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*Research Article*

# Evaluation of Data Extracted from Floor Plans for Apartment Complex Remodeling

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South Korea has witnessed an increasing social demand for housing supply due to rapid urban population growth from the 1950s through the 1970s. At least two million houses have been in use for 30 years or more since the implementation of policies related to the mass production of apartment houses 20–30 years ago. Methods for improving the aging of domestic apartment houses and their living environment are reconstruction and remodeling, and the government has been encouraging remodeling by easing laws and regulations related to it. During the early stages of a typical remodeling project, many candidate floor plans arise in the process of finalizing the floor plan, resulting in significant time consumption in the iterative process for reviews and revisions. Extracting quantitative indicators by comparing floor plans before and after remodeling at the initial design stage and comparing the indicators of the target complex with the existing case can facilitate a more time-efficient and economical decision-making process. In this study, quantitative indicators were extracted from floor plans by applying a structural evaluation program for remodeling of apartment housing at five existing domestic apartment complexes (nine buildings in total), and a detailed comparative analysis was conducted. Evaluated indices included variations of floor area, load-bearing wall, nonbearing wall, slab, weight, area moment of inertia, torsional resistance, and visualization of removed, remaining, and new bearing walls. The proposed method can continuously accumulate data from domestic apartment house remodeling projects and accelerate the process by shortening the time required for final decision-making in future remodeling projects.

## 1. Introduction

In South Korea, the rapid growth of the urban population from the 1950s to the 1970s has resulted in an increasing public demand for housing supply. The proportion of detached houses was the largest in the 1990s, whereas the proportion of apartment houses rapidly increased from the 2000s. According to the 2020 Population and Housing Census [1], the number of apartment houses was approximately 14,410,000 units, accounting for 77.8% of the total number of housing units. Two to three decades after the implementation of policies related to the mass production of apartment houses, the issue of aging apartment houses is arising as a social problem requiring an appropriate solution. As of 2020, the number of housing units that were 20 years or older was 9.1 million, which accounted for 49.1% of the total number of housing units, an increase of 400,000 units from 8.7 million units (48.0%) in 2019. In the case of apartment houses having the highest proportion of residential households, 4.97 million units (42.7%) were older than 20 years and 1.12 million units (9.6%) were older than 30 years among the total 11.66 million units [1]. In the case of the first new town project, which started in 1989 for apartment complexes in Bundang-gu, Seongnam-si, 84% of apartment complexes have exceeded 15 years of service life, revealing the serious aging problem of apartment houses [2]. Thus, there is an increasing need for maintenance projects as the number of aging apartment houses increases in South Korea.

There are two types of maintenance projects for addressing the aging issue of domestic apartment houses and improving their living environment: reconstruction and remodeling [3, 4]. Reconstruction is a method of completely removing an old apartment house and constructing a new one. By contrast, remodeling is a method of improving the residential environment by removing a part of an apartment house and performing horizontal and vertical expansion, as well as structural reinforcement while maintaining most of the main structural members. Reconstruction is a suitable method for satisfying the needs of stakeholders such as building owners and residents; however, this method tends to be larger on a construction scale and costlier than remodeling [5, 6]. Although remodeling may be disadvantageous that there are restrictions on changing the existing floor plan compared with reconstruction, it has the advantages of a short construction period, low cost, and environmental friendliness in terms of lower construction waste [7, 8]. Therefore, the South Korean government has been encouraging remodeling rather than reconstruction, and regulations related to remodeling eligibility have been eased compared with those for reconstruction [9].

A load-bearing wall system has been mostly adopted for apartment houses in South Korea [10]. This practice could be attributed to economic feasibility, which is the main advantage of the bearing wall system. The floor height must be at least 3.2 m due to the height of the beam when applying a beam-column system to apartment houses, while it can be designed to be 2.6 m with a bearing wall system. In this way, a nine-story building, in which the beam-column system has been applied, can be constructed to be an eleven-story building with the same height by applying the bearing wall system. However, because space is partitioned by walls in the case of the bearing wall system, this system has the drawback that there are restrictions on floor plan changes during the remodeling process. As such, apartment houses, in which the bearing wall system has been applied inevitably, require the process of removing or adding load-bearing walls during the remodeling process [11, 12].

The expansion and change of the floor plan are considered at the initial stage of the remodeling project, and the floor plan after remodeling is created by reflecting this decision. In this process, demolition, maintenance, and addition of bearing walls are determined to some extent. Because the demolition of the bearing wall is directly related to the structural stability of the entire building, it is ideal to conduct a structural review at the initial design stage. However, due to a lack of information about structural analysis in the initial design plan and frequent changes in design until the decision of the final plan, structural analysis is usually not conducted at the initial design stage. Furthermore, because current regulations regarding the permissible amount of bearing wall removal have not been established, determining the available extent of bearing wall removal prior to structural analysis and reflecting it in the design are extremely difficult. However, because most aged buildings exhibit issues such as nonapplication of seismic design, concrete cracking, and rebar corrosion [13], and because horizontal and vertical expansion should be considered during remodeling, structural evaluation is essential.

Various studies have been conducted on structural stability evaluation for apartment house remodeling. In particular, since 2014, when vertical expansion during apartment remodeling was permitted, there has been active research on structural stability issues and related solutions [14–16]. Yoon et al. conducted an analytical review of allowable values and evaluation criteria for concrete carbonation, chloride content, cracks, surface degradation, and rebar corrosion based on domestic and foreign standards related to reinforcement concrete durability [17]. As a result, a reasonable approach was presented to structural stability evaluation for remodeling. Furthermore, Choi et al. and Yoo analyzed the structural stability of slabs and walls during the remodeling process using the finite element method [18, 19]. Hong et al. conducted a study involving a brief evaluation of a structural stability method based on the location and amount of bearing walls in apartment house remodeling [11]. Structural stability evaluation for apartment house remodeling consumes considerable manpower and time as well as requires copious information, which can be obtained only at the end of the remodeling project. Thus, most of the previous studies have addressed technologies that can be applied after finalizing the floor plan, while studies on developing technologies that enable structural evaluation at the initial design stage are scarce. Kim et al. introduced a method for the quantitative evaluation of floor plans based on building information modeling during the early stages of an apartment remodeling project [20]. Choi et al. derived a checklist to be considered in the planning stage of vertical expansion remodeling in terms of floor plans, structure, environmental performance, and economic efficiency [21]. Kim et al. presented an automation method of extracting and analyzing data on slabs and walls from before and after remodeling plans [22]. Extracting quantitative indicators from floor plans before and after remodeling at the initial design stage and identifying the status of the target complex by comparing indicators with the existing remodeling case could significantly save time and money in remodeling design. Therefore, this study aims to apply the authors' previous research [22] to five existing apartment complexes (nine buildings in total) in South Korea to extract quantitative indicators from floor plans and conduct a detailed comparative analysis. The resulting quantitative data in this study could be utilized to significantly reduce the time required at the initial design process for remodeling projects as well as the number of design changes before the finalized floor plan.

## 2. Automated Floor Plan Evaluation

Typical remodeling of apartment houses in South Korea includes horizontal and vertical expansion of the floor plan; in this process, the bearing wall, the main structural member, is removed or added. In a typical remodeling project, several candidate floor plans and revision processes are considered until the floor plan is finalized. However, structural analysis proceeds after the finalization of the floor plan, while plans are qualitatively evaluated without analyzing structure-related indices at the initial design stage. To solve this problem, our research team developed a program that could automatically extract and analyze various indicators of floor plans before and after remodeling [22]. The developed program can conduct basic analysis using computer-aided design (CAD) plans at the initial stage of the remodeling project. The outputs of this developed program include the amount of removed, remaining, and new bearing walls; three-dimensional views of each wall component overlaid on floor plans and their dimensions; area moment of inertia of walls; torsional resistance of floor plans; and structural performance index. However, the existing program has drawbacks that it does not support building floor plans and that its analysis covers only a simple unit floor plan. Through a series of algorithm updates, the program can now evaluate the building floor plan and calculate the dead load of floors by analyzing the nonbearing wall and slab in addition to the load-bearing wall. Moreover, the visualization function was added to provide an intuitive view of changes in bearing walls before and after remodeling by utilizing an overlapped plan. The main purpose of this study was to apply the updated automated floor plan evaluation program to five existing apartment complexes (nine buildings in all) in South Korea and perform a detailed comparative analysis. Thus, this paper intends to briefly describe the development and algorithm of the program. The detailed development process, algorithms, and data validation of this program can be found in the authors' previous work [22].

The program was developed in MATLAB (MathWorks) and operates according to the following flow: (1) preprocessing before and after remodeling plans based on CAD into image files; (2) importing, recognizing, and comparing the two image files; (3) computing parameters; and (4) reporting and visualizing. Figure 1 shows the main graphical user interface screen of the developed program. This program imports the preprocessed before and after remodeling plans using Import Plans buttons. Subsequently, the computing process proceeds by pressing the Structural Properties button. Based on the dimensional information obtained from floor plans, various parameters are calculated. Figure 2 shows a screenshot displaying the amount of removed, remaining, and new bearing walls, their rates and weights, area moment of inertia of walls ($I_{xx}$ and $I_{yy}$), and torsional resistance of floor plans (geometry center, mass center, and the distance between two centers). A user inputs the wall height (m), longest dimension of the wall (m), and density of reinforced concrete (kg/m$^3$), and the program utilizes these inputs to convert the information of floor plans into physical dimensions. The longest dimension of the wall (m) refers to the actual length of the longest wall in floor plans. Furthermore, the developed program provides information related to the non-bearing wall, dead load, and overlapped plan. The calculation and comparative analysis results for each index are described in detail in the next section.

## 3. Information of Evaluated Apartment Complexes

Nine building floor plans (Building IDs A–I) from five existing apartment complexes (Complex IDs I–V) were evaluated using the developed program. Information about the evaluated five apartment complexes is given in Table 1, and floor plans of all buildings before and after remodeling are shown in Figure 3. Building IDs A and B, C and D, E and F, G and H, and I are in apartment complexes I, II, III, IV, and V, respectively. The structural type of all nine buildings is identical to a load-bearing wall structure with reinforced concrete. Four apartment complexes, except complex I, are located in Seoul, South Korea. According to Article 2, Subparagraph 25 of the Housing Act [23], apartment houses exceeding 15 years from the initial year of completion may be remodeled. The initial year of completion of the nine apartment buildings listed in Table 1 is in the early to middle of the 1990s, while the remaining four complexes (except Complex ID V) are currently undergoing remodeling. The remodeling project of Complex ID V was discontinued in October 2021 due to structural stability issues. Figure 3 reveals that all buildings have undergone horizontal expansion, and the resulting building-to-land ratio increased to 12.5%–40.2%, with an average increase of 25.4%. According to the Housing Act [23], vertical expansion may be permitted for two floors or less in 14-story buildings or three floors or less in 15-story or higher buildings. Because all buildings other than Building IDs C and D (12 and 13 floors, respectively) have 15 or more stories, vertical expansion was performed on three floors. In Table 1, the (−) and (+) signs refer to the floor below and above ground, respectively. According to the Housing Act [23], the number of units that can be added after remodeling is up to 15%; thus, the number of units increased by 14.9%, 13.9%, 13.4%, 14.1%, and 15.0% for Complex IDs I–V, respectively. The floor area ratio is calculated total floor area/land area $\times$ 100%. The floor area ratio of the target complexes was 229.4% on average before remodeling and increased to 354.4% on average after remodeling. According to Articles 54 and 55 of the Seoul Metropolitan Government Ordinance on Urban Planning, in the case of a new building in the Type 3 general residential area, the building-to-land ratio and the floor area ratio are limited to 50% and 250%, respectively. Later, the South Korean government announced its housing supply plan in 2021, indicating that the floor area ratio may be raised by 120% in the case of reconstruction. Thus, if this plan is applied, the floor area ratio can be set to a maximum of 300% for the reconstruction of apartments located in Seoul. By contrast, the provisions of eased regulations formulated after deliberation by the competent building committee may be applied in the case of remodeling, exceeding this limit. Therefore, the floor area ratios of the apartment complexes II, IV, and V exceeded 300% after remodeling.

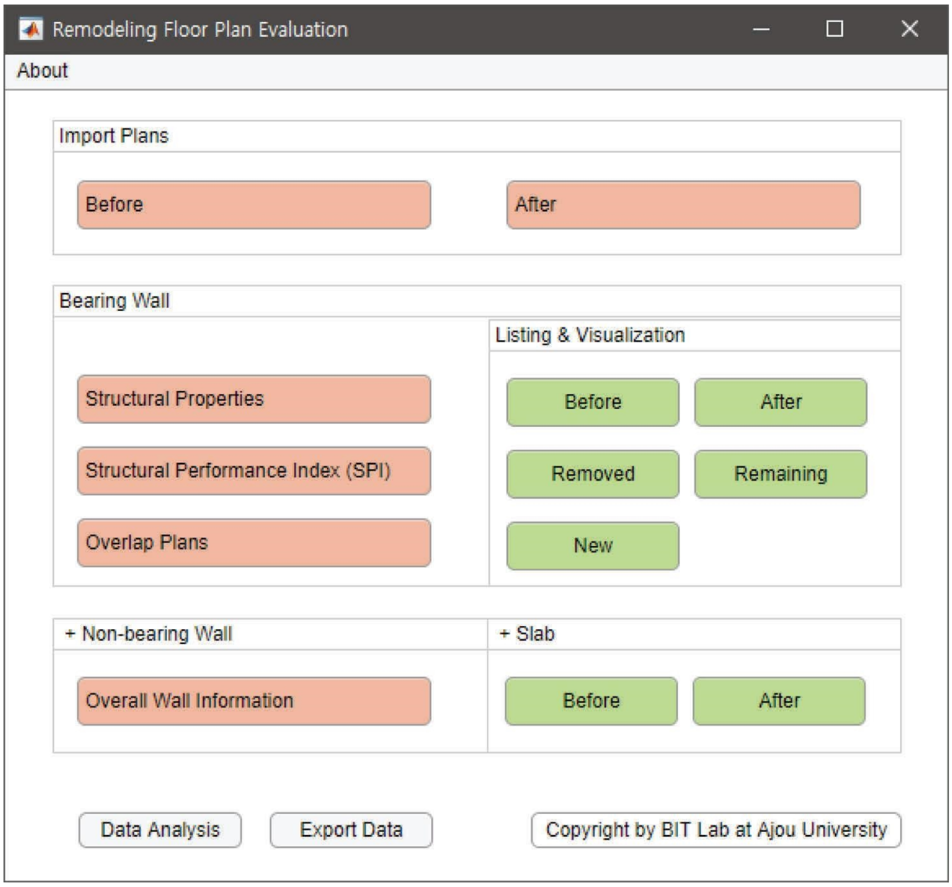



Figure 1: Graphical user interface of the developed program.

## 4. Analyses of before and after Remodeling Floor Plans

Table 2 summarizes the data extracted by inputting the floor plans of the nine apartment buildings into the developed automated floor plan evaluation program. This table provides 11 indices extracted from floor plans under the categories of before and after remodeling, and all indices are per floor data without considering the number of floors. Among the indices in this table, the LB-wall and NB-wall refer to the load-bearing wall and nonbearing walls, respectively, and eccentricity refers to the distance between the geometry center and the mass center. The analysis and detailed description of each index are given in the subsequent subsection.

*4.1. Floor Area.* A crucial factor in the changed floor plan after remodeling is the expansion of the existing residential space. According to the Housing Construction Promotion Act [24], houses with a unit area of 85 $m^2$ or less were designated as national housing. The domestic apartment house market has, since then, consistently reflected the demand for living in a better environment over the past half century, exhibiting preference for a wider residential space compared with the past [25]. Thus, recent remodeling of domestic apartment houses has been required to include horizontal expansion. Figure 4 compares the floor area variation of the nine apartment buildings analyzed after remodeling. After remodeling, the average floor area increased by 41%. The total area of Building ID E, whose increase in the total area was the largest, nearly doubled from 669 to 1,253 $m^2$, whereas that of Building ID I increased by 12% from 853 to 961 $m^2$, indicating the smallest increase rate. Notably, the floor plan of each complex (Figure 3) shows that the number of units increased in the case of Building IDs E, F, and I, unlike Building IDs A–D, G, and H. When the number of units before and after remodeling is the same, the increment ratio shown in Figure 4 has a linear relationship with the expanded residential space of each unit; however, this is inapplicable in the case where the number of units has increased.

Typically, interunit walls, which separate units, are subjected to higher loads compared with other bearing walls. Consequently, the removal of interunit walls is prohibited during domestic apartment remodeling. Because horizontal expansion in left and right directions is impossible due to interunit walls during remodeling, as shown in Figure 3, expansion should be applied along forward and backward directions [26, 27]. In addition to limits set by the land borderline, horizontal expansion in the remodeling of apartment houses is subjected to the building-to-land ratio [28], floor area ratio [29], right to sunlight [30], and distance between buildings [30]. The Seoul Metropolitan Government

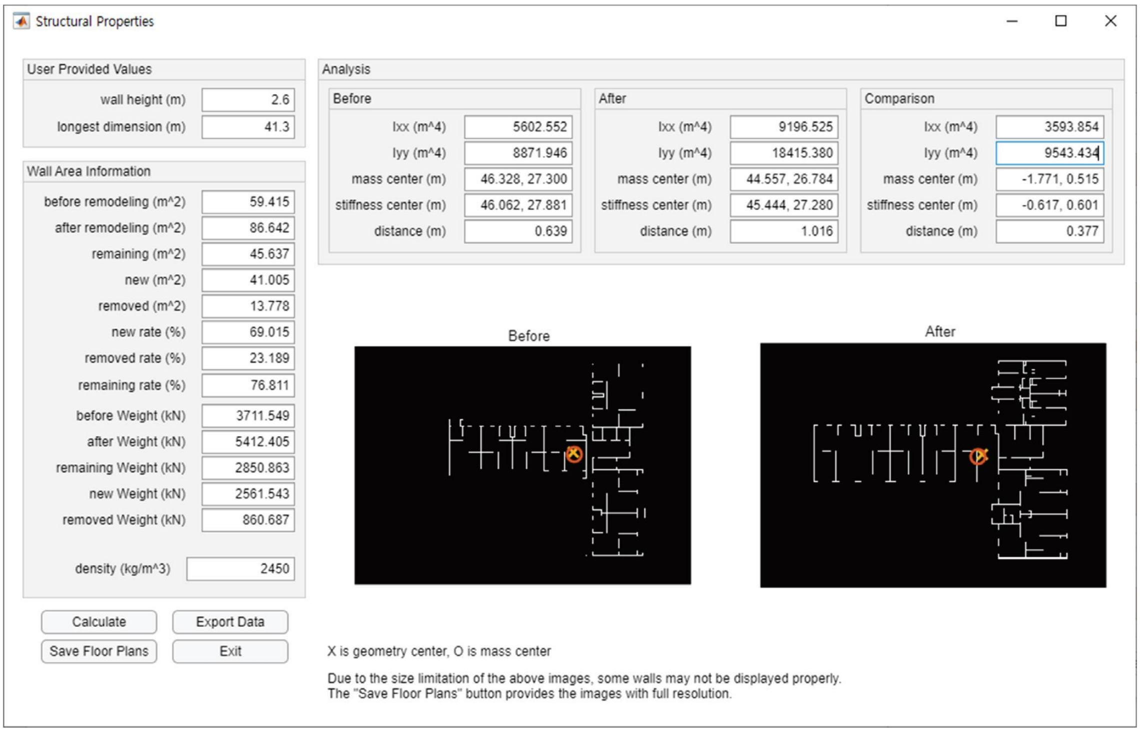


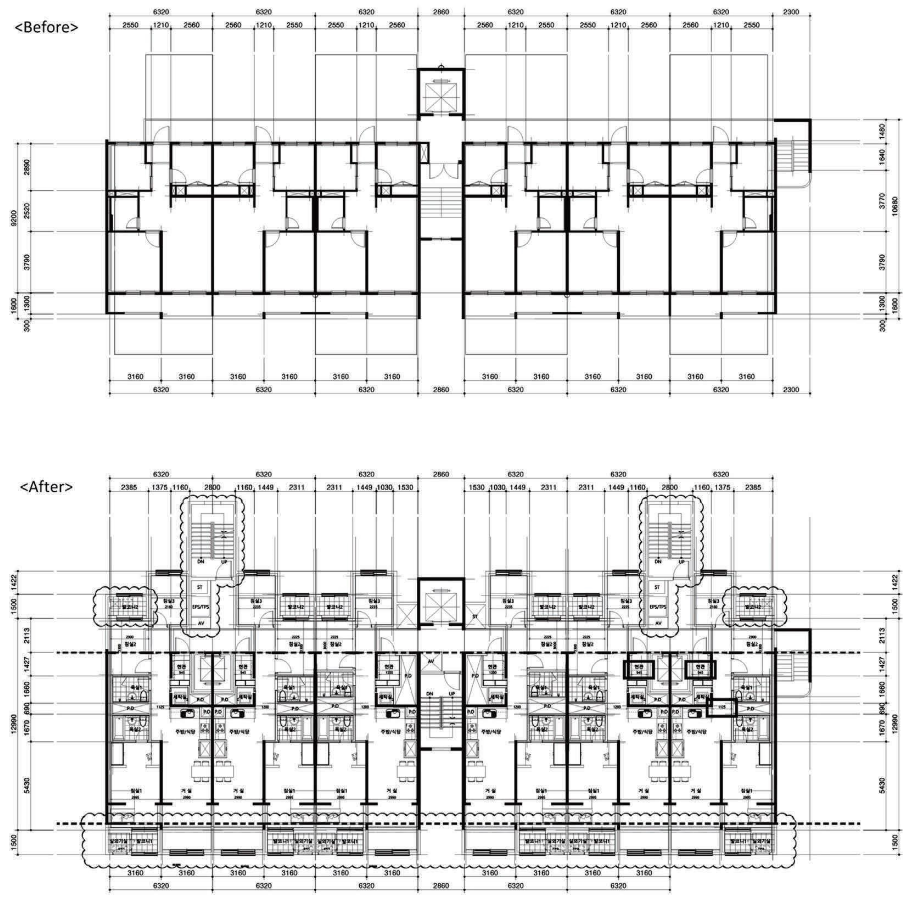

Figure 2: Automated floor plan evaluation.

Table 1: Apartment complex information.

| Items | Complex ID (Building ID) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | I (A and B) | | II (C and D) | | III (E and F) | | IV (G and H) | | V (I) | |
| | Before | After | Before | After | Before | After | Before | After | Before | After |
| Location | Gyeonggi province | | Seoul | | Seoul | | Seoul | | Seoul | |
| Land area ($m^2$) | 24,193 | | 7,215 | | 53,259 | | 10,286 | | 4,848 | |
| Year of completion | 1995 | Ongoing | 1992 | Ongoing | 1992 | Ongoing | 1992 | Ongoing | 1992 | Canceled |
| Building area ($m^2$) | 3,014 | 5,111 | 1,768 | 2,274 | 8,295 | 14,883 | 2,407 | 4,134 | 1,037 | 1,726 |
| Building-to-land ratio (%) | 12.5 | 21.1 | 24.5 | 31.5 | 15.6 | 28.0 | 23.4 | 40.2 | 21.4 | 35.6 |
| Total floor area ($m^2$) | −4,837<br>+41,669 | −32,226<br>+64,154 | −4,135<br>+18,845 | −10,580<br>+28,480 | −8,019<br>+97,362 | −93,453<br>+153,988 | −5,281<br>+28,211 | −14,774<br>+44,374 | −1,095<br>+11,491 | −7,110<br>+18,797 |
| Floor area ratio (%) | 172.2 | 264.1 | 268.5 | 399.7 | 182.8 | 289.1 | 274.3 | 431.4 | 248.9 | 387.8 |
| # Units | 563 | 647 | 208 | 237 | 1,753 | 1,988 | 298 | 340 | 120 | 138 |
| # Floors | −1<br>+25 | −2<br>+28 | −1<br>+12–13 | −4<br>+13–15 | −1<br>+15 | −3<br>+18 | −2<br>+15 | −3<br>+18 | −1<br>+15 | −3<br>+18 |

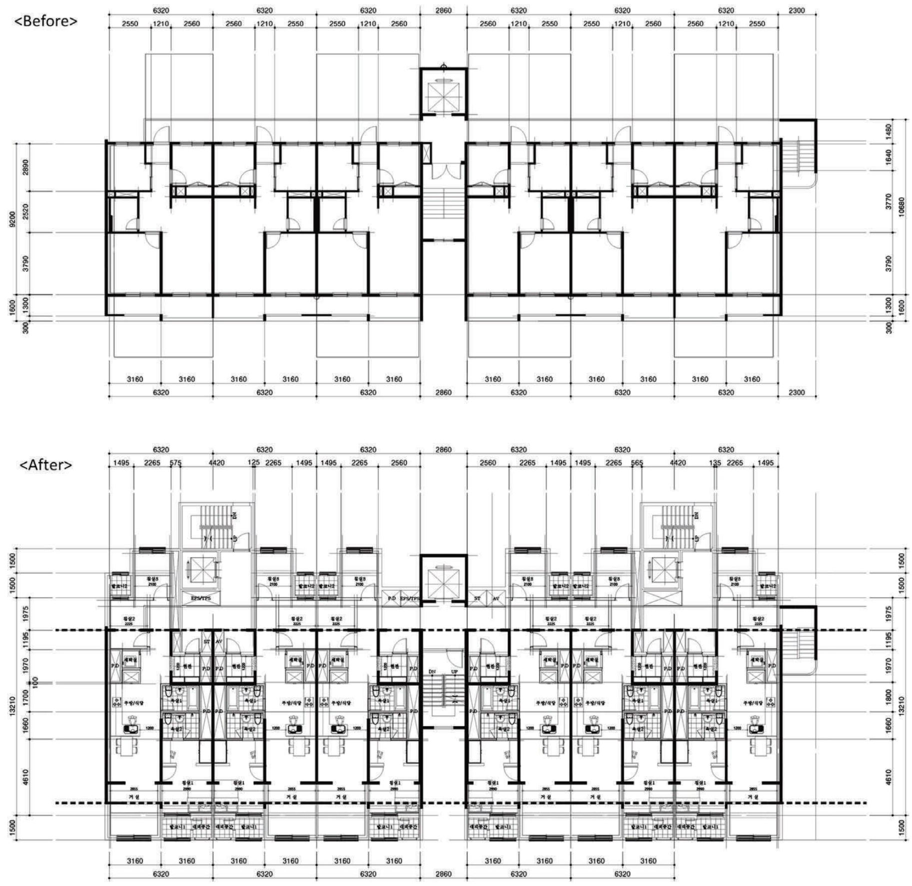
has recently eased restrictions on the building-to-land ratio applied to horizontal expansion during recent remodeling. The building-to-land ratio was previously allowed up to 30%; however, this rule has been revised to allow the building committee to determine the ratio by deliberation, depending on the plan and site status. Consequently, in the case of Building IDs C–I located in Seoul, the building-to-land ratio after remodeling has mostly increased by 30% or higher, as depicted in Table 1. By contrast, in the case of Building IDs A and B located in Gyeonggi-do, the building-to-land ratio after remodeling is relatively low at 21.1%.

*4.2. Load-Bearing Wall.* Most of the recent domestic apartment house remodeling projects have involved reorganization of the floor plan as well as horizontal expansion. Thus, the removal and addition of the load-bearing wall partitioning the space are inevitable. As more bearing walls are demolished, a greater margin is available for the reorganization of space during remodeling. Nevertheless, excessive demolition of bearing walls can degrade the structural stability of the entire building. Figure 5 shows a plot comparing the variation of load-bearing wall areas of the nine apartment buildings. The average value of the area per floor of the load-bearing wall before remodeling was 58 $m^2$, while that after remodeling nearly doubled to 110 $m^2$. With respect to the increment ratio, after remodeling, the load-bearing wall increased from a minimum of 1.5 times (Building ID D) to a maximum of 3.3 times (Building ID E). Building IDs E and F exhibited a more than twofold increase, with 332% and 265%, respectively.




(a)

Figure 3: Continued.

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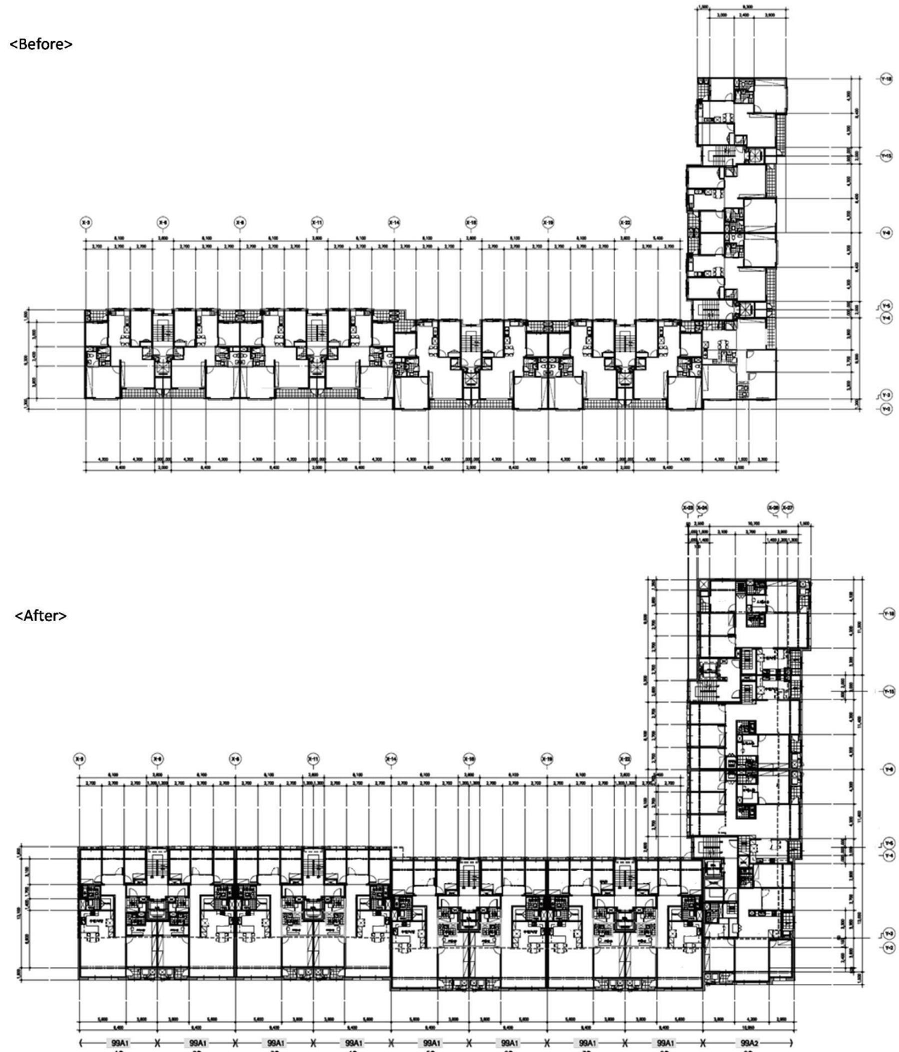


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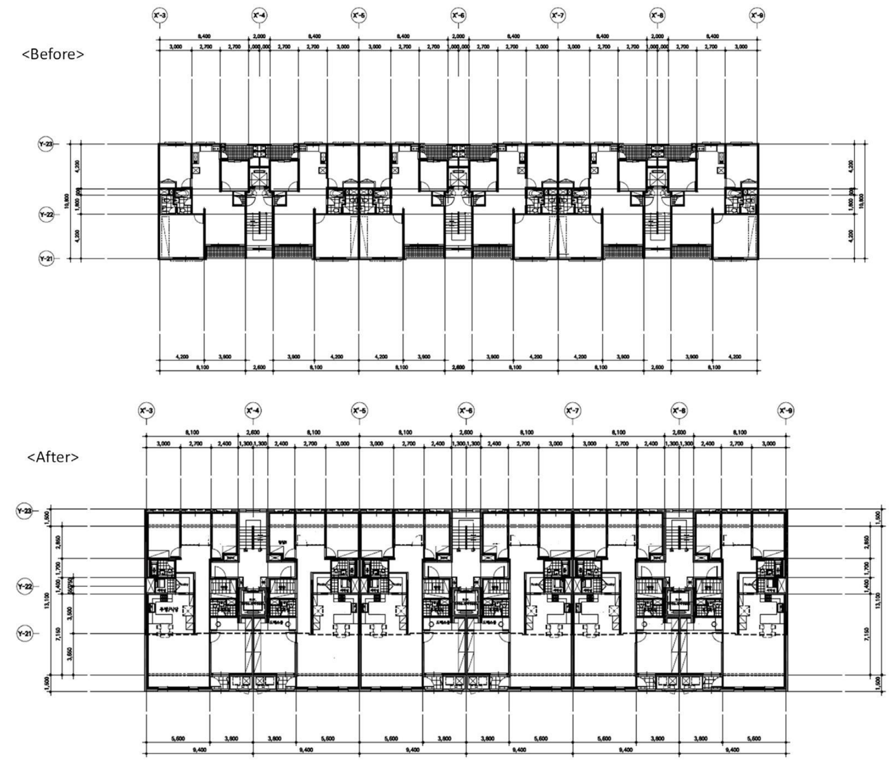


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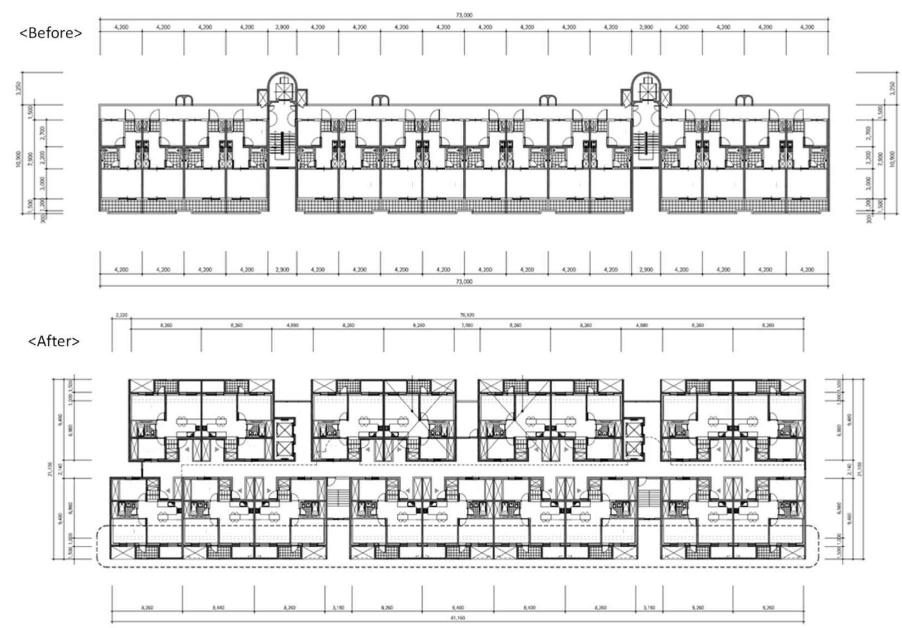


(e)

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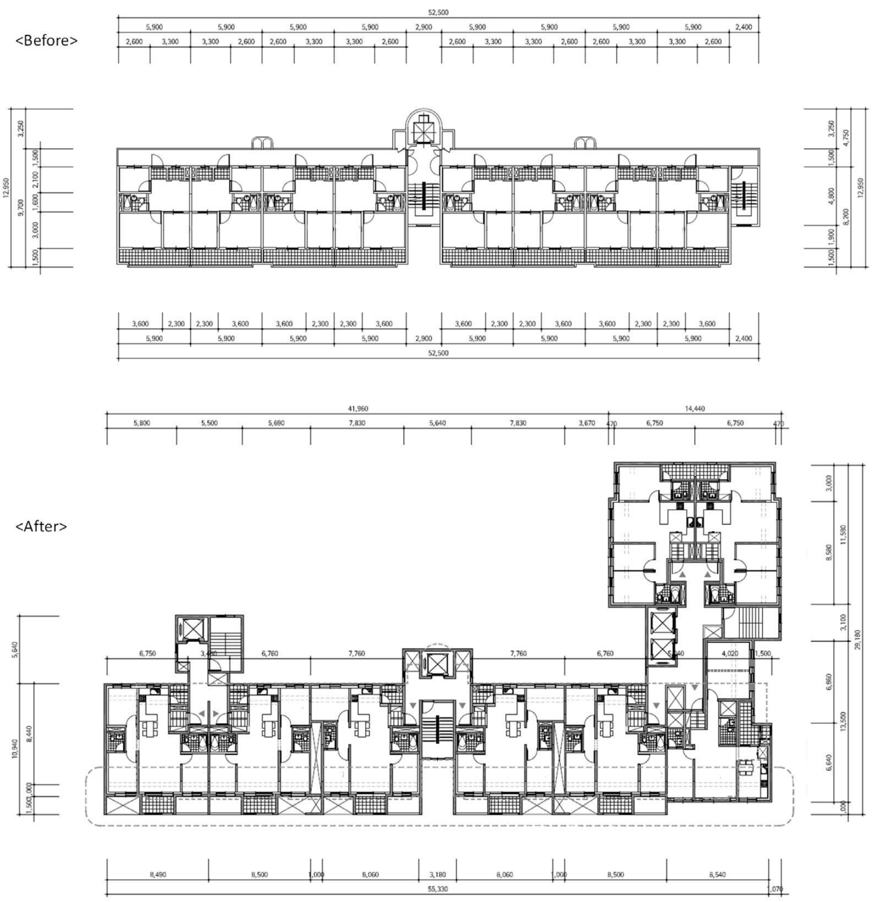


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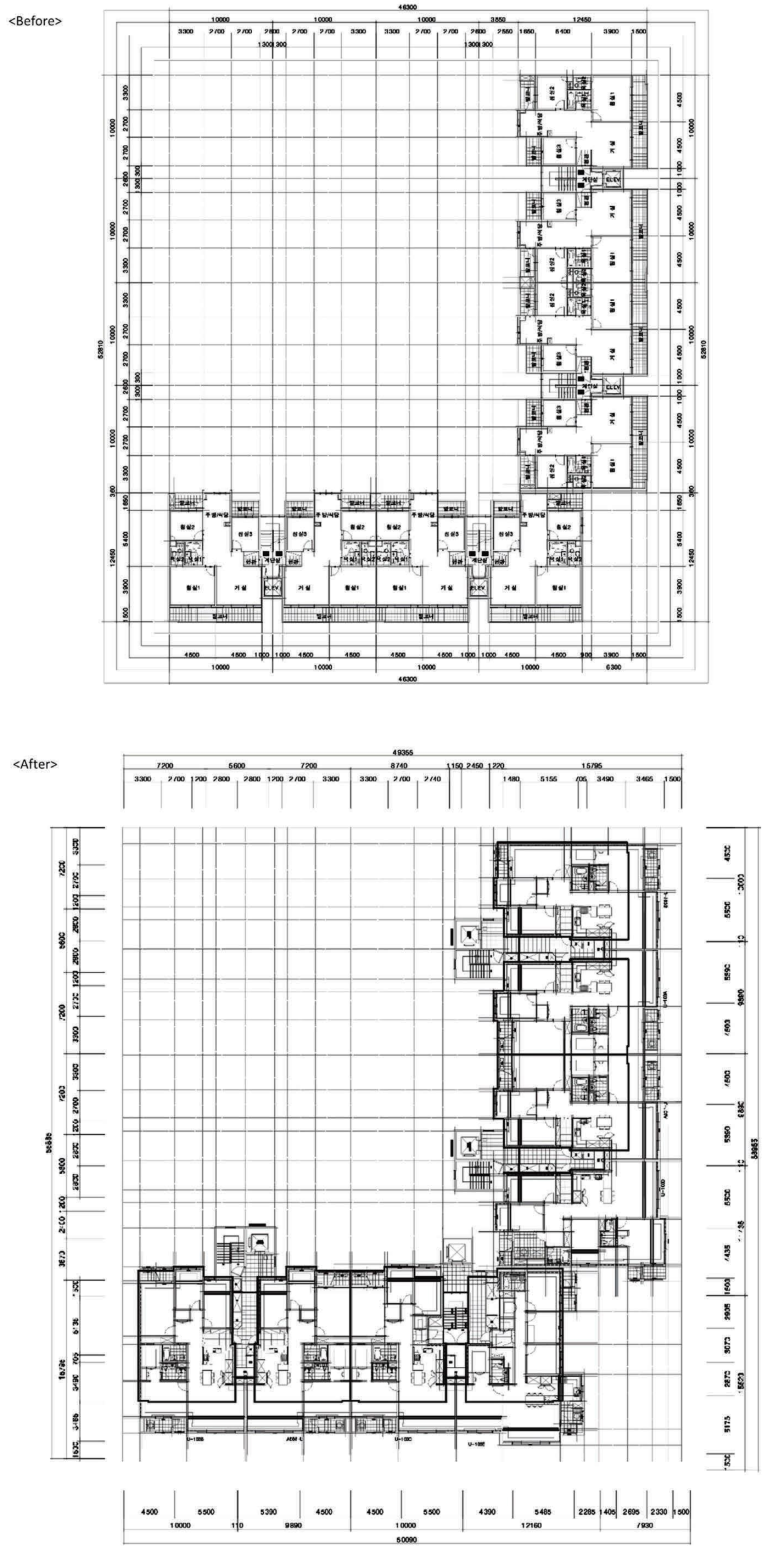


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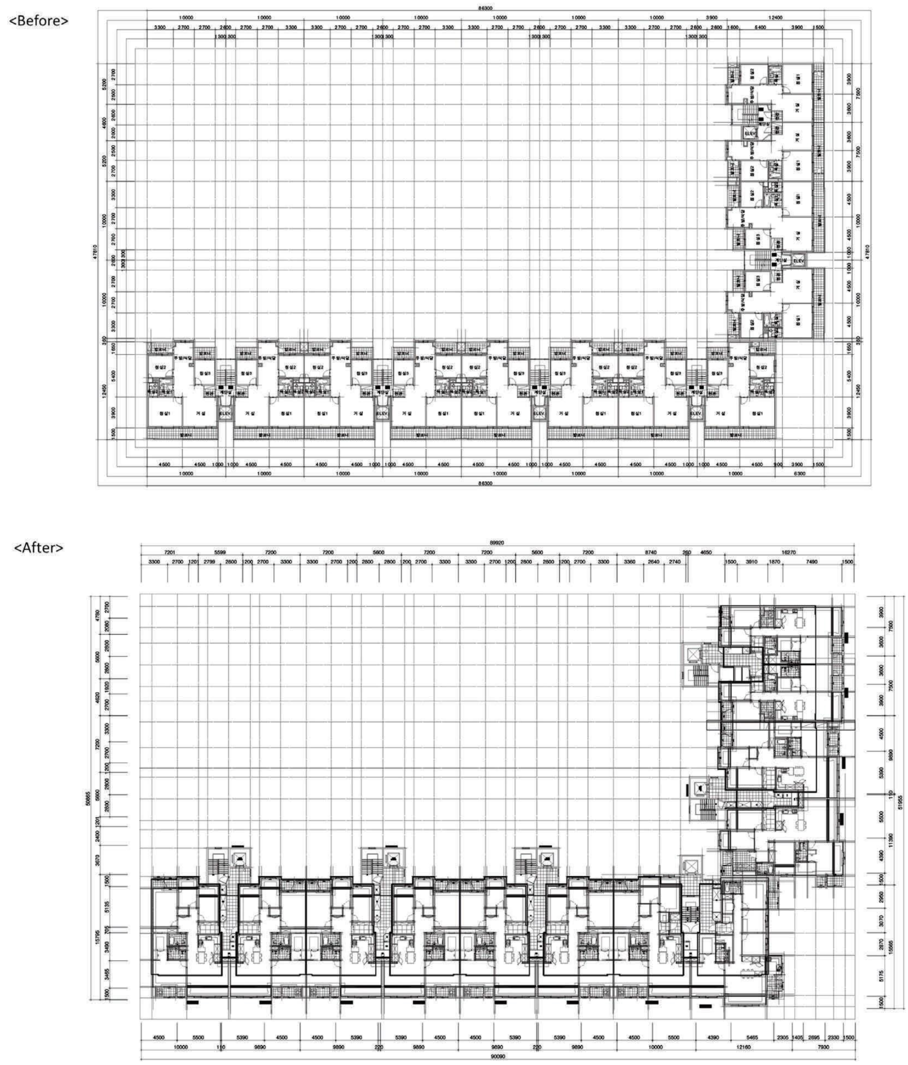


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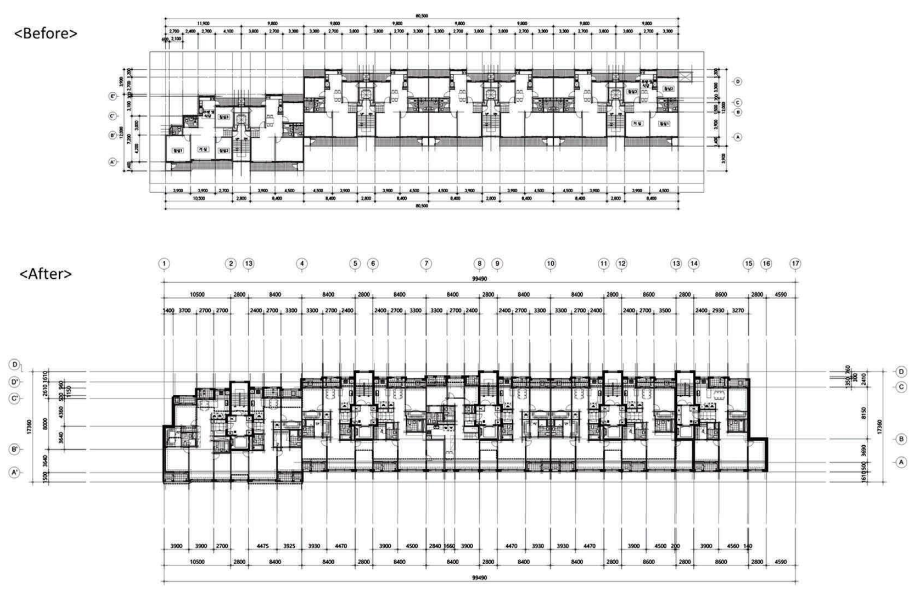



(i)

Figure 3: Before and after remodeling floor plans. (a) Building ID A, (b) Building ID B, (c) Building ID C, (d) Building ID D, (e) Building ID E, (f) Building ID F, (g) Building ID G, (h) Building ID H, and (i) Building ID I.

Table 2: Data extracted from the nine floor plans.

| Types | Index (per floor) | Building ID A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|
| Before | Floor area ($m^2$) | 554 | 554 | 1,165 | 592 | 669 | 418 | 955 | 1,371 | 853 |
| | LB-wall area ($m^2$) | 36 | 36 | 84 | 45 | 48 | 31 | 65 | 113 | 59 |
| | NB-wall area ($m^2$) | 15 | 15 | 51 | 25 | 53 | 24 | 27 | 45 | 31 |
| | Floor dead load (kN) | 5,763 | 5,763 | 13,596 | 7,031 | 8,927 | 5,224 | 10,222 | 16,197 | 9,516 |
| | LB-wall weight (kN) | 2,254 | 2,254 | 5,233 | 2,808 | 3,000 | 1,955 | 4,072 | 7,075 | 3,688 |
| | NB-wall weight (kN) | 712 | 712 | 2,487 | 1,235 | 2,553 | 1,159 | 1,330 | 2,204 | 1,523 |
| | Slab weight (kN) | 2,797 | 2,797 | 5,876 | 2,988 | 3,374 | 2,109 | 4,820 | 6,918 | 4,305 |
| | Weight/area ($kN/m^2$) | 10.4 | 10.4 | 11.7 | 11.9 | 13.3 | 12.5 | 10.7 | 11.8 | 11.2 |
| | $I_{xx}$ ($m^4$) | 583 | 583 | 8,366 | 402 | 304 | 162 | 16,159 | 19,399 | 832 |
| | $I_{yy}$ ($m^4$) | 6,010 | 6,010 | 57,278 | 13,070 | 20,906 | 7,928 | 11,193 | 80,374 | 33,413 |
| | Eccentricity (cm) | 55.8 | 55.8 | 81.7 | 59.4 | 33.3 | 93.1 | 15.6 | 183.8 | 79.9 |
| After | Floor area ($m^2$) | 780 | 793 | 1,669 | 895 | 1,253 | 728 | 1,170 | 1,816 | 961 |
| | LB-wall area ($m^2$) | 65 | 66 | 146 | 70 | 159 | 83 | 104 | 182 | 110 |
| | NB-wall area ($m^2$) | 25 | 21 | 50 | 27 | 3 | 9 | 27 | 6 | 17 |
| | Floor dead load (kN) | 9,249 | 9,170 | 19,430 | 10,209 | 14,462 | 8,600 | 12,803 | 19,905 | 10,871 |
| | LB-wall weight (kN) | 4,103 | 4,142 | 8,563 | 4,389 | 7,995 | 4,481 | 5,598 | 10,435 | 5,184 |
| | NB-wall weight (kN) | 1,209 | 1,026 | 2,445 | 1,307 | 145 | 446 | 1,301 | 307 | 838 |
| | Slab weight (kN) | 3,937 | 4,002 | 8,422 | 4,514 | 6,321 | 3,674 | 5,904 | 9,163 | 4,849 |
| | Weight/area ($kN/m^2$) | 11.9 | 11.6 | 11.6 | 11.4 | 11.5 | 11.8 | 10.9 | 11.0 | 11.3 |
| | $I_{xx}$ ($m^4$) | 2,489 | 2,220 | 22,006 | 1,892 | 6,273 | 4,807 | 26,785 | 32,913 | 2,600 |
| | $I_{yy}$ ($m^4$) | 11,306 | 10,079 | 104,132 | 20,197 | 86,668 | 24,532 | 18,791 | 128,467 | 85,888 |
| | Eccentricity (cm) | 13.1 | 31.7 | 196.2 | 70.9 | 12.8 | 38.9 | 90.7 | 77.9 | 78.2 |

Recent common-sized apartments in South Korea have mostly comprised three rooms, with typically two rooms and a living room being adjacent to a front balcony, which is often called a three-bay system. For most of the domestic apartment houses in the past, a two-bay system (A–D, and F–I in Figure 3) or (rarely) a one-bay system (Building ID E) was applied. The recent trend shows that the number of bays is being increased for reasons such as daylighting and that it is rarely increased even during remodeling. Building IDs E and F correspond to cases where the number of bays was increased from 1 to 2 and 2 to 3, respectively. As such, unlike other buildings, in which the number of bays was maintained, Building IDs E and F showed a larger increase in load-bearing walls after remodeling.

The rise in the floor area requires the increase in the load-bearing wall area to maintain structural performance. To determine the correlation between the size of the floor area and the proportion of the bearing wall, the relationship between the increment ratios of the load-bearing wall and the floor area for the nine apartment buildings after remodeling was plotted, as shown in Figure 6. The increase rate of the floor area was 113%–187%, while that of the bearing wall was 156%–332%, indicating that the bearing wall area-to-unit area ratio increased after remodeling. This result can be attributed to the application of the domestic seismic design code, which has become stricter since 2016. When the increase rate of the floor area was less than 160%, the increase rate of the load-bearing wall area was 156%–187%, whereas it sharply rose to more than 2.6 times when the increase rate of the floor area was 160% or higher (Building IDs E and F). As described previously, this result could be attributed to the increase in the number of bays in apartment Complex ID III after remodeling.

Table 3 and Figure 7 present the area of removed, remaining, and new bearing walls and their ratios with respect to the total bearing wall area before remodeling, respectively. An average of 22% of load-bearing walls were removed in the nine apartment buildings after remodeling, ranging from 7.2% (Building ID E) to 42.1% (Building ID I). The proportion of the remaining bearing walls was calculated to be 78.4% on average. The proportion of new bearing walls ranged from 75.7% to 238.8%, with an average of 101% for nine buildings. The highest proportion of new bearing walls was for Building IDs E (238.8%) and F (195.0%), which may be attributed to the increase in the number of bays.

Because the addition of load-bearing walls in the remodeling project proceeds after the removal of walls, the remaining bearing walls alone must support the load of the entire building during the construction process between the removal and addition of bearing walls. Because the removal of the bearing wall is thus directly related to safety, removal must be carefully designed. Table 4 lists the total area of the bearing wall and area of the remaining bearing wall-to-floor area ratios before remodeling. Bearing walls constituted an average of 7.2% of the nine buildings' floor area before remodeling, while the proportion decreased to an average of 5.6% after the removal of bearing walls. In the case of Building ID I, where the largest amount of bearing walls was removed, the bearing walls that were 6.9% of the floor area before remodeling were removed up to 4.0%. This result suggests that the proportion of removed bearing walls in Building ID I was considerably large compared with the remaining eight buildings. The reasons for the discontinuation of the remodeling project of Building ID I may include this excessive removal of bearing walls.

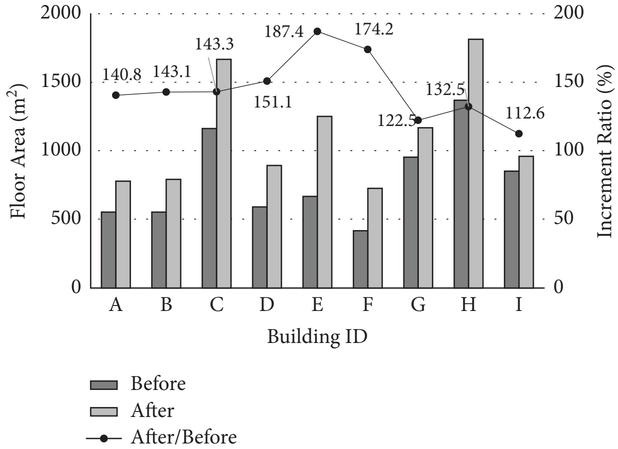



Figure 4: Floor area variation after remodeling.

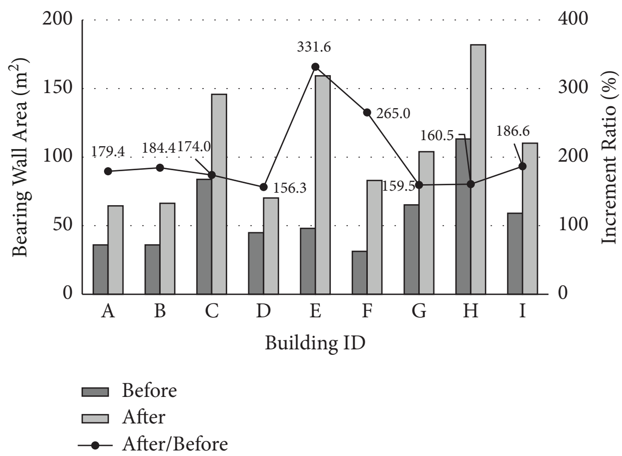



Figure 5: Variation of load-bearing wall areas after remodeling.

*4.3. Weight.* The increase in the weight of the entire building after remodeling is inevitable due to horizontal and vertical expansions as well as the rise in the bearing wall area, which leads to an increase in the lateral load. Furthermore, the increase in the weight of the entire building requires strengthening of the foundation, and the excessive addition of the foundation leads to a rise in the construction cost, which is a major factor decreasing the feasibility of remodeling apartment houses. Thus, the increasing floor weight after remodeling could be calculated from candidate floor plans presented at the early stage of a remodeling project; this outcome will significantly contribute to the remodeling planning and decision-making process. In this study, the developed program was utilized to compute the weights of the bearing wall, nonbearing wall, and slab before and after remodeling, calculate the floor weight by adding them, and obtain the unit floor weight by dividing this value by the floor area. Figure 8 compares the values calculated for the nine apartment buildings. The average floor weight after remodeling increased from 9,138 to 12,744 kN, approximately 1.4 times. The increase in the floor weights of Building IDs E and F with the increased number of bays was the largest among nine buildings at 162.0% and 164.6%, respectively. By contrast, the increase in the floor weight after remodeling was the smallest in Building ID I (114.2%). This result may be directly attributed to the smallest floor area increment of Building ID I (Figure 4). The unit floor weight was

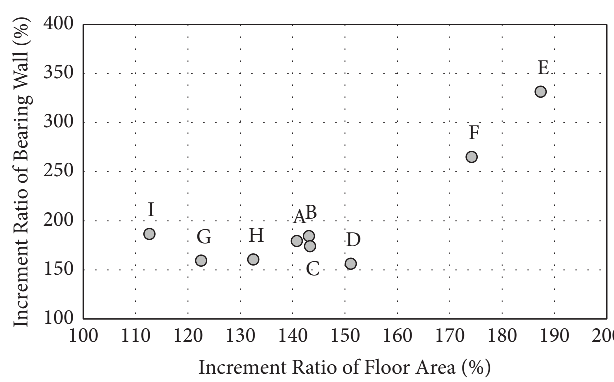



Figure 6: Relationship between increment ratios of the load-bearing wall and the floor area.

Table 3: Area of removed, remaining, and new load-bearing walls after remodeling ($m^2$).

| Wall type | Building ID | | | | | | | | | AVG |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | |
| Removed | 7.8 | 5.4 | 17.2 | 13.5 | 3.5 | 9.4 | 10.7 | 17.2 | 24.9 | 12.2 |
| Remaining | 28.2 | 30.6 | 66.6 | 31.4 | 44.6 | 21.9 | 54.5 | 96.1 | 34.2 | 45.3 |
| New | 36.3 | 35.7 | 79.2 | 38.8 | 114.7 | 61.0 | 49.5 | 85.7 | 76.0 | 64.1 |

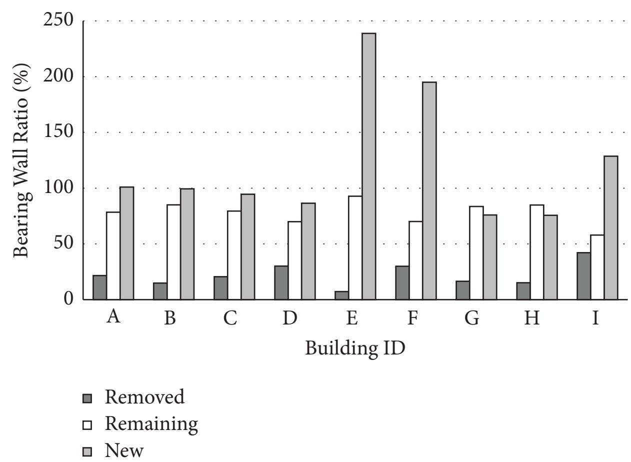



Figure 7: Ratio of removed, remaining, and new load-bearing walls after remodeling.

Table 4: Bearing wall-to-floor area ratios before remodeling (%).

| Wall type | Building ID | | | | | | | | | AVG |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | |
| Total | 6.5 | 6.5 | 7.2 | 7.6 | 7.2 | 7.5 | 6.8 | 8.3 | 6.9 | 7.2 |
| Remaining | 5.1 | 5.5 | 5.7 | 5.3 | 6.7 | 5.2 | 5.7 | 7.0 | 4.0 | 5.6 |

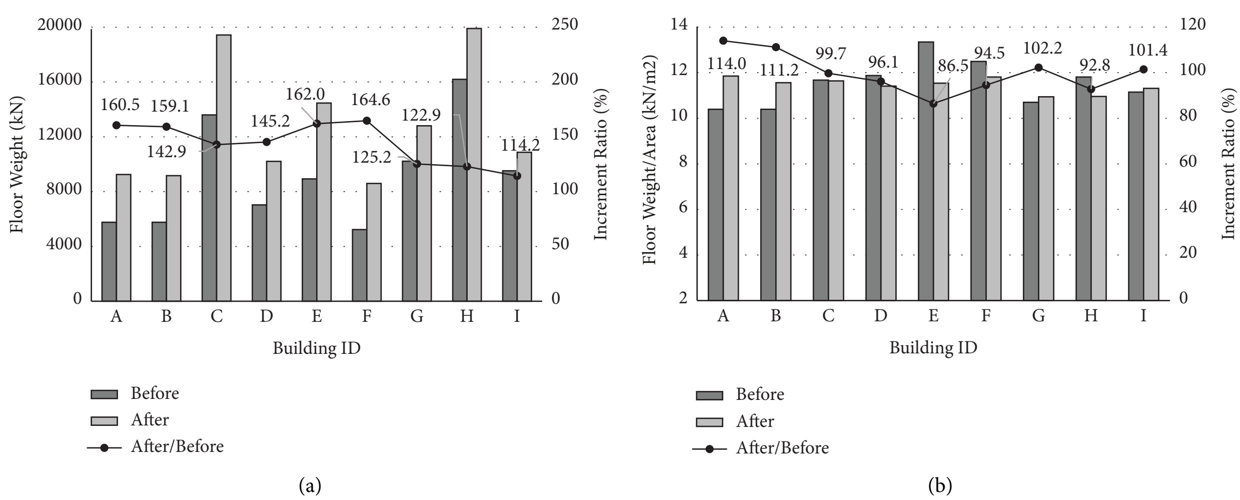



Figure 8: Variation of the floor weight and unit floor weight after remodeling: (a) floor weight and (b) unit floor weight.

10.4–13.3 kN/$m^2$ before remodeling and 10.9–11.9 kN/$m^2$ after remodeling, and its increment ratio was 86.5%–114.0%, indicating no significant change. This is because the floor weight after remodeling increased by an average of 39.5% for nine buildings, and the floor area increased by a similar proportion (41.1%).

All nine apartment buildings have the bearing wall-type structure; thus, load-bearing walls support the entire weight of buildings. Table 5 lists the floor weight per unit area of the load-bearing wall before and after remodeling and after removal of walls. The floor weight divided by the bearing wall area was calculated before and after remodeling. The averaged floor weight per unit area of the bearing wall decreased from 161.4 to 120.7 kN/m$^2$ after remodeling, which was 74.7% of the weight before remodeling. This result suggests that the load supported by the load-bearing wall decreased to an average of 3/4 level after remodeling. The largest and smallest reductions in the floor weight per unit area of bearing walls after remodeling were found in Building IDs E (48.9%) and D (92.9%), respectively. The floor weight per unit area of the bearing wall for Building ID E decreased by less than half after remodeling because an increase of 62% in the floor weight was considerably high (Figure 8), while the bearing wall area increased excessively by 3.3 times (Figure 5). In the case of Building ID D, the decrease in the floor weight per unit area of the bearing wall was the least because the floor weight increased by 45.2%, while the bearing wall area increased only by 56.3%, the smallest among nine apartment buildings. The case of removal assumed a state in which both load-bearing and nonbearing walls were removed, and the floor weight per unit area was obtained by dividing the floor weight before remodeling by the area of the remaining bearing walls. The averaged floor weight per unit area of the bearing wall at the removal stage was reduced by 57.9% compared with that before remodeling. The lowest floor weight per unit area of the bearing wall at this stage was found in Building ID H (73 kN/m$^2$) because the area (Table 3) and the proportion (Figure 7) of bearing wall removal were the smallest among nine buildings. In other words, this is because the area and proportion of the remaining bearing walls were the largest. By contrast, the largest floor weight per unit area of the bearing wall at the removal stage was found in Building ID I (127 kN/m$^2$), which was 40% larger than that of the other eight buildings. This may be attributed to excessive bearing wall removal, as analyzed previously.

Figure 9 shows the relationship between the increment ratios of the load-bearing wall, nonbearing wall, and slab weights and the floor area. The analysis result indicates that the load increase rate of the load-bearing wall and slab has a proportional relationship with the increase rate of the total area. This is expected because horizontal expansion increased the areas of the slab and bearing walls, thereby increasing their weight. By contrast, because the nonbearing wall had a large deviation depending on the design of the space, there was no clear correlation with the increment ratio of the floor area. Among the nine apartment buildings, Building IDs E and F, which had an increased number of bays, exhibited the highest values for all indicators other than the increment ratio of the nonbearing wall weight.

Figure 10 shows the ratios of the weight of the load-bearing wall, nonbearing wall, and slab (a) before and (b) after remodeling. The weight ratio of nonbearing walls exhibited a decreasing trend in all apartment complexes. The nonbearing wall weight, which accounted for an average of 17.1% of the floor weight, decreased to 8.4% after remodeling. The nonbearing wall weight of Building IDs A and B was the smallest at 12.4% before remodeling, while it was maintained at a similar proportion after remodeling. The largest decrease in the nonbearing wall weight was found in Building IDs E and F, at 27.6% and 17%, respectively. Contrary to the case of nonbearing walls, the overall ratio of bearing wall weights increased after remodeling. The ratio of the bearing wall weight before remodeling was 38.9% as the average of nine buildings, while it increased to an average of 47.5% after remodeling. The ratio of the bearing wall weight for Building ID D was the smallest at 43%, and the bearing wall weight comprised more than half of the floor weight for Building IDs E, F, and G. In the case of the slab, there was no considerable change before and after remodeling. The increase in the ratio of the bearing wall weight was the highest in Building ID E (5.9%) and the lowest in Building ID A (6.0%). There was nearly no change in slab weight ratios in the nine buildings after remodeling, with an 8.7% decrease in the nonbearing wall and 8.7% increase in the bearing wall. Such changes indicate strengthened structural performance of the building after remodeling.

*4.4. Area Moment of Inertia.* Figure 11 compares the area moment of inertia of the x-directional and y-directional bearing walls to review the changes in the x-direction and *y*-direction stiffness before and after remodeling. The area moment of inertia of Building IDs A, B, D–F, and I with a relatively small bearing wall area (Figure 5) was determined to be low. In all cases, both $I_{xx}$ and $I_{yy}$ increased after remodeling. This is because the bearing wall area increased after remodeling. Because most of the domestic apartment houses are designed to be long in the *x*-direction, the area of the y-directional bearing wall is larger than that of the x-directional bearing wall, and $I_{yy}$ is significantly larger than $I_{xx}$. Note that Building ID G has a larger x-directional bearing wall area than the y-directional bearing wall area (Figure 3(g)). As shown in Figure 3, Building IDs A, B, D–F, and I are typical apartment houses in the long form along the *x*-direction, while Building IDs C, G, and H have an extension along the *y*-direction. Interestingly, Building ID F had a long form along the *x*-direction before remodeling, while it underwent a floor shape change with an extension in the *y*-direction after remodeling. For these reasons, $I_{xx}$ of Buildings IDs A, B, D–F, and I before remodeling is extremely low at an average of 478 m$^4$, which is approximately 3.3% of the average $I_{xx}$ of 14,641 m$^4$ for the other three buildings (Building IDs C, G, and H). The average $I_{xx}$ of the nine apartment buildings before remodeling is 5,199 m$^4$, and the average $I_{yy}$ is 26,243 m$^4$, which is five times larger than $I_{xx}$. The average $I_{xx}$ of the nine apartment buildings after remodeling is 11,332 m$^4$, and the average $I_{yy}$ is 54,451 m$^4$, exhibiting an approximately twofold increase after remodeling. The highest area moment of inertia was found in Building IDs E and F, which may be attributed to the highest bearing wall area in Building IDs E and F after remodeling (Figure 5).

Table 6 lists the change in $I_{yy}$-to-$I_{xx}$ ratios before and after remodeling for nine apartment buildings. The $I_{yy}$ of the remaining eight buildings, other than Building ID G, was calculated to be on average 25 and 9 times larger than $I_{xx}$ before and after remodeling, respectively. This result

Table 5: Floor weight per unit area of load-bearing walls (kN/m$^2$).

| Stages | Building ID | | | | | | | | | AVG |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | |
| Before | 160.2 | 160.2 | 162.3 | 156.4 | 185.9 | 166.9 | 156.8 | 143.0 | 161.2 | 161.4 |
| Removal | 100.2 | 92.4 | 89.3 | 96.1 | 76.7 | 97.2 | 89.4 | 73.0 | 127.0 | 93.5 |
| After | 143.3 | 138.3 | 133.3 | 145.3 | 90.8 | 103.7 | 123.2 | 109.5 | 98.7 | 120.7 |

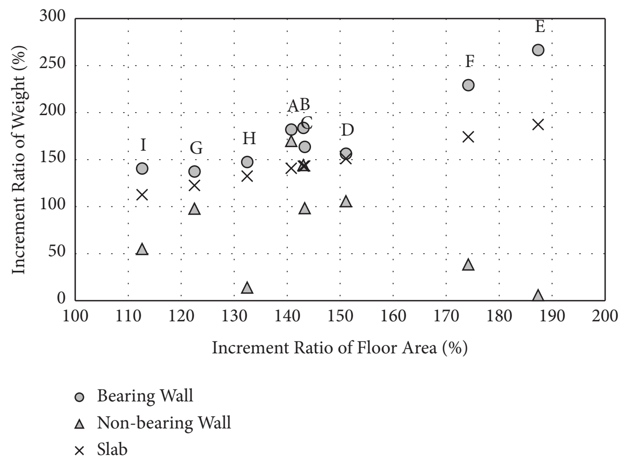



Figure 9: Relationship between increment ratios of the load-bearing wall, nonbearing wall, and slab weights and the floor area.

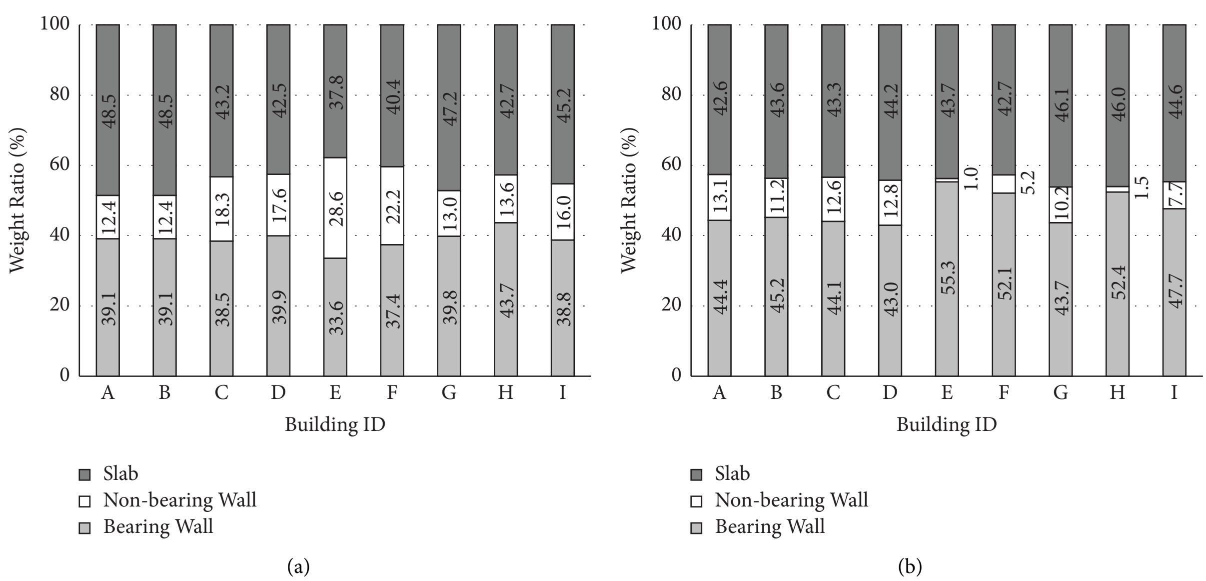



Figure 10: Floor weight ratio before and after remodeling. (a) Before remodeling and (b) after remodeling.

suggests that the x-directional lateral resistance is extremely weak compared with that along the $y$-direction. The differences between $I_{yy}$ and $I_{xx}$ after remodeling, other than those of Building ID G, significantly decreased, suggesting that the lateral resistance of the weak axis was well strengthened. As shown in Figure 3(g) and Table 2, because the bearing wall area in the $x$-direction is peculiarly larger than that in the $y$-direction in Building ID G, $I_{xx}$ is larger than $I_{yy}$. Although the bearing wall area increased by 60% after remodeling (Figure 5), the calculated $I_{yy}$-to-$I_{xx}$ ratio was the same. The largest differences between $I_{yy}$ and $I_{xx}$ before remodeling were found in Building IDs E and F, which decreased excessively after remodeling. This is because a significant amount of load-bearing walls along the weak axis ($x$-direction) was added after remodeling.

*4.5. Torsional Resistance.* Seismic load acts on the center of mass at each layer of a structure, and the rotation of the structure occurs based on its center of geometry. Thus,

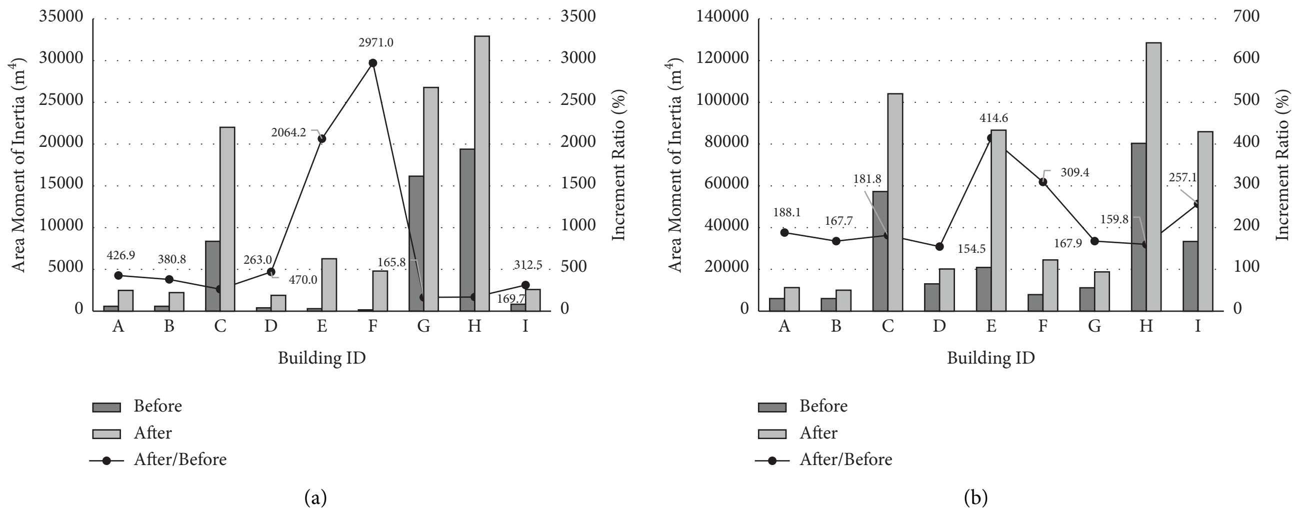



Figure 11: Variation of $x$- directional and $y$-directional area moment of inertia after remodeling: (a) $I_{xx}$ and (b) $I_{yy}$.

Table 6: $I_{yy}$-to-$I_{xx}$ ratio.

| Stages | Building ID | | | | | | | | | AVG |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | |
| Before | 10.3 | 10.3 | 6.8 | 32.5 | 68.8 | 49.0 | 0.7 | 4.1 | 40.2 | 24.7 |
| After | 4.5 | 4.5 | 4.7 | 10.7 | 13.8 | 5.1 | 0.7 | 3.9 | 33.0 | 9.0 |

eccentricity (distance between the centers of mass and geometry) and the amount of torsional deformation have a linear relationship. When eccentricity is large, the torsional resistance of the structure is disadvantageous because the structure is easily twisted even when subjected to a relatively small lateral load. Therefore, reviewing the centers of mass and geometry as well as the distance between the two is necessary. Figure 12 compares the nine apartment buildings in terms of eccentricity before and after remodeling. The calculated eccentricities of eight buildings before remodeling, except for Building ID H, were 100 cm or less. On the other hand, the eccentricity of Building ID H was 184 cm, which was considerably larger than that of the other eight buildings. The eccentricities of six buildings, except for Building IDs C, D, and G, decreased after remodeling. The largest decrease in the after/before rate was found in Building ID A, equivalent to the 1/4 level after remodeling. In addition, the eccentricity of Building ID H, which was the largest before remodeling, shrank to less than half, reaching 77.9 cm after remodeling. The eccentricities of Building IDs C, D, and G increased after remodeling; in particular, the eccentricities of Building IDs C and G increased by 2.4 and 5.8 times, respectively, after remodeling compared with those before remodeling.

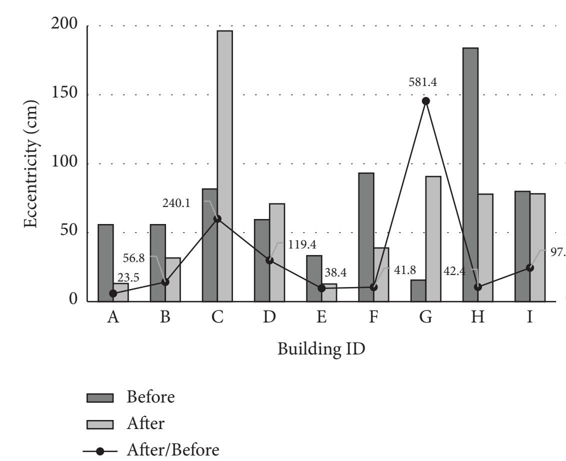
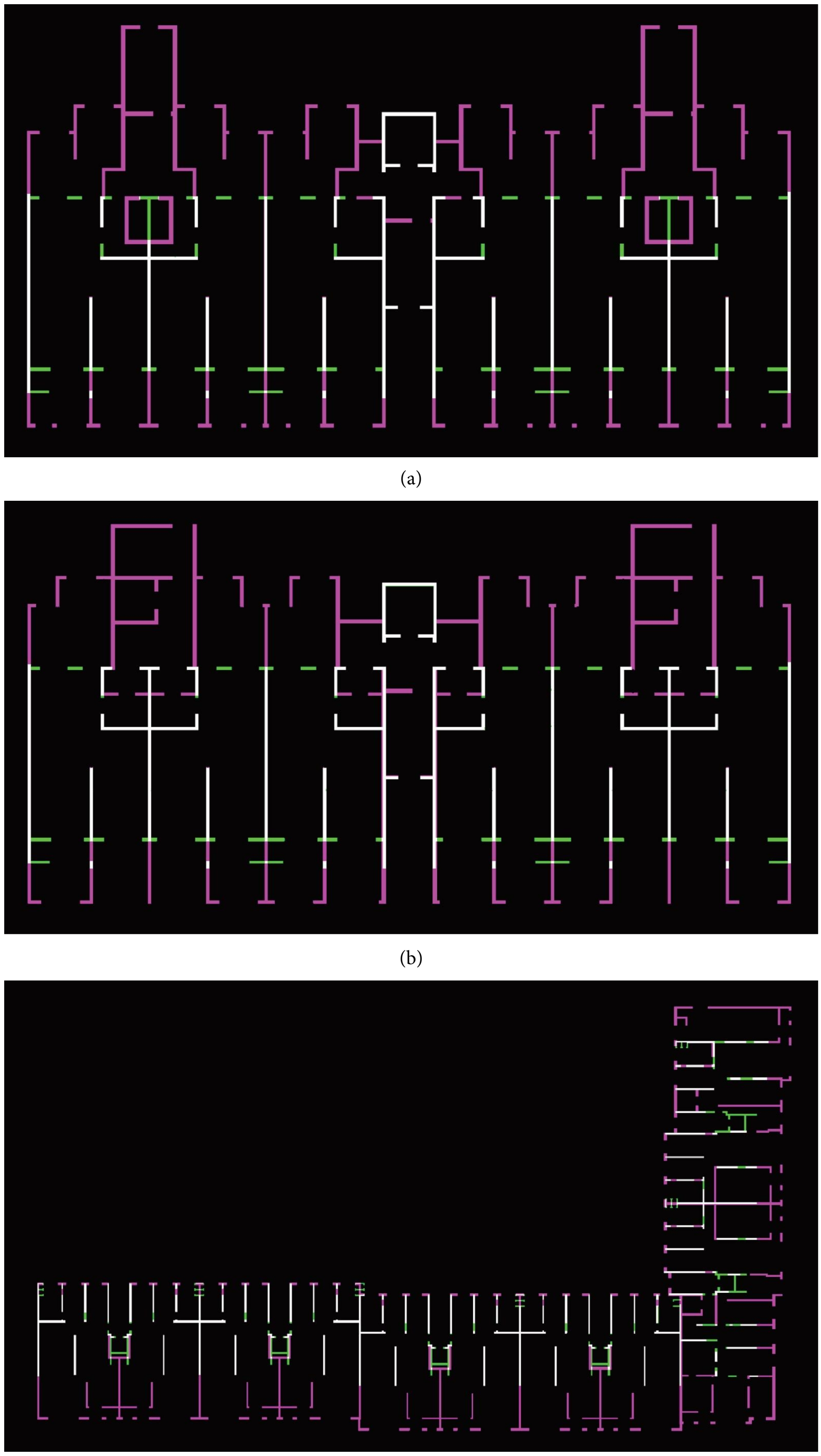



Figure 12: Eccentricity variation after remodeling.

*4.6. Visualization.* The developed automated floor plan evaluation program includes a visualization function to intuitively compute changes in load-bearing walls before and after remodeling. Figure 13 shows the overlapped and color-coded floor plans of the nine apartment buildings; green, white, and purple indicate removed, remaining, and new bearing walls, respectively. This function can intuitively visualize changes in bearing walls before and after remodeling as well as an addition of a core, further enabling the review of the thickness of bearing walls and possible errors associated with the locations of walls in floor plans. Figure 13 intuitively depicts the number of units incremented of Building IDs E, F, and I after remodeling and that the floor area increment and addition of load-bearing walls of Building ID E are the largest among nine buildings. In addition, Building ID F was changed from an I-shape to an L-shape after remodeling; in this regard, the location of the added bearing wall can be identified in detail.

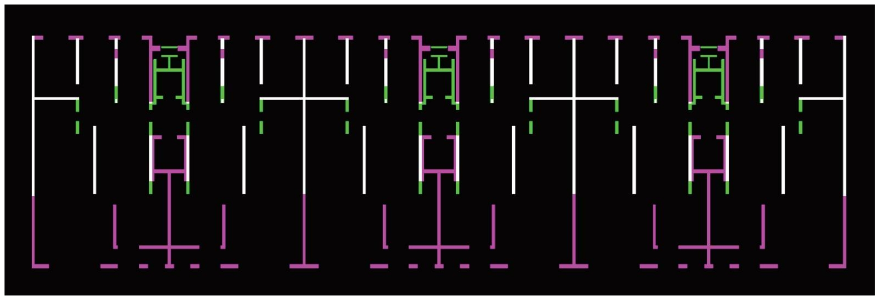


(a)

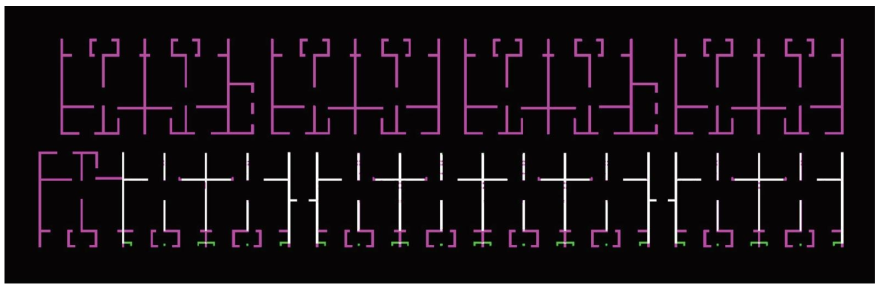
(b)

(c)

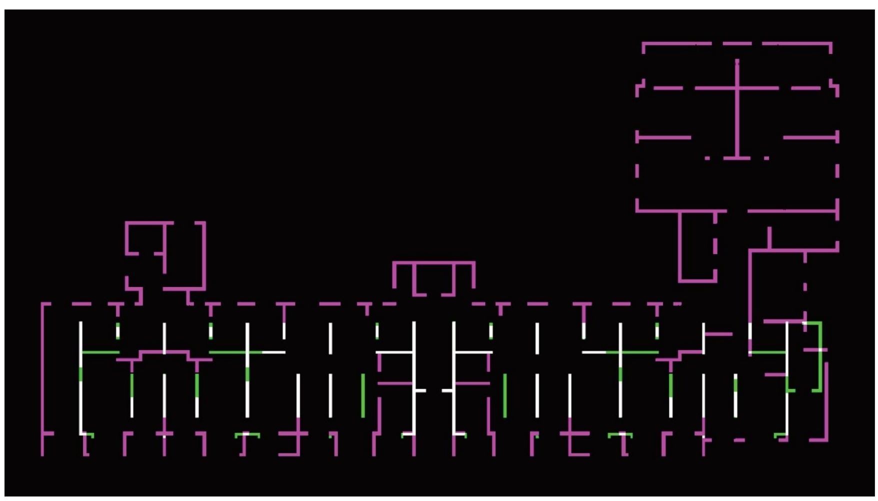
Figure 13: Continued.



(d)

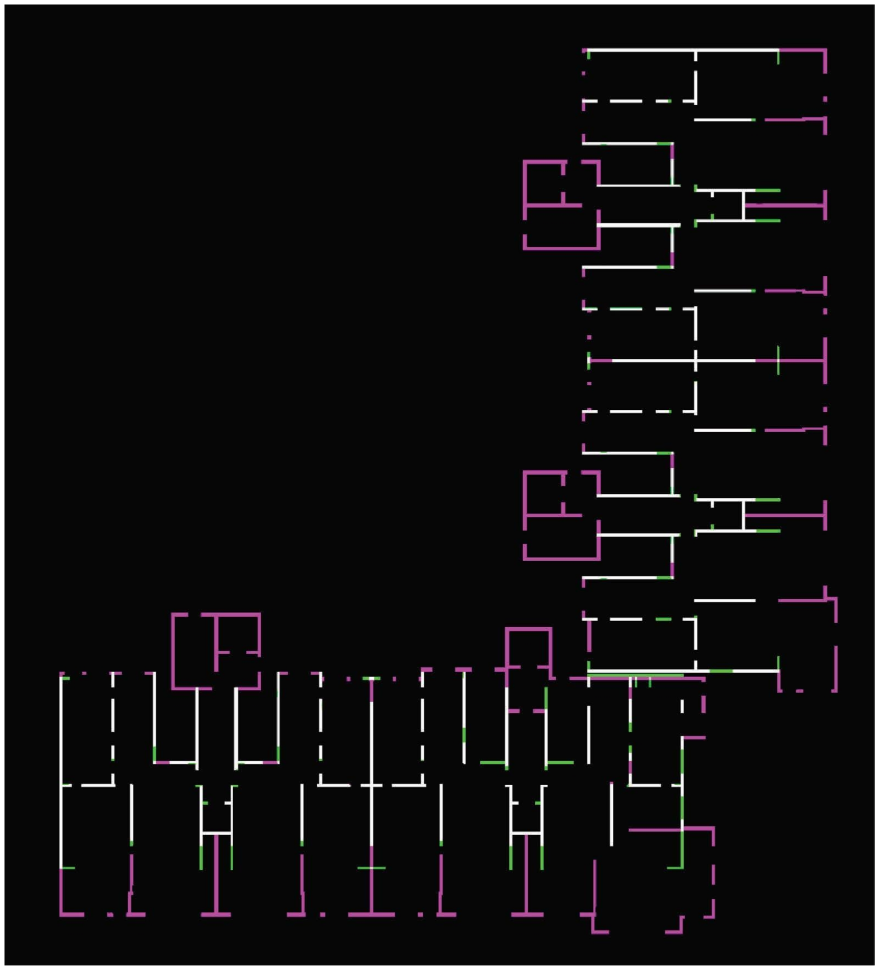


(e)

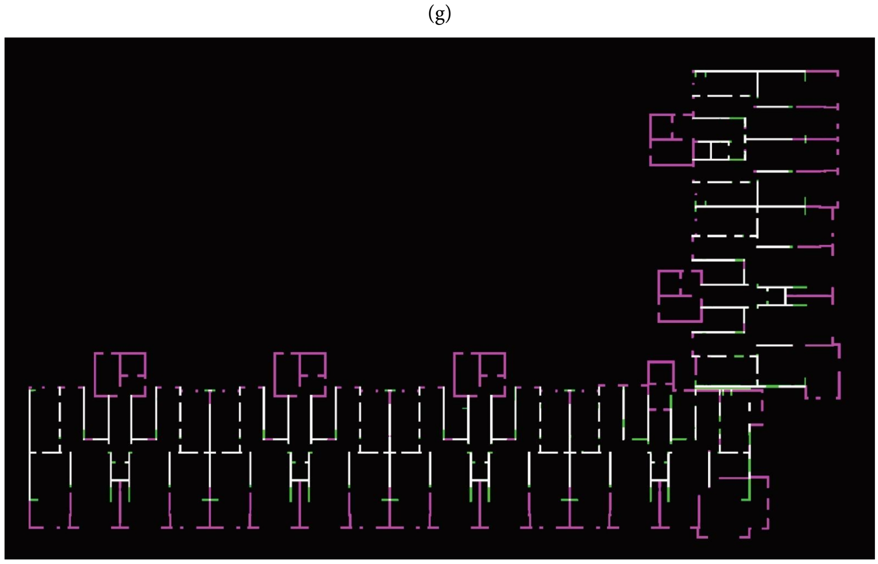


(f)

Figure 13: Continued.

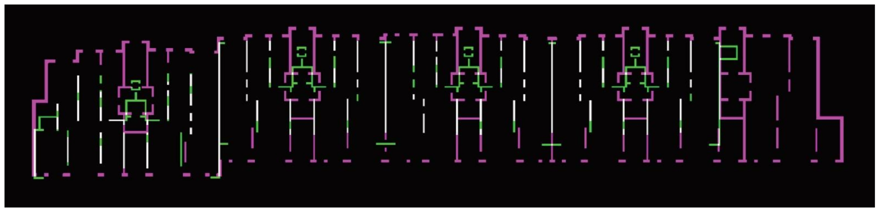


(g)



(h)

Figure 13: Continued.



(i)

Figure 13: Overlapped and color-coded floor plans. (a) Building ID A, (b) Building ID B, (c) Building ID C, (d) Building ID D, (e) Building ID E, (f) Building ID F, (g) Building ID G, (h) Building ID H, and (i) Building ID I.

## 5. Conclusions

During the early stages of a typical remodeling project, many candidate floor plans arise and then undergo an iterative revision process. However, because structural analysis proceeds after the finalization of the floor plan, qualitative evaluation of floor plans is performed without the analysis of structure-related indices at the initial design stage. To solve this problem, an automated plan analysis program for remodeling that could quickly and accurately calculate various pieces of information from the input of floor plans before and after remodeling was developed. The developed program was applied to nine apartment buildings, and a detailed comparative analysis of the data obtained from the result was conducted for presenting quantitative guidelines that could be utilized in the early stage of remodeling projects.

According to the data computed from the nine floor plans before and after remodeling, horizontal expansion after remodeling proceeded in all cases and the floor area increased by 113%–187%. The area of load-bearing walls for all buildings approximately doubled after remodeling. The proportion of removed bearing walls for the nine buildings ranged from 7.2% to 42.1%, with an average of 22%, and that of new bearing walls ranged from 75.7% to 238.8%, with an average of 101%. One of the most critical indices in remodeling projects is the data related to the removal of load-bearing walls. Although experts have long been discussing this topic in South Korea, there is still no clear answer to the acceptance criteria for bearing wall removal. Because the removal of load-bearing walls is directly related to the stability of an entire structure, it should be carefully considered for remodeling design.

The weight of the entire building after remodeling increased, ranging from 1.14 to 1.65 times, due to horizontal and vertical expansions as well as the increase in the bearing wall area. However, the change in the unit floor weight ($kN/m^2$) after remodeling was not significantly large, and the unit floor weight of five out of nine buildings decreased. This study analyzed the floor weight per unit area of the load-bearing wall before remodeling, after removal of walls, and after remodeling, the average values of the nine buildings were determined to be 161.4, 93.5, and 120.7 $kN/m^2$, respectively. In all cases, both $I_{xx}$ and $I_{yy}$ approximately doubled on average after remodeling. In addition, the significant decrease in differences between $I_{yy}$ and $I_{xx}$ after remodeling suggests that the design was prepared to strengthen the lateral resistance of the weak axis.

The results of this study are limited in evaluating the detailed structural performance of apartment buildings because they only provide data that can be calculated from before and after remodeling plans. For such a detailed structural analysis, several additional types of information as well as considerable time and effort are required. This study aimed to rapidly evaluate multiple candidate plans presented at the early stage and provide data that could contribute to decision-making for the finalized plan after extracting them from existing buildings and conducting a comparative analysis on the data. Although the amount of data is limited thus far, we will be able to continuously accumulate data from domestic apartment house remodeling projects by utilizing the developed automated floor plan evaluation program. This accumulated database will contribute to the presentation of standards that can be used in future apartment house remodeling projects, revision of related laws, and monitoring the progress of projects.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

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