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Automated Data Analysis of Floor Plans for the Remodeling of Apartment Housing

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Abstract: In 2020, it was estimated that more than 2.4 million households in South Korea are over 30 years old. That is, more than 40% of all houses in Korea are old and that they require proper rehabilitation. The two options to improve poor living conditions are reconstruction and remodeling. Compared to reconstruction, remodeling has advantages in terms of the construction period, cost, and environmental impact. As such, the current Korean regulations are more favorable for remodeling than reconstruction. Typically, several candidate floor plans are presented in the early stages of an apartment remodeling project. Extracting information about bearing walls and other structural elements from the multiple plans to compare those plans quantitatively is one of the essential tasks during the early stage of a project. To cope with this task, an automated data extraction method for walls and slabs from before and after remodeling plans is developed. Through the developed program, load-bearing walls, non-bearing walls, slabs, and weight changes after remodeling can be analyzed and visualized in a fast and automated manner.

Keywords: remodeling, apartment house, automated floor plan analysis, CAD, Revit add-on

1. INTRODUCTION

In 2020, it was estimated that more than 2.4 million households in South Korea are over 30 years old. That is, more than 40% of all houses in Korea are old and that they require proper rehabilitation. The two options to improve poor living conditions are reconstruction and remodeling. Reconstruction involves demolishing the existing structure and building a new one. Therefore, reconstruction is subject to various regulations, such as the current building law, urban planning, floor area ratio, and population density control. In addition, greater construction scale and cost are expected for the reconstruction compared to remodeling. Remodeling, on the other hand, may not have the flexibility enough to accommodate the requirements of the residents due to its inherent limitations on the design of plans and its size. Remodeling, however, has advantages over reconstruction in the construction period and cost. Moreover, the amount of construction waste generated by remodeling is less than that of reconstruction; thus, it is environmentally friendly. According to the current legislation in Korea, for these reasons, remodeling is recommended by the relatively loose regulation compared to reconstruction.

In order to make an expansion as well as reconfiguration of the space during remodeling, removal of some bearing walls is inevitable, although they are critical load-carrying elements. The amount of change in the bearing walls to be removed, remained, and newly built after remodeling is reflected not only in the vertical load, but also in the lateral force resistance, such as the center of mass and stiffness, lateral displacement, ratio of the strong and weak axis, and others. As such, it is very important to calculate the exact amount of bearing walls to be changed. However, many candidate plans submitted during the initial stage of a remodeling project are not quantitatively evaluated in general mainly due to limited time and cost.

Various studies have been conducted on the evaluation of the candidate plans during the early design process of remodeling. Lee and Cha [1] presented a model for calculating the estimated construction cost by correcting uncertainties due to various potential risks based on past remodeling projects. Hong et al. [2] suggested a decision-making support model for the selection of an appropriate alternative remodeling plan. Kim et al. [3] presented the performance evaluation system by comparing apartment remodeling cases in Korea with Japan. Many studies on the structural performance evaluation of apartment housing after remodeling have also been conducted [4-7]. Choi et al. [8, 9] investigated the structural behaviors of the slab using the finite element method. Lee et al. [10] suggested a method of structural performance evaluation of remodeling plans by separating the slab and the wall. By computing the amount of bearing walls and embedded steel reinforcement changed after remodeling, the structural performance of the building was estimated. Hong and Jung [11] evaluated the seismic performance of the newly constructed shear wall by analyzing the relationship between the position of new walls and their amount. As such, the existing research works are mainly focused either on the establishment of models to support early decision making or structural performance evaluation upon finalization of the plan. If important indices related to the structural performance of a plan can be reviewed and reflected during the initial design process of remodeling; then, it would be able to reduce the time, effort, and cost of repetitive review and revision processes.

The main purpose of this study is to automatically calculate the changes in the walls and weight of the floor quantitatively, and to provide some essential structural information to the designer in real-time during the early stage of a remodeling project. An add-on of AutoCAD's Revit was developed using Dynamo that automatically extracts quantitative data of walls and floors from before- and after-remodeling plans. Through the developed program, load-bearing walls, non-bearing walls, slabs, and weight changes after remodeling can be analyzed and visualized in a fast and automated manner, and this will be used to support finalizing the floor plan efficiently and effectively.

2. HAND CALCULATION

In order to derive the information and algorithms necessary to implement the Revit add-on, part of its function was tested by hand calculation prior to the development of the program. The unit household plan was used instead of the reference floor plan, and the bearing wall was the only parameter considered during the hand calculation. The process of the hand calculation was as follows: 1) bearing walls and non-bearing walls were identified from the before- and after-remodeling floor plans and were marked separately, 2) IDs were assigned to each of the walls, and walls to be removed, remained, and newly constructed were identified and marked, and 3) amount of each wall was computed and tabulated [12, 13]. By comparing the before- and after-remodeling plans, if a wall is in both plans at the identical location; then, it is classified as a remaining wall. If a wall exists in the before-remodeling plan, but not on the after-remodeling plan; then, it is classified as a removed wall. On the contrary, if a wall is found only in the after-remodeling plan; then, it is a newly constructed wall.

The required time for the hand calculation of the amount of bearing walls from unit household plans before and after remodeling is shown in

Table **1**. It took approximately two hours to identify bearing walls and non-bearing walls from the plans, and to mark them. Classifying walls by type (removed, remained, and newly built), took about four hours. It took another four hours to calculate the dimension of each wall in accordance with the type and labeling. The hand calculation, therefore, took about 10 hours in total. If one wants to calculate additional information about non-bearing walls, slab, and floor weight change, even from reference floor plans instead of unit household plans, then much more time and effort will be required. In addition, an increasing amount of manual computation would lead to an increased probability of miscalculation. Considering the fact that several candidate plans are generated during the early stage of a remodeling project in general; therefore, the development of automated data analysis of floor plans for the remodeling of apartment housing is essential.

Table 1. Working hours of the hand calculation for the analysis of a unit household plan

Stage	Process	Working hours
1	Identification of the bearing and non-bearing walls, and labeling	2
2	Identification of removed, remained, and newly built walls	4
3	Calculation of the dimension of each wall	4
	Total	10

3. AUTOMATED ADD-ON PROGRAM

Dynamo extension was implemented to enable the automated data extraction from the before- and after-remodeling plans on Revit. The tasks and corresponding subtasks of the developed add-on program are listed in

Table **2**. The program consists of four tasks and seven subtasks. The tasks are: A. input, B. preprocessing, C. operation, and D. output. The subtasks are: A1. import of CAD files, B1. assignation of the layers, B2. examination of the errors, C1. separation of the removed, remaining, and newly constructed elements, C2. computation of the quantitative data, D1. report, and D2. visualization.

Table 2. Tasks of the developed add-on program

Task	Subtask
A. Input	A1. Import of CAD files
B. Preprocessing	B1. Assignation of the layers
	B2. Examination of the errors
C. Operation	C1. Separation of the removed, remaining, and new elements
	C2. Computation of the quantitative data
D. Output	D1. Report
	D2. Visualization

Upon import of the before- and after-remodeling CAD files (A1 subtask), the preprocessing (B task) should be performed. B1 subtask is to classify and assign the six types of layers: bearing walls, non-bearing walls, and slabs of before- and after-remodeling plans. During this subtask, error often occurs when other elements are included in the layer or when object lines are unclosed. It is essential, therefore, to carefully review each layer so that the lines are composed properly. In addition, if there are multiple lines overlapped but appearing as a single line, it could cause the program to run in a continuous loop. Therefore, an automated examination of the errors (B2 subtask) needs to be performed prior to further progression. B1 subtask is considered quite difficult to automate when layers are not properly classified in before- and after-remodeling files. B2 subtask, on the other hand, was automated in the proposed add-on program as follows.

3.1. Line Review Function

The line review function (B2 subtask) aims to either automatically correct errors or to display errors for users to manually correct them. Since reviewing all the lines in plans is unnecessary, the reviewing function only considers the six predefined layers during the B1 subtask. Initially, the program tries to connect each line using Dynamo's Curve.SuperJoint method. Consequently, elements without error, unclosed elements, overlapped lines are listed. For the overlapped lines, errors are resolved simply by deleting them. For the unclosed element, on the other hand, a dark green line connecting the two vertices of the open part is generated. If the generated line is either horizontal or vertical, the new line stays, and errors are revolved (left element in Figure 1), The new line is then automatically added to the corresponding existing layer, so that no additional work is needed for users. If the generated line connecting the two vertices is angled, on the other hand, the line is deleted and an error is highlighted by having a circle around the open part as an example shown in Figure 1 (right element) for users to manually correct them. The notification circle is designated as a new group so that it can be deleted or simply not included for further analyses after correction. The B2 subtask implemented in the developed add-on program significantly reduced the time and effort required to review the lines in the plans.

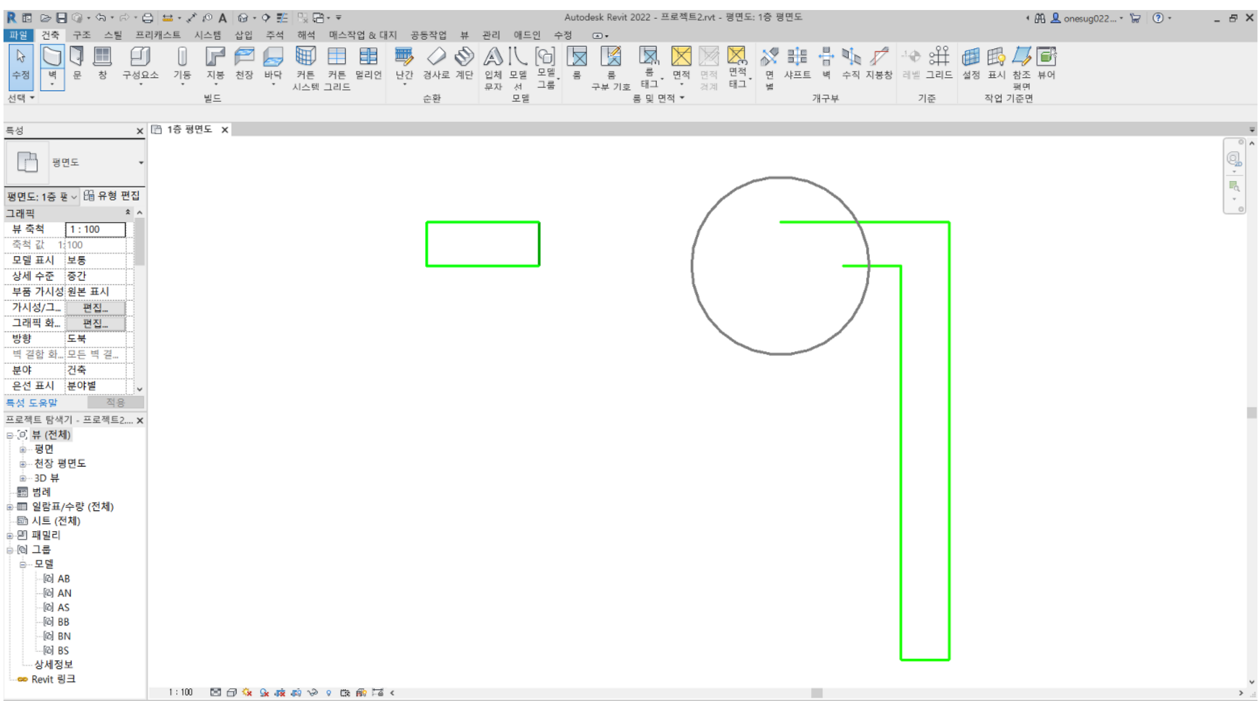


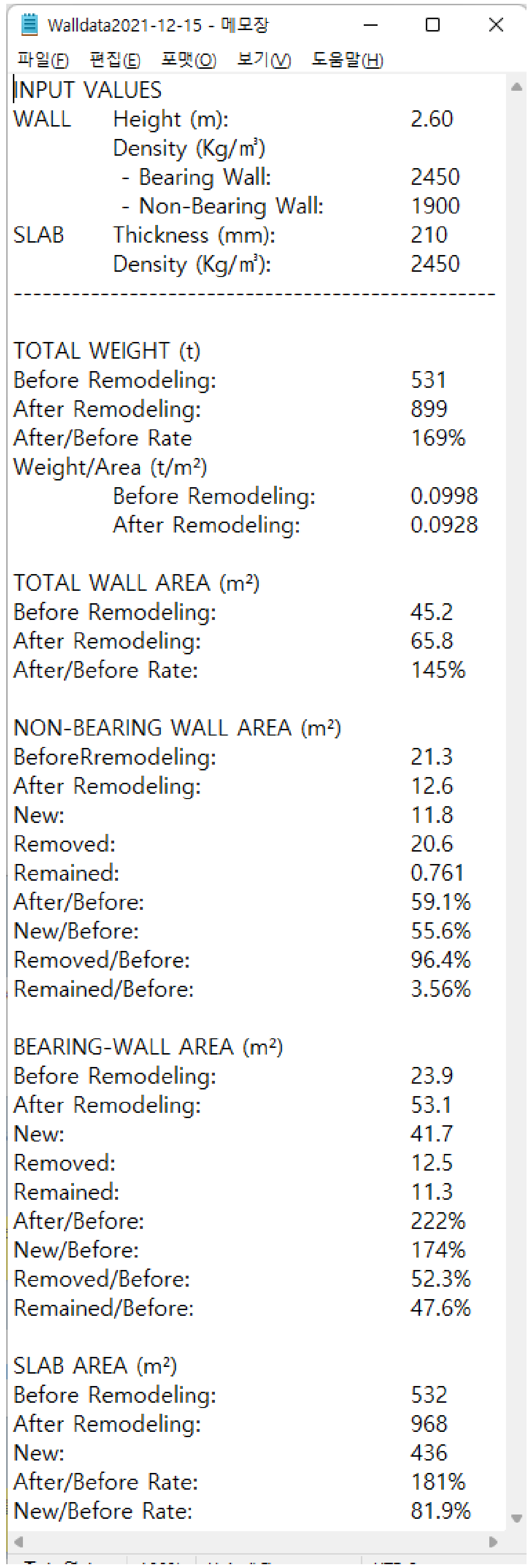
Figure 1. Automated correction of an unclosed wall element (left), and notification of an error (right)

3.2. Data Analysis and Presentation Functions

While A and B tasks listed in Table **2** are a manual process, C and D are executed in a fully automated manner as the developed add-on program runs. For the C1 subtask, all the lines from the predefined six layers are converted into vector format, generating 2-D objects (surfaces) through the Dynamo's Surface.ByPatch method. Utilizing the PolySurface and Geometry.Intersect methods, the overlapping sections between before- and after-remodeling plans (remaining walls and slabs) are obtained and saved as remaining elements. Subsequently, based on the remaining elements, removed and new elements are computed and saved using Solid.DifferenceAll method. As a result of the C1 subtask, nine elements are obtained and saved separately: removed, remaining, and new elements from each of the bearing wall, non-bearing wall, and slab layers.

During the C2 subtask, areas of the nine elements are calculated using Surface.Area method. Rates of removed, remaining, and new walls and slabs are computed subsequently. In addition, dead load, unit weight, weight change after the remodeling are calculated. The dead load calculation is based on the predefined inputs, including wall height, slab thickness, and densities of reinforced concrete and non-bearing wall, and the user can modify these input values. The entire data computed during the C2 subtask are automatically saved along with the date of analysis.

D1 subtask is for the reporting of the data obtained during the previous task, and an example is shown in Figure 2. The top seven lines of the report contain the user input values, including basic information of walls and slab for dead load calculation as mentioned earlier, and the rest is the output data. Output data include weight and area of walls and slab before and after remodeling. The data in the example report are from the actual case of apartment house remodeling, located in Seoul, Korea. Note that unlike unit household plans were used for the hand calculation in section 2, the example report is based on floor plans of before and after remodeling. After the remodeling, the bearing wall amount increased by 222% from 23.9 m^2 to 53.1 m^2, and the removal rate is quite high at 52.3%. The dead load increased by 169% from 531 tons to 899 tons. Therefore, it can be concluded briefly


Walldata2021-12-15 - 메모장

파일(F) 편집(E) 서식(O) 보기(V) 도움말(H)

INPUT VALUES

WALL	Height (m):	2.60
	Density (Kg/m³)	
	- Bearing Wall:	2450
	- Non-Bearing Wall:	1900
SLAB	Thickness (mm):	210
	Density (Kg/m³):	2450

TOTAL WEIGHT (t)

Before Remodeling:	531
After Remodeling:	899
After/Before Rate	169%
Weight/Area (t/m²)	
Before Remodeling:	0.0998
After Remodeling:	0.0928

TOTAL WALL AREA (m²)

Before Remodeling:	45.2
After Remodeling:	65.8
After/Before Rate:	145%

NON-BEARING WALL AREA (m²)

BeforeRremodeling:	21.3
After Remodeling:	12.6
New:	11.8
Removed:	20.6
Remained:	0.761
After/Before:	59.1%
New/Before:	55.6%
Removed/Before:	96.4%
Remained/Before:	3.56%

BEARING-WALL AREA (m²)

Before Remodeling:	23.9
After Remodeling:	53.1
New:	41.7
Removed:	12.5
Remained:	11.3
After/Before:	222%
New/Before:	174%
Removed/Before:	52.3%
Remained/Before:	47.6%

SLAB AREA (m²)

Before Remodeling:	532
After Remodeling:	968
New:	436
After/Before Rate:	181%
New/Before Rate:	81.9%

Figure 2. Report of the proposed add-on

that the demand-capacity ratio (dead load/bearing wall area) became more favorable after the remodeling since the bearing wall increment rate (222%) is greater than the load increment rate (169%). For the slab, the previous area was 532 m^2 and expanded to 968 m^2 after the remodeling, which is an 81.9% increment. In addition to the text-based report, the result of the developed add-on program is visualized as a color-coded plan, so that changes after remodeling can be recognized intuitively (Figure 3). In the plan, removed, remaining, and new bearing walls are in red, blue, and green, respectively, and removed, remaining, and new non-bearing walls in orange, light green, and sky-blue, respectively.

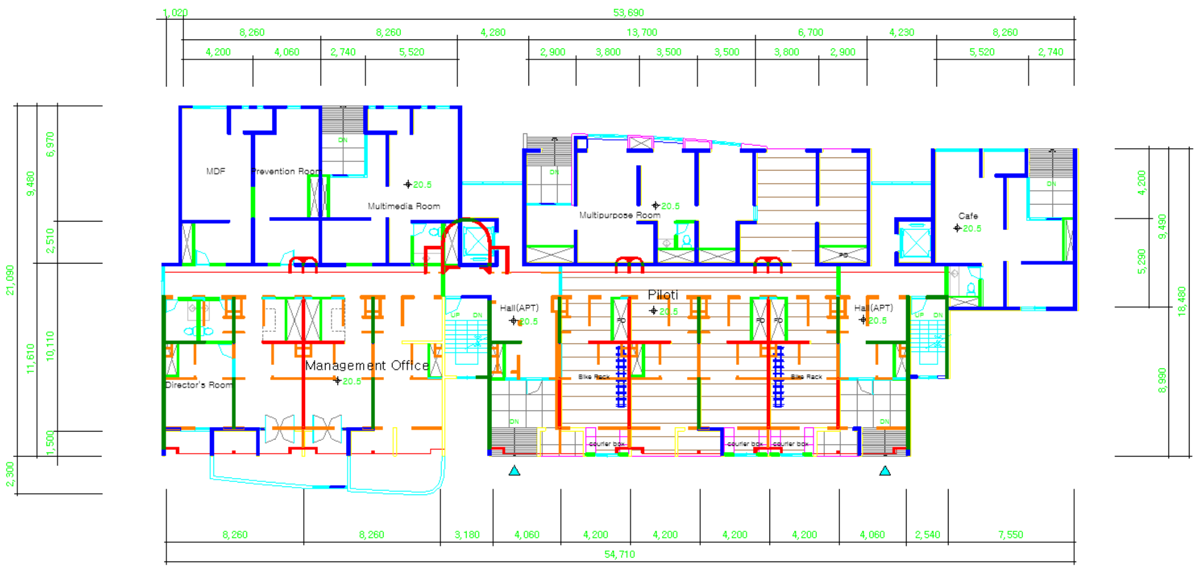


Figure 3. Color-coded visualization of the plan after remodeling (removed, remaining, and new bearing walls are in red, blue and green, respectively, and removed, remaining, and new non-bearing walls in orange, light green, and sky-blue, respectively)

The time taken to obtain the results (Figures 2 and 3) using the developed add-on program was approximately 2 hours and 20 minutes on average as a result of three test operations. Among the seven subtasks listed in

Table **2**, the B1 subtask (assignation of the layers) took the longest at about 2 hours, and the B2 subtask (examination of the errors) took about 10 minutes. The rest of the five subtasks (A1 and C1-D2) took less than 10 minutes. Compared to the hand calculation (

Table **1**), which took about 10 hours, the developed add-on program markedly shortened the work time. Considering that the bearing wall amount was the only variation for the hand calculation, and several candidate plans are presented in a typical apartment remodeling project, such time reduction using the proposed add-on program is quite significant progress.

4. RESULTS

During the early stage of a typical apartment house remodeling project, several plan candidates are presented. In this stage, quick and accurate calculation of the amount of change in walls and slab, and corresponding weight variation after remodeling are essential to determine the suitability of the presented plans. This study aims to develop an add-on program for providing quantitative data through an automated evaluation of before- and after-remodeling plans. The developed program calculates changes in bearing walls, non-bearing walls, slab, and weight after remodeling in a fast and automated manner.

The Revit extension program, Dynamo, was utilized to develop the proposed add-on program. Upon input of before- and after remodeling plans and assigning of the layers, the developed program generates objects of walls and slab, and calculates quantitative data automatically. As a result, the work that took about 10 hours by conventional hand calculation could be completed in 2 hours and 20 minutes with much more information, which could be extremely challenging to compute by the hand calculation. With respect to the accuracy of the developed program, the output data must be exact since the computations are based on the coordinates of vector graphics. In addition, with a help of the line review function, which is for the review and correction of the input plans, the accuracy of the output data would be unquestionable. The output data could be applied in construction management. With the accurate quantity of removed and new walls and slab, construction costs can be estimated more accurately, and construction schedule can be planned considering more detailed information on resources and tasks.

Among several subtasks of the proposed method, a single subtask, assignation of the layers, took 2 hours, while the rest took less than 20 minutes. The development of a function that automatically separates and classifies bearing walls, non-bearing walls, and slab from before- and after remodeling plans, however, was not included in the scope of this study. Rather, this part was left as a task to be addressed in follow-up research, due to its level of challenge, and expecting time and effort. Once the assigning of the layers could also be automated and implemented in the developed add-on program, it is obvious that the program could be far more practical in the apartment housing remodeling market in Korea.

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