," 10% for "safety/constructability," and 10% for "environmental ability," respectively. Similar to the weight calculation method of the large categories, this study analyzed the level of importance of the middle categories, calculated the weights of the middle categories, and finally adjusted the scores by proportioning them with those of the large categories. The scores of the

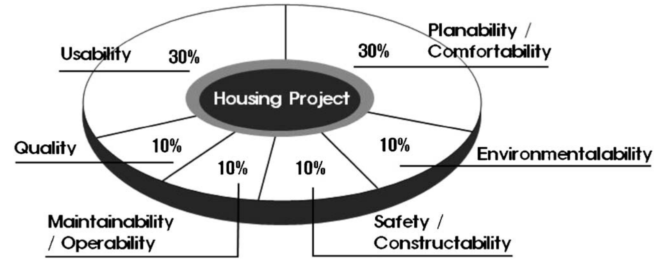


**Fig. 3.** Results of AHP in main category

evaluation items resulting from the AHP method are shown in Table 5. The result shows that the experts considered the most important "planability/comfortability" and "usability" in measuring the level of the design performance of public multifamily housing projects, whereas equally important among "quality," "maintainability/operability," "safety/constructability," and "environmental ability."

### *Step 2-3: Third Delphi Round for Completing PES*

As explained in the research framework, the weights of the large and midcategories were calculated by using the AHP method in the second Delphi round, and finally, the evaluation standard was developed in the third Delphi round. Based on the PES and the weights on large and midcategory, which were revised and calculated by the first and second Delphi rounds, the research team and Delphi panels developed a detailed scoring standard and finally developed the evaluation standard consisting of evaluation items and rating criteria.

The system of the evaluation items consists of large, middle, and small categories, as well as evaluation content. The evaluation items have six large categories: "planability/comfortability," "usability," "quality," "maintainability/operability," "safety/constructability," and "environmental ability." Each large category is divided into midcategories to evaluate each large category more concretely. In addition, small categories for each midcategory are devised in order to develop the evaluation indices with which each midcategory is evaluated.

Furthermore, the rating criteria are the standard with which to evaluate quantitatively the level of the design performance of public multifamily housing projects based on actual case studies. Based on the above explanation, the evaluation standard for "planability/comfortability," was devised as shown in Table 5. For the evaluation standard for the other items, refer to MOCT (2006). Of the six large categories, the "planability/comfortability" consists of four midcategories. Among the rating criteria described in the fifth column of Table 5, the relative evaluation is marked with an asterisk (*). For the relative evaluation, the researchers divided the cases into several groups by evaluating them based on each rating criterion, after which each group was given score(s), the weights on the small category. For example, in the case of the first rating criterion with regard to the arrangement angle of the main building (fifth column of Table 5), the cases were divided into three groups by measuring the arrangement angle of the main building. "Two scores" were given to the relatively highest group in the arrangement angle of the main building; "one score" to the midgroups; and "no score" to the lowest group. In addition, the other rating criteria which were not marked with an asterisk (*), score(s) within parentheses in the small category were given to each case based on whether or not there were rating criteria in each case. For example, in the case of





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**Table 5.** Evaluation Standard of Planability/Comfortability

| Large category | Midcategory | Small category | Evaluation content | Rating criteria |
|---|---|---|---|---|
| Planability/ comfortability (30) | Main building characteristics (8) | Arrangement angle of main building (2) | Natural sunshine and heating effect | *Relative evaluation according to three scales depending on the arrangement angle of main building |
| | | Specialization of the highest floor household (2) | Changes of the rooftop style | Attic: 1 score<br>Rooftop garden: 1 score |
| | | Specialization of the first floor household (1) | Changes in the first floor style | Installing a private garden: 1 score |
| | | Side pitch of building (1) | Ventilation efficiency and vista | *Relative evaluation according to two scales depending on the average side pitch of building |
| | | Front/back side design changes (1) | Get out of simple elevation | Changes in the front elevation: 0.5 score, changes in the rear elevation: 0.5 score |
| | | Side design changes (1) | Get out of simple elevation | *Relative evaluation according to two scales depending on the ratio of changes in side design |
| | Harmony with surrounding environments (10) | Exterior design of lower floors (2) | Changes and familiarity of inside complex | Material change: 2 scores<br>Color change: 1 score |
| | | Uniqueness of exterior amenities (3) | Planning in external amenities of the complex | Linking to open space: 1 score, specialization of main entrance: 1 score, walkways: 1 score |
| | | Consideration of topology (3) | Establishing ecofriendly space | Deck parking lot: 1 score, arrangement based on topology: 1 score, facility arrangement based on topology: 1 score, flatlands: 1 score |
| | | Skyline changes (2) | Level of overcoming the monotony | 2-stage change: 1 score, over 3-stage change: 2 scores |
| | Parking lot plan (8) | Number of parked cars per household (%) (3) | Ample parking space | *Relative evaluation according to four scales depending on the ratio of the number of parked cars |
| | | Ratio of underground parking lot (%) (3) | Securing green space in the ground level | *Relative evaluation according to four scales depending on the ratio of the number of underground parking lot |
| | | Integration of underground parking lot and main building (2) | Convenience to use the underground parking lot | Integration of underground parking lot and main building: 1 score |
| | Consideration on the path of flow (4) | Ratio of the first-floor piloti (3) | Offering open space to the 1st floor | *Relative evaluation according to four scales depending on the piloti ratio |
| | | Vista and pedestrian axis (1) | Elements considering movement | Vista axis: 1 score<br>pedestrian axis: 1 score |



the second rating criterion with regard to the specialization of the highest floor household (fifth column of Table 5) if the case had an "attic" or a "rooftop garden," one score was given; and if it did not, no score was given.

## Case Study

### *Data Collection*

Based on the aforementioned evaluation standard on design performance, the research team analyzed the level of design performance of public multifamily housing projects whose design was begun in 2000 and those currently under construction. To get a reliable analysis result on the level of design performance, it is helpful to measure the performance of the two projects that have the same topological and other conditions but delivered either through the DB or DBB method.

However, in reality, this is impossible. Therefore, this study selected a project whose construction characteristics, size, and period by project are similar. Meanwhile, the organization and business of the owner generally play a significant role in the performance of the facility. Therefore, two public corporations that have a similar organization and structure were selected in this study. The two public corporations have performed public multifamily housing construction projects by dividing the category of each project either as public lease, public sale, or as a mixed type of the two according to the sales method of the public multifamily housing projects. Therefore, it is required for considering public multifamily housing projects of the same type by considering these three types for a more effective analysis.

Totally, ten projects delivered by the DB method since 2000 were identified from the public corporations. There were 38 projects delivered by the DBB method from one public corporation, whereas another corporation had 16. Due to the lack of the projects delivered by the DB method, the research team selected and analyzed survey to surveys on the DBB projects that are



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**Table 6.** Number of Analyzed Projects and Their Types

| Category | Number of cases analyzed: A Corporation | B Corporation | Total | Number of cases analyzed depending on types: Public sale | Public lease | Public sale+public lease | Total |
|---|---|---|---|---|---|---|---|
| DB method | 7 | 3 | 10 | 4 (DB 1–4) | 3 (DB 5–7) | 3 (DB 8–10) | 10 |
| DBB method | 11 | 3 | 14 | 6 (DBB 1–6) | 5 (DBB 7–11) | 3 (DBB 12–14) | 14 |

similar to those of the DB method in the projects' characteristics and location. The criteria for selecting the projects of the DBB method to be analyzed are as follows:

1. A project that is similar in sale type (public lease, public sale, public lease+public sale);
2. A project with the DBB method whose size of household is similar to the DB method;
3. A project with the DBB method that the construction period of the DB project is similar; and
4. A project with the DBB method located closely to the DB project.

Based on the above criteria, 14 projects delivered by the DBB method since 2000 were identified from the public corporations. Table 6 shows the number of finalized cases and types to be analyzed based on these criteria. The DB 1 ~ 10 and DBB 1 ~ 14 within parentheses in Table 6 represent each case study of Tables 8–10. In addition, as shown in Table 7, this study grouped the cases based on the above-mentioned four criteria, and these groups were analyzed by using evaluation standards with respect to design performance. The evaluation by each group was intended to analyze the difference depending on delivery methods, wherein the cases delivered by the DB or DBB had similar conditions in terms of the sale type, the size of unit household, the construction period (the starting day of the project), and region. Table 7 described a profile of each group. For example, the DB1, the DBB1, and the DBB2 for the Group "A" used in Table 8 on public sale generally had similar characteristics.

### Analysis for Evaluating Design Performance

The public multifamily housing projects collected in this study, as stated previously, can be categorized according to public sale, public lease, or public sale+public lease. Such a type is determined by the purpose of the project and shows significant differences in terms of finishing level. That is, the public sale is the type of public multifamily housing constructed to be sold to the public who are from various backgrounds. The public lease is the type of public multifamily housing constructed to be issued on a long-term lease to the public by the government. Therefore, public multifamily housing for public sale shows differences in terms

**Table 7.** Profile of Collected Cases

| Sale type | Name of groups | Case | Size of unit household ($m^2$) | Starting day of project | Region |
|---|---|---|---|---|---|
| Public sale (refer to Table 8) | A | DB1 | 75–84 | October 31, 2003 | Urban area |
| | | DBB1 | 55–84 | April 7, 2003 | Metropolis |
| | | DBB2 | 59–84 | April 28, 2003 | Metropolis |
| | B | DB2 | 84 | April 22, 2004 | Metropolis |
| | | DBB3 | 75–84 | July 31, 2004 | Metropolis |
| | | DBB4 | 59–84 | February 7, 2004 | Metropolis |
| | C | DB3 | 84 | December 31, 2003 | Suburb |
| | | DB4 | 84 | December 31, 2003 | Suburb |
| | | DBB5 | 84 | June 24, 2004 | Suburb |
| | | DBB6 | 75–84 | August 30, 2003 | Suburb |
| Public lease (refer to Table 9) | A | DB5 | 48–59 | December 31, 2001 | Suburb |
| | | DBB7 | 51–59 | October 9, 2001 | Suburb |
| | | DBB8 | 51–59 | March 23, 2002 | Suburb |
| | B | DB6 | 65–84 | March 20, 2002 | Metropolis |
| | | DBB9 | 59–84 | May 21, 2002 | Metropolis |
| | | DBB10 | 51–76 | October 31, 2003 | Metropolis |
| | C | DB7 | 59 | December 30, 2000 | Suburb |
| | | DBB11 | 51–59 | November 11, 2001 | Suburb |
| Public sale+lease (refer to Table 10) | A | DB8 | 49–134 | December 13, 2005 | Metropolis |
| | | DBB12 | 39–84 | December 29, 2005 | Urban area |
| | B | DB9 | 39–134 | December 30, 2005 | Metropolis |
| | | DBB13 | 49–114 | December 30, 2005 | Urban area |
| | C | DB10 | 84–167 | December 30, 2005 | Metropolis |
| | | DBB14 | 59–134 | December 30, 2005 | Urban area |



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**Table 8.** Results of Evaluating Design Performance in Public Sale

| Evaluation items | | Group A | | | Group B | | | Group C | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Large category | Midcategory | DB1 | DBB1 | DBB2 | DB2 | DBB3 | DBB4 | DB3 | DB4 | DBB5 | DBB6 |
| Planability/comfortability | Main building characteristics | 8.0 | 4.5 | 5.5 | 6.5 | 5.0 | 6.0 | 6.5 | 6.0 | 5.5 | 6.0 |
| | Harmony with surrounding environments | 9.0 | 7.0 | 9.0 | 8.0 | 7.0 | 4.0 | 10.0 | 9.0 | 7.0 | 5.0 |
| | Parking lot plan | 5.0 | 4.0 | 8.0 | 5.0 | 4.0 | 6.0 | 6.0 | 6.0 | 6.0 | 5.0 |
| | Consideration on the path of flow | 3.5 | 2.0 | 3.5 | 3.5 | 3.0 | 2.0 | 3.0 | 4.0 | 3.0 | 2.0 |
| Usability | Sunshine and ventilation | 10.0 | 3.0 | 6.0 | 10.0 | 8.0 | 6.0 | 7.0 | 8.0 | 8.0 | 7.0 |
| | Flexible space | 4.5 | 3.5 | 3.5 | 4.5 | 4.0 | 2.5 | 3.5 | 4.5 | 3.5 | 4.5 |
| | Specialization of unit-household | 7.0 | 1.0 | 3.0 | 5.0 | 5.0 | 5.0 | 7.0 | 7.0 | 5.0 | 7.0 |
| | Utility | 4.5 | 3.5 | 6.0 | 4.5 | 4.0 | 3.0 | 6.0 | 5.5 | 4.5 | 4.0 |
| Quality | Analysis on the level of finishing material | 3.0 | 3.0 | 4.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | Analysis on the level of facility | 4.0 | 2.5 | 4.0 | 4.0 | 3.0 | 3.5 | 4.0 | 4.0 | 4.0 | 4.0 |
| Maintainability/operability | Maintenance and repair | 2.0 | 0.0 | 4.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Energy-saving plan | 6.0 | 5.0 | 6.0 | 6.0 | 3.0 | 4.0 | 4.0 | 6.0 | 4.0 | 3.0 |
| Safety/constructability | Safety plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Fire plan | 5.0 | 3.5 | 5.0 | 5.0 | 5.0 | 3.5 | 5.0 | 5.0 | 3.5 | 3.5 |
| Environmental ability | Environmental plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Ecological floor space ratio | 6.0 | 2.0 | 8.0 | 6.0 | 7.0 | 3.0 | 6.0 | 5.0 | 6.0 | 7.0 |
| Total | | 81.5 | 48.5 | 80.5 | 78.0 | 67.5 | 57.0 | 77.5 | 79.5 | 69.5 | 67.0 |

of size and finishing level as compared with the type of public lease. To enhance the reliability of the analysis, the research team analyzed the level of design performance by dividing the projects depending on the types.

### Public Sale

As shown in Table 6, there are four public multifamily housing projects delivered by the DB method as public sale since 2000 and six projects, whose type and size are similar to the four public multifamily housing projects, in the case of the DBB method. As shown in Table 8, the ten projects (i.e., four project for the DB and six projects for the DBB) were again categorized into three groups (refer to Table 7) depending on the similarities—the size of unit household, starting day of projects, and region—of the project characteristics.

By applying the evaluation standard developed in Step 2.2 on the three groups, the level of design performance was evaluated, and Table 8 shows the results for public sale. For example, Group "A" of the three groups indicated that in terms of "main building characteristics" of the large category, "planability/comfortability," the DB1 (8.0) was superior to the DBB1 (4.5) and the DBB2 (5.5). In particular, the DBB2 (8.0) was superior to the DB1 (5.0) or the DBB1 (4.0) in terms of "parking lot plan." The reason for this is that the floor space of the projects provided, as the parking lot per household and underground parking was larger than that of other projects, and the projects were constructed with the structure, which integrated the underground parking lot and the main building. In the case of the large category, "usability," the DB1 method was shown to be superior to the DBB method in terms of "sunshine and ventilation," and "specialization of unit-household." The "level of finishing material and facilities" did not show any significant difference depending on the delivery methods.

### Public Lease

Just like the evaluation of design performance in public sale, the research team categorized three DB projects and five DBB projects into three groups depending on their characteristics (refer to Tables 6 and 7). As shown in Table 9, in the Group "A," all of the midcategories on the large category, "planability/comfortability" and "usability," indicated that the DB5 was superior to the DBB7&8. The analysis result of the "ecological floor space ratio" in terms of "environmentalability" showed that the DB5 (7.0) was somewhat better than the DBB7&8 (4.0) and all of the other evaluation items indicated that the DBB method was similar to the DB method. Generally, the DB5 in Group A was evaluated as showing better design performance than that of the DBB7&8. In addition, the level of design performance of the DBB method in public lease was inferior to that of the aforementioned public sale.

### Public Sale+Public Lease

Based on the three projects delivered by both DB and DBB methods (refer to Table 6 and 7), combining public sale and public lease were examined and the result is shown in Table 10. Just like the evaluation of design performance in public sale and public lease, the research team categorized three DB projects and three DBB projects into three groups (refer to Table 7).

As shown in Table 10, the analysis results of Group "A" showed that there were no differences between DB8 and DBB12 in the large categories of "quality," "maintainability/operability," and "safety/constructability." However, the DB8 was superior to the DBB12 in the large categories of "usability" and "environmental ability," and in particular, highly superior to the DBB12 in terms of "sunshine and ventilation," "flexible space," and "ecological floor space ratio."



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**Table 9.** Results of Evaluating Design Performance on Public Lease

| Evaluation items | | Group A | | | Group B | | | Group C | |
|---|---|---|---|---|---|---|---|---|---|
| Large category | Midcategory | DB5 | DBB7 | DBB8 | DB6 | DBB9 | DBB10 | DB7 | DBB11 |
| Planability/comfortability | Main building characteristics | 6.0 | 3.5 | 4.0 | 6.5 | 3.5 | 3.5 | 6.0 | 2.5 |
| | Harmony with surrounding environments | 9.0 | 6.0 | 3.0 | 8.0 | 7.0 | 2.0 | 9.0 | 4.0 |
| | Parking lot plan | 5.0 | 4.0 | 3.0 | 6.0 | 4.0 | 3.0 | 5.0 | 2.0 |
| | Consideration on the path of flow | 4.0 | 2.5 | 2.5 | 3.5 | 2.5 | 2.5 | 3.5 | 1.5 |
| Usability | Sunshine and ventilation | 6.0 | 3.0 | 2.0 | 7.0 | 4.0 | 4.0 | 4.0 | 2.0 |
| | Flexible space | 5.5 | 2.5 | 3.0 | 3.5 | 4.5 | 3.5 | 4.0 | 2.5 |
| | Specialization of unit-household | 6.0 | 0.5 | 1.0 | 7.0 | 4.0 | 2.0 | 5.0 | 2.0 |
| | Utility | 6.5 | 3.5 | 4.5 | 5.5 | 6.0 | 5.5 | 6.5 | 3.0 |
| Quality | Analysis on the level of finishing material | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 |
| | Analysis on the level of facility | 4.0 | 2.0 | 2.0 | 4.0 | 2.0 | 2.0 | 4.0 | 2.0 |
| Maintainability/operability | Maintenance and repair | 4.0 | 2.0 | 2.0 | 4.0 | 2.0 | 2.0 | 4.0 | 2.0 |
| | Energy-saving plan | 6.0 | 5.0 | 3.0 | 4.0 | 4.0 | 3.0 | 5.0 | 3.0 |
| Safety/constructability | Safety plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Fire plan | 5.0 | 5.0 | 3.5 | 5.0 | 3.5 | 3.5 | 5.0 | 5.0 |
| Environmental ability | Environmental plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Ecological floor space ratio | 7.0 | 4.0 | 4.0 | 5.0 | 5.0 | 3.0 | 5.0 | 3.0 |
| Total | | 81.0 | 81.5 | 50.5 | 44.5 | 77.0 | 60.0 | 74.0 | 42.5 |

## Effect of Delivery Methods on Design Performance

So far, the research team analyzed the design performance level (Tables 8–10) of public multifamily housing projects based on project type, as either public sale, public lease, or public+public lease. The research team also analyzed the impact of the delivery method on the design performance of public multifamily housing projects by examining whether the differences among midcategories made for evaluating design performance are due to the difference by delivery methods or by other factors using the ANOVA test. In previous research, the ANOVA test was used to measure how much independent variables (i.e., test time, form of equipment technology, safety and environmental factor, and delivery method in past research), affect each dependent variable (i.e., quality, technology, duration of steel erection, and performance) (McCabe et al. 1999; Goodrum and Haas 2002; Irizarry et al. 2005; Debella and Ries 2006). The following is a brief overview of the ANOVA test.

## ANOVA

An ANOVA is a very useful method in all research studies that deal with quantitative data. Major assumptions of ANOVA are the homogeneity of variances, which assumes that the variances in the different groups of the design are similar, and there is normal distribution of the data within each treatment group. ANOVA tests the null hypothesis that there are no mean differences between groups or treatments in the population (McCabe et al. 1999, 2002).

As shown in Tables 8–10, ANOVA was used to identify the kind of differences of the 16 midcategories with which the level of design performance was evaluated would show depending on delivery method. With the results of the ANOVA test, the influence of delivery methods on design performance was identified in this study. This study necessitates comparing two groups of observations—DB and DBB methods—both of which are independent but with a different mean for each group to identify the effect of delivery methods on design performance. So, the one-way ANOVA test was used in this paper.

The ANOVA model for single-factor studies can stated as follows:

$$Y_{ij} = \mu_i + \epsilon_{ij} \quad (1)$$

where $Y_{ij}$=value of the response variable in the $j$th trial for the $i$th factor level or treatment; $\mu_i$=parameters; and $\epsilon_{ij}$=independent $N(0,\sigma^2)$. $i=1,\ldots,r$; $j=1,\ldots,n_i$.

The total variability of the $Y_{ij}$ observations is denoted by SSTO for total sum of squares

$$\mathrm{SSTO} = \sum_i \sum_j (Y_{ij} - \overline{Y}_{..})^2 \quad (2)$$

The treatment sum of squares (SSTR) is denoted by Eq. (3)

$$\mathrm{SSTR} = \sum_i n_i(\overline{Y}_{i.} - \overline{Y}_{..})^2 \quad (3)$$

The SSTR=measure of the extent of differences between the estimated factor level means, based on the deviations of the estimated factor level mean $\overline{Y}_{i.}$ around the overall mean $\overline{Y}_{..}$.

The error sum of squares (SSE) is denoted by Eq. (4)

$$\mathrm{SSE} = \sum_i \sum_j (Y_{ij} - \overline{Y}_{.})^2 = \sum_i \sum_j e_{ij}^2 \quad (4)$$

The SSE=measure of the random variation of the observations around the respective estimated factor level means. Thus, the total sum of squares for the analysis of variance is therefore made up of these two components

$$\mathrm{SSTO} = \mathrm{SSTR} + \mathrm{SSE} \quad (5)$$



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**Table 10.** Results of Evaluating Design Performance on Public Sale+Public Lease

| Evaluation items | | Group A | | Group B | | Group C | |
|---|---|---|---|---|---|---|---|
| Large category | Midcategory | DB8 | DBB12 | DB9 | DBB13 | DB10 | DBB14 |
| Planability/comfortability | Main building characteristics | 7.0 | 6.0 | 7.0 | 6.0 | 6.0 | 6.0 |
| | Harmony with surrounding environments | 10.0 | 8.0 | 9.0 | 6.0 | 10.0 | 6.0 |
| | Parking lot plan | 5.0 | 7.0 | 8.0 | 4.0 | 5.5 | 4.0 |
| | Consideration on the path of flow | 3.0 | 4.0 | 4.0 | 2.0 | 4.0 | 3.0 |
| Usability | Sunshine and ventilation | 8.0 | 3.0 | 6.0 | 6.0 | 10.0 | 7.0 |
| | Flexible space | 5.0 | 1.5 | 4.5 | 2.5 | 4.5 | 3.0 |
| | Specialization of unit-household | 4.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.0 |
| | Utility | 4.5 | 4.0 | 5.0 | 5.5 | 4.5 | 5.5 |
| Quality | Analysis on the level of finishing material | 3.5 | 3.5 | 3.0 | 3.5 | 3.0 | 3.5 |
| | Analysis on the level of facility | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Maintainability/operability | Maintenance and repair | 2.0 | 1.0 | 2.0 | 1.0 | 2.0 | 1.0 |
| | Energy-saving plan | 5.0 | 5.0 | 5.0 | 3.0 | 5.0 | 4.0 |
| Safety/constructability | Safety plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Fire plan | 5.0 | 5.0 | 5.0 | 3.5 | 5.0 | 3.5 |
| Environmentalability | Environmental plan during construction | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| | Ecological floor space ratio | 8.0 | 4.0 | 8.0 | 6.0 | 7.0 | 4.0 |
| Total | | 76.0 | 61.0 | 76.5 | 59.0 | 76.5 | 59.5 |

Based on the aforementioned formula, the $F$ test is conducted to determine whether the factor level means $\mu_i$ are equal. In this study, the hypotheses for the $F$ test were set as follows:

$$H_0:\mu_1=\mu_2=\cdots=\mu_r, H_a:\text{not all } \mu_i \text{ are equal} \tag{6}$$

$H_0$ shows there is no difference among the midcategories of design performance depending on delivery methods. $\mu_r$=values produced from the 16 midcategories of the case study discussed previously. The $F$ value can be calculated by Eq. (7)

$$F=\{(\mathrm{SSTR}/df_{\mathrm{between}})/(\mathrm{SSE}/df_{\mathrm{within}})\}=(\mathrm{MS}_{\mathrm{between}}/\mathrm{MS}_{\mathrm{within}}) \tag{7}$$

where, $df_{\mathrm{between}}=K-1$ ($K$=number of groups); $df_{\mathrm{within}}=N-K$ ($N$=number of cases); and MS=SSE/$df$(SSE). Based on the above concepts, the SPSS Program for Windows 12.0 version is used for the ANOVA test.

### *Analysis of Difference on Design Performance Depending on Delivery Methods*

Based on the 16 midcategories extracted from the result of the case studies, this study performed an ANOVA test to analyze the differences in the design performance between two groups that have a different delivery method (i.e., DB and DBB). To perform the ANOVA test, the following assumptions must be satisfied:
1. Each sample group must follow the normal distribution;

**Table 11.** Results of Levene's Test Using SPSS

| Midcategory | Levene's test | $df_{\mathrm{between}}$ | $df_{\mathrm{within}}$ | $p$ value |
|---|---|---|---|---|
| Main building characteristics | 8.878 | 1 | 22 | 0.007 |
| Harmony with surrounding environments | 7.347 | 1 | 22 | 0.013 |
| Parking lot plan | 3.366 | 1 | 22 | 0.080 |
| Consideration on the path of flow | 2.051 | 1 | 22 | 0.166 |
| Sunshine and ventilation | 0.705 | 1 | 22 | 0.410 |
| Flexible space | 1.690 | 1 | 22 | 0.207 |
| Specialization of unit- household | 0.728 | 1 | 22 | 0.403 |
| Utility | 1.000 | 1 | 22 | 0.328 |
| Analysis on the level of finishing material | 0.035 | 1 | 22 | 0.854 |
| Analysis on the level of facility | 82.500 | 1 | 22 | 0.000 |
| Maintenance and repair | 1.163 | 1 | 22 | 0.293 |
| Energy-saving plan | 0.561 | 1 | 22 | 0.462 |
| Safety plan during construction | — | 1 | — | — |
| Fire plan | 103.125 | 1 | 22 | 0.000 |
| Environmental plan during construction | — | 1 | — | — |
| Ecological floor space ratio | 3.229 | 1 | 22 | 0.086 |



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**Table 12.** Result of ANOVA Test Using SPSS

| Midcategory | Source of variation | Sum square | $df$ | MS | $F$ | $p$ value |
|---|---|---|---|---|---|---|
| Parking lot plan | Between groups[a] | 6.786 | 1 | 6.786 | 3.436 | 0.077 |
| | Within groups[b] | 43.454 | 22 | 1.975 | — | — |
| | Total | 50.240 | 23 | — | — | — |
| Consideration on the path of flow | Between groups | 6.171 | 1 | 6.171 | 18.526 | 0.000 |
| | Within groups | 7.329 | 22 | 0.333 | — | — |
| | Total | 13.500 | 23 | — | — | — |
| Sunshine and ventilation | Between groups | 41.630 | 1 | 41.630 | 9.410 | 0.006 |
| | Within groups | 97.329 | 22 | 4.424 | — | — |
| | Total | 138.958 | 23 | — | — | — |
| Flexible space | Between groups | 8.703 | 1 | 8.703 | 15.071 | 0.001 |
| | Within groups | 12.704 | 22 | 0.577 | — | — |
| | Total | 21.406 | 23 | — | — | — |
| Specialization of unit-household | Between groups | 32.215 | 1 | 32.215 | 11.473 | 0.003 |
| | Within groups | 61.775 | 22 | 2.808 | — | — |
| | Total | 93.990 | 23 | — | — | — |
| Utility | Between groups | 4.074 | 1 | 4.074 | 4.303 | 0.050 |
| | Within groups | 20.832 | 22 | 0.947 | — | — |
| | Total | 24.906 | 23 | — | — | — |
| Analysis on the level of finishing material | Between groups | 0.005 | 1 | 0.005 | 0.045 | 0.834 |
| | Within groups | 2.329 | 22 | 0.106 | — | — |
| | Total | 2.333 | 23 | — | — | — |
| Maintenance and repair | Between groups | 3.868 | 1 | 3.868 | 4.537 | 0.045 |
| | Within groups | 18.757 | 22 | 0.853 | — | — |
| | Total | 22.625 | 23 | — | — | — |
| Energy-saving plan | Between groups | 9.430 | 1 | 9.430 | 11.196 | 0.003 |
| | Within groups | 18.529 | 22 | 0.842 | — | — |
| | Total | 27.958 | 23 | — | — | — |
| Ecological floor space ratio | Between groups | 14.668 | 1 | 14.668 | 5.872 | 0.024 |
| | Within groups | 54.957 | 22 | 2.498 | — | — |
| | Total | 69.625 | 23 | — | — | — |

[a]The relation between DB and DBB.

[b]The relations within DB or DBB.

2. Each sample group has the same variance; and
3. Each sample must be independent.

First, it has to be analyzed whether the data (Tables 8–10) that were used to evaluate the level of design performance of public multifamily housing projects would satisfy the above assumptions. In the SPSS statistical package, Levene's test can be used to verify the homogeneity of variance, which is the assumption that each sample group follows the normal distribution and the variance is equal. The concept of Levene's test is to verify whether $k$ number of any arbitrary samples has equal variance, and the amount of test statistics in a group with the size of $N$ divided into $k$ number of subgroups can be expressed as Eq. (8), where $N_i$=sample size of the $i$th subgroup

$$W=\left\{(N-k)\sum_{i=1}^{k}N_i(\overline{Z_i}-\overline{Z_{ik}})^2\right\}\Bigg/\left\{(k-1)\sum_{i=1}^{k}\sum_{j=1}^{N_i}(Z_{ij}-\overline{Z_i})^2\right\} \quad (8)$$

where $Z_{ij}$ represents one of the following three definitions:

- $Z_{ij}=|Y_{ij}-\overline{Y_i}|$, $\overline{Y_i}$=mean value of the $i$th subgroup;
- $Z_{ij}=|Y_{ij}-\tilde{Y}_i|$, $\tilde{Y}_i$=median value of the $i$th subgroup; and
- $Z_{ij}=|Y_{ij}-\overline{Y_i}|$, $\overline{Y_i}$=10% trimmed mean of the $i$th subgroup.

Also, $\overline{Z_i}$=group mean of $Z_{ij}$, whereas $\overline{Z_{ij}}$=overall mean of the $Z_{ij}$.

The result of Levene's test using SPSS (refer to Table 11) showed that the four midcategories—"main building characteristics," "harmony with surrounding environments," "analysis on the level of facilities," and "fire plan"—deviate from a 95% confidence interval (i.e., $p$ value $<0.05$). The two midcategories—"safety plan during construction," and "environmental plan during construction"—were also excluded from the ANOVA test since there were no differences among their variance. As shown in Tables 8–10, the scores of design performance for the two midcategories are equal in all groups (i.e., Groups A, B, C). It was determined that the two midcategories did not have the same variance, thus they were excluded from the ANOVA test. Therefore, ten out of 16 midcategories, excluding the six items, were considered. As shown in Table 12, the result of the ANOVA test shows that "parking lot plan ($F=3.436$, $p$ value=0.077)" and "analysis on the level of finishing material ($F=0.045$, $p$ value =0.834)" deviated from a 95% confidence interval ($p$ value $>0.05$). In other words, the null hypothesis that there is no difference in the mean of the two groups cannot be applied to these two items, and therefore, it cannot be said that there is a differ-



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**Table 13.** Results of Descriptive Statistics

| Midcategory | Delivery method | $N$ | Mean | Standard deviation | Standard error | 95% confidence interval Lower | 95% confidence interval Upper | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| Consideration on the path of flow | DB | 10 | 3.600 | 0.3944 | 0.1247 | 3.318 | 3.882 | 3.0 | 4.0 |
| | DBB | 14 | 2.571 | 0.6753 | 0.1805 | 2.182 | 2.961 | 1.5 | 4.0 |
| | Total | 24 | 3.000 | 0.7661 | 0.1564 | 2.676 | 3.324 | 1.5 | 4.0 |
| Sunshine and ventilation | DB | 10 | 7.600 | 2.0111 | 0.6360 | 6.161 | 9.039 | 4.0 | 10 |
| | DBB | 14 | 4.929 | 2.1649 | 0.5786 | 3.679 | 6.179 | 2.0 | 8.0 |
| | Total | 24 | 6.042 | 2.4580 | 0.5017 | 5.004 | 7.080 | 2.0 | 10 |
| Flexible space | DB | 10 | 4.400 | 0.6146 | 0.1944 | 3.960 | 4.840 | 3.5 | 5.5 |
| | DBB | 14 | 3.179 | 0.8460 | 0.2261 | 2.690 | 3.667 | 1.5 | 4.5 |
| | Total | 24 | 3.688 | 0.9647 | 0.1969 | 3.280 | 4.095 | 1.5 | 5.5 |
| Specialization of unit-household | DB | 10 | 5.600 | 1.3499 | 0.4269 | 4.634 | 6.566 | 4.0 | 7.0 |
| | DBB | 14 | 3.250 | 1.8683 | 0.4993 | 2.171 | 4.329 | 0.5 | 7.0 |
| | Total | 24 | 4.229 | 2.0215 | 0.4126 | 3.376 | 5.083 | 0.5 | 7.0 |
| Utility | DB | 10 | 5.300 | 0.8233 | 0.2603 | 4.711 | 5.889 | 4.5 | 6.5 |
| | DBB | 14 | 4.464 | 1.0645 | 0.2845 | 3.850 | 5.079 | 3.0 | 6.0 |
| | Total | 24 | 4.813 | 1.0406 | 0.2124 | 4.373 | 5.252 | 3.0 | 6.5 |
| Analysis on the level of finishing material | DB | 10 | 4.000 | 0.0000 | 0.0000 | 4.000 | 4.000 | 4.0 | 4.0 |
| | DBB | 14 | 3.071 | 0.9376 | 0.2506 | 2.530 | 3.613 | 2.0 | 4.0 |
| | Total | 24 | 3.458 | 0.8459 | 0.1727 | 3.101 | 3.816 | 2.0 | 4.0 |
| Maintenance and repair | DB | 10 | 2.600 | 0.9661 | 0.3055 | 1.909 | 3.291 | 2.0 | 4.0 |
| | DBB | 14 | 1.786 | 0.8926 | 0.2386 | 1.270 | 2.301 | 0.0 | 4.0 |
| | Total | 24 | 2.125 | 0.9918 | 0.2025 | 1.706 | 2.544 | 0.0 | 4.0 |
| Ecological floor space ratio | DB | 10 | 6.300 | 1.1595 | 0.3667 | 5.471 | 7.129 | 5.0 | 8.0 |
| | DBB | 14 | 4.714 | 1.8157 | 0.4853 | 3.666 | 5.763 | 2.0 | 8.0 |
| | Total | 24 | 5.375 | 1.7399 | 0.3552 | 4.640 | 6.110 | 2.0 | 8.0 |

ence in the level of design performance depending on delivery methods. Therefore, it was analyzed that eight of ten midcategories excluding the two items showed a difference depending on delivery methods.

First, in the design of public multifamily housing projects, the openness of the resident's flow and safety in movement in terms of "consideration on the path of flow ($F=18.526$, $p$ value $=0.000$)" showed the largest difference depending on the delivery methods. Second, "flexible space ($F=15.071$, $p$ value$=0.003$)" showed that the DB method, which extensively uses variable walls, had differences in design performance compared with that of the DBB method.

Third, the specialization of the front door of each household and the extensibility of the kitchen in terms of "specialization of unit-household ($F=11.473$, $p$ value$=0.003$)" showed that there is a difference in design performance between the DB and DBB methods as well as various construction knowledge to save energy in terms of "energy-saving plan" ($F=11.196$, $p$ value $=0.003$).

Fourth, "sunshine and ventilation ($F=9.410$, $p$ value=0.006)" of unit-household showed that the DB method, which has relatively more bays in each unit-household, showed a difference in design performance compared to the DBB method. Fifth, a green tract of land (%), water space, green way, afforestation of retaining wall, and program parking in terms of "ecological floor space ratio ($F=5.872$, $p$ value=0.024)" showed a difference depending on delivery methods.

Sixth, in the case of "maintenance and repair ($F=4.537$, $p$ value=0.045)," the prefabrication of interior facilities for maintenance and repair showed a difference depending on the delivery methods. Finally, in the case of "utility ($F=4.303$, $p$ value=0.050)," the bathroom space of unit-household, natural ventilation, and air flow, service space, and housewives' flow consideration showed that there is a difference in design performance between the DB and DBB methods.

In addition, in order to identify which of the eight midcategories showing differences depending on delivery methods produced superior results when they were applied to different delivery method (i.e., DB and DBB), the results of descriptive statistics of Tables 8–10 were used. As shown in Table 13, the "consideration on the path of flow" produced superior design performance when DB (mean 3.60, SD 0.39) was used instead of DBB (mean 2.57, SD 0.67). In the results of the mean and standard deviation on the remaining seven midcategories, the DB method produced better design performance than that of the DBB method in all of the seven items.

## Conclusion

Compared with the traditional DBB method, in general the DB method offers several advantages such as construction duration, cost, and quality in terms of the number of defect occurrences. However, the evaluation of the quality of a final product such as the frequency of defect occurrence may be the result of the delivery methods and that of the responsibility of the contractor who performed the project. Therefore, this study aimed at evaluating



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the design performance, in terms of quality, not of the final product but of the product in the initial stage of the project depending on delivery method.

Meanwhile, the most important issue while conducting this study was to provide objectivity and appropriateness to the evaluation standard constituted as evaluation items and rating criteria, which were developed by the research team and could be subjective. Therefore, the Delphi and AHP methods were used to provide as much objectivity as possible. Based on the evaluation standard developed through the process, the study then evaluated the design performance of public multifamily housing projects delivered either by the DB or DBB methods. In addition, the influence of delivery methods on design performance was identified through the ANOVA test.

While conducting the study the research team anticipated that the DB method in which practical experiences in construction can be easily applied into the design stage would play a significant role in the level of design performance limited to "constructability." However, due to the peculiarity of the Korean construction market where design evaluation has much more of an effect on the contractor selection process than that of the DBB method, the DB method showed superior design performance compared with that of the DBB method in eight midcategories (i.e., consideration on the path of flow, sunshine and ventilation, flexible space, specialization of unit-household, utility, analysis on the level of finishing material, maintenance and repair, and ecological floor space ratio).

This study developed the methodology (refer to Fig. 1) that the construction industry practitioners can use to analyze quantitatively the performance evaluation of qualitative aspects among various performance evaluation items of delivery methods and evaluate the design performance of other project types such as road or office construction projects other than public multifamily housing projects that specifically reflect Korea's situation. Furthermore, construction firms and owners can use the results of this study in selecting a delivery method appropriate to the project characteristics based on the evaluation items that have a significant influence on the design performance by the delivery method.

However, it should be pointed out that some of the other items, such as unit cost and construction speed, were not considered in evaluating the design performance depending on delivery methods. Therefore, it is difficult to confirm the superiority of the DB method with only the results of this study. In the future, it is necessary to analyze the design performance and the results of this study simultaneously, considering cost and time.

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