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A BIM-BASED MODULE DESIGN METHODOLOGY FOR THE ROOF PLANNING OF MODERNIZED KOREAN TRADITIONAL WOODEN BUILDINGS

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ABSTRACT: This study proposes a design methodology for modernized Korean traditional wooden buildings, *modernized-Hanok*, with a roof-*Kan* module based on parametric design. In the *modernized-Hanok*, the subordinate relationship between the body and roof structures has been diminished. Therefore, the purpose of the design methodology is to provide a tool that allows designers to plan the roof-frame structures unconstrained by plane shapes using Autodesk's Revit. Once the user determines the desired roof type, purlin number, module size, and reference dimensions, the parameters of families in the module interact with each other with functional formulas. As a result, the roof-frame module is automatically placed at the designated position with the appropriate roof shape. This module-based methodology provides users with a high degree of freedom in design.

KEYWORDS: Korean traditional wooden buildings, Roof-frame, Module design, *Modernized-Hanok,* BIM

1 INTRODUCTION

The *Hanok,* a Korean traditional timber-frame structure created by assembling elements, is one of the most challenging architectural types in terms of design, modeling and construction due to its atypical morphological characteristics. Recently, to overcome the difficulties of planning and constructing *Hanok* and to promote its market expansion, R&D projects for modernizing *Hanok* have been actively pursued, with efforts to create an environment that allows for more convenient design and modeling while securing structural and construction performance [1, 2].

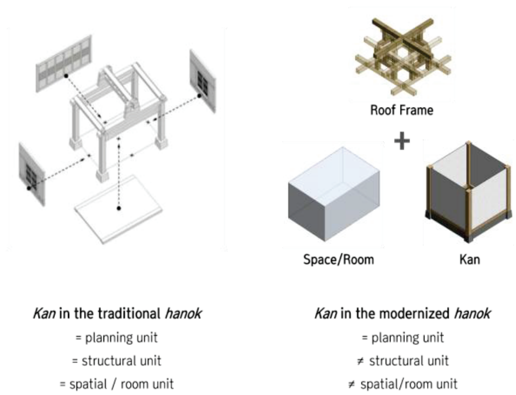

Figure 1: *Concept diagram of Traditional Korean House(Left) & Modernized-Hanok(Right)*

The research of design and modeling methodologies laid the groundwork for the *modernized-Hanok* and securing the structure and construction performance. The precedent *Hanok* BIM design methodologies are as follows. First is the member-unit design methodology, in which the modeling data is completed by stacking members [3]. Second is the joint-unit design methodology, in which the joinery is constructed by assembling members and placing the modeling data [4, 5]. The third is the integrated *Kan* unit design methodology, in which a *Kan* is an integrated unit of the shape of each member and joinery and surface elements such as floors and wall libraries [6]. The limitation of these methodologies is that they focus on the modeling process rather than the design process; therefore, they deteriorate the ability to respond to design change with a low degree of freedom.

In contrast to the precedent methodologies, the research team proposed a 'module-based design methodology' as a solution to the fragmented modeling-based design process. With the 'module-based design methodology' presented, the research team recently developed a '*Hanok* BIM Design Support Program' that allows the users, including both experts and non-experts to approach the *Hanok* design process in a more user-friendly way and contribute to the revitalization of the *Hanok* industry with the support of the Ministry of Land, Transport, and Maritime Affairs of the Korean Government.

The overall design process of the '*Hanok* BIM Design Support Program' is carried out through the arrangement of the modules. Meanwhile, the simple repetitive arrangement tasks, which do not correspond to the

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designer's substantive design tasks, fall within the scope of automation. For example, the beginning of the design process provides an environment in which modules could be used to derive various plans using the spatial module. Then, the roof frame module is placed on the rectangular grid system of the building, completed with the spatial module, and an independent roof structure is created with members such as purlins and beams. Finally, in the latter part of the design, the details could be designed reasonably by replacing the already determined modules with members, and roof tiles are placed on each reference point of the planned roof frame.

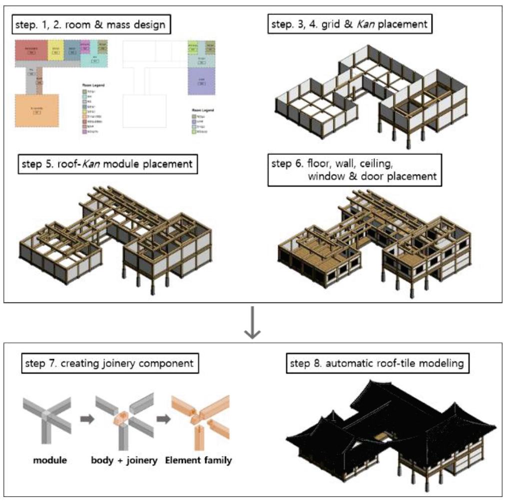


Figure 2: *Design process of the 'Hanok BIM Design Support Program'*

This paper specifically concerns the methodology of the roof frame design step of the '*Hanok* BIM Design Program' that the research team developed and proposed. One of the limitations of planning traditional *Hanok* is that the *Kan,* a bay unit, contains all of the body and roof structures and space in one unit. However, in the *modernized-Hanok*, the subordinate relationship between the body and roof structures has been diminished due to improved structural performance, such as horizontal expansion in the direction of the beam without columns. As a result, the modern *Kan* is no longer a composite unit of the body and roof structures. Therefore, isolating the roof structure from the body structure in the design process on the premises became crucial.

Hence, the research team approached the roof as an independent structure and proposed a module-based methodology to devise a roof-*Kan* module that allows designers to plan the most complicated 3D atypical curved roof-frame structure unconstrained by the body structure. This roof-*Kan* module was developed by extracting data from traditional *Hanok* and implemented using Autodesk Revit, a widely used BIM tool, to approach the design process in a more user-friendly way and contributes to the revitalization of the *Hanok* industry. The '*Hanok* BIM Design Support Program' was completed as a Revit's Plug-in, and released to the public through 'Autodesk's BIM guidebook' and the department of Architecture and Architectural Engineering, Seoul National University.

2 MODERNIZED-HANOK DESIGN, MODELING AND ROOF-KAN MODULE

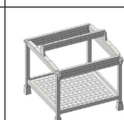
2.1 HANOK MODELING METHODOLOGY AND ROOF-FRAME PLAN

The design methodology of what the library unit is composed of in precedent research can be classified into individual component units (M1), joint units combined by Skeleton-Assembly (M2), and integrated modules that are unitized by both the body and the roof (M3), depending on the unit type and level of detail (LOD) in *Hanok* design, modeling methodology, and planning [8]. As mentioned above, the roof and body are unbinding independent structures in *modernized-Hanok* and can be planned separately.

The roof planning methodology's strength comes from the ability of establishing various planning unit libraries. Additionally, the amount of libraries necessary is inversely proportional to the level of detail (LOD). Therefore, many libraries are required in cases where the *Family in Family* concept is weakly applied, such as in M1 and M2, while M3 requires a smaller number of libraries. On the other hand, the relationship equation within the unit is proportional to the number of families within the planning unit. In other words, while the relationship equation is defined at the level of component size for M1, it extends to the scope of detail design, such as connections for M2, and M3 has the possibility of parametric design based on the relationship between components.

Therefore, regarding roof planning, M1 effectively represents the details of the roof's shape as various components are differentiated and detailed. On the other hand, the unit planning elements of M3 are advantageous for organizing each part's shape, size, and composition, as multiple components are interconnected.

Table 1: *Classification of precedent Roof frame structure Design Methodology*

Metho-dology	M1	M2	M3
Library Unit	Member	Skeleton-Assembly Joinery	Kan
			
LOD	5	2 → 5	5
Relation with Design Process	Low	High	Low
Relation with Body part	Low	Medium	Equal

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Possibility of Parametric Design in Unit	Low	Medium	High
Link with Other Units	Very High	Medium	Low
Difficulty	Difficult	Medium	Easy

The *modernized-Hanok*'s roof structure is mediated by the body structure but can create an independent shape. In particular, since the structure of the *Jungdori* (middle purlin) and the *Jongdori* (top purlin) is separate from the body structure, related lower components can be planned independently. In other words, since the pre-defined information is associated with the *Jusimdori* (column-raw purlin), the *Daedulbo* (main beam*)* connected to the body, the horizontal range of the roof part can be adjusted through these components, and the lower pieces are linked as independent relational functions. Therefore, the information that needs to be input to create the shape, height, and curve of the roof is the roof type, the position of a *Jungdori* and a *Jongdori*, and the relational function information that can adjust the lower components. Once the input of information about the wooden structure is completed, the roof tiles can be generated, and the position of the tiles can be determined with the *Seokkarae* (rafters) and the *Gaepan* (shingle) based on the reference points of the purlins. However, information related to the definition of the outermost coordinates of the roof, eaves extension, *Buyeon* (double rafters*)*, the curves of the rafters (hipped and hipped-gabled roof), location of the gable (hipped-gabled roof), length of purlin extension (gabled roof) must be defined independently.

Table 2: *Classification of Roof-element's Information by Process*

Type of Information	Subject	By Para-meter	By User
Pre-defined Information	Geometry of Jusimdori & Daedulbo	-	
Information to define	Roof type		●
	Geometry of Jongdori		●
	Geometry of Jungdori & Jongbo		●
Information to be defined	Geometry of Seokkarae	●	
	Geometry of Gaepan	●	
	Extruding of Eaves		●
	Installation of Buyeon		●
	Ang-gok & Anheorigok (Paljak or Woojingak)		●
	Location of Hapgak (Paljak)		●
	Length of Bbaelmok (Matbae)		●
	Composition of Hoecheom		●

2.2 DEFINING THE ROOF-KAN COMBINED MODULE

The design and modeling of *Modernized-Hanok* differ from traditional *Hanok* in that it can plan the body and roof in a loose relationship. Therefore, the planning stages of the body and roof can be done independently, and using modules that meet the objectives of each step is highly effective in the early stages of design. In other words, the main focus of roof planning is to define the shape and scale of the roof. The conditions that modules should have are as follows.

2.2.1 COMPONENTS OF INDIVIDUAL MODULE

To plan the roof part of *Modernized-Hanok*, the roof-*Kan* combined module should be considered from two significant aspects. First, it should follow the principles of traditional wooden architecture for roof construction while simultaneously accommodating the wide spans in the beam direction. In other words, it should reflect the planning logic of the body part but should not be entirely dependent on the structural logic of the body by forming an independent roof structure. Therefore, it should be possible to independently implement the morphological characteristics of the roof, such as *Matbae* (gabled), *Paljak* (hipped-and-gabled), *Woojingak* (hipped), and linked to the planar system.

Firstly, it is necessary to define the scope of the components included in the roof-*Kan* module. In *Modernized-Hanok*, the roof is composed of four main layers, including the roof tile surface, the *Boto* (roof-filling soil) and the *Jeoksim* (roof-filling wood) layer, the *Seokkarae* and *Gaepan* layer and the purlin and related substructures, which are components of the roof-*Kan* combined module. However, since the *Jusimdori* and the *Daedulbo* located at the boundary of the building must be modified according to the orientation of the building's facade, it is reasonable to include them in the roof plan to minimize errors. On this premise, the components in the vertical range of the roof-*Kan* module consist of the *Jusimdori*, *Daedulbo, Jungdori*, *Jongbo*, *Dongjaju* (short-column on beam*)* and *Daegong* (truss post). The horizontal range is one *Kan* unit of the body in the purlin direction and the entire *Kan* unit in the beam direction, and this is repeated within each *Chae,* a building unit, to implement the roof for each house.

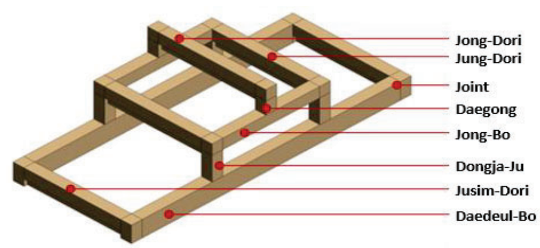

Figure 3: *Roof-Kan Assembly Module Basic Type*

2.2.2 TYPES OF THE ROOF-KAN COMBINED MODULE

The *Modernized-Hanok*'s roof frame is consisting the edge-*Kan*, which defines the shape and scale of the roof, and the middle-*Kan*, which defines only the scale. This research suggests that the proposed roof-*Kan* module should also reflect this characteristic of *Modernized-Hanok* and be operated in a dualized module.

The vertical position of the roof parts can be divided into three levels based on the purlin members to determine the roof scale. First, the *Jusimdori* and the *Daedulbo* are placed at the lower level of *Jusimdori*. The *Jungdori* and the *Jongbo* should be placed at the *Jungdori level* and the *Jongdori* at the *Jongdori* level. Additionally, the *Dongjaju* and *Daegong* are placed at each level, and a purlin connecting member is created in the outer direction of the beam to correspond to the cornered houses.

The middle-*Kan* is composed of only the substructures mentioned above, but the edge-*Kan* requires additional substructures that can determine the shape of the roof. The starting position of *Jongdori* and *Jungdori* determines the shape of the edge-*Kan*. And the *Jongdori, Jungdori*, and *Jusimdori* touch the surface parallel to the outer edge of the edge-*Kan* in the *Matbae* roof. At the same time, the *Jungdori* is on the linear of 45 degrees to the direction of the *Jusimdori*, and the *Jongdori* is on the vertical plane in *Paljak* roof. In the case of the *Woojingak* roof, it creates the roof surface by allowing the starting points of the *Jungdori* and *Jongdori* to touch the linear that is 45 degrees to the direction of the *Jusimdori*. Therefore, the edge-*Kan*, the types of roof are determined by the existence of the *Chunyeo* (angle rafters) located on a straight line in the 45-degree direction, and the starting coordinate of the *Jongdori* again defines the *Paljak* and *Woojingak*. In addition, each roof requires different substructures to form its shape, with *Matbae* requiring extended purlins, while *Paljak* and *Woojingak* need *Chunyeo, Waegidori (*outer purlin*)*, and *Chungryang (additional beam on purlin direction)*. Therefore, the module must secure the required substructures to create desired roof shape [9].

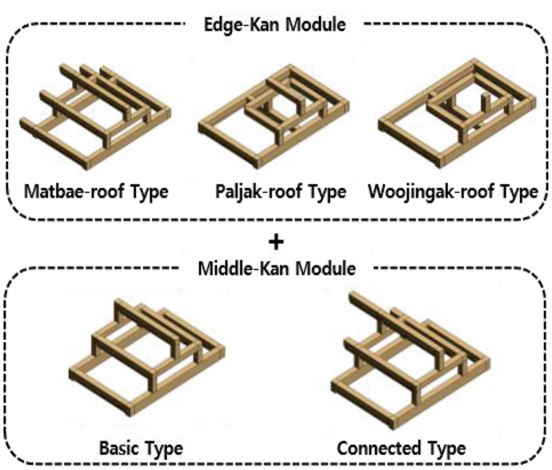

Figure 4: *Type of Roof-Kan Assembly Module*

3 IMPLEMENTAION OF ROOF-KAN COMBINED MODULE

3.1 ROOF SHAPE DETERMINATION FORMULA

A correlated function is a logic that can implement changes in each target by controlling the common factors among multiple targets. Revit's parameters consist of the parameter's name, the parameter's value, and the formula between parameters, and they work by connection with the target element.

The parameters work in two ways. The first is to link the parameter's value to the target element. For example, when modeling a rectangular shape, values for length, width, and height are defined simultaneously during the modeling process. By creating a parameter and linking it to the length, width, and height of the target element, the length value of the parameter can be linked to the length value of the target absence, allowing for changes in the shape of the target element through the parameter.

The second method involves linking each parameter through a formula. For example, "Height = Length/12" is a simple function that defines the dependent parameter "Height" as the value of the independent parameter "Length" divided by 12. If the parameters "Height" and "Length" are linked to the height and length of the target element, adjusting the parameter value for "Length" can adapt not only the length but also the height. The defined formula expression serves as the algorithmic basis for enabling continuous changes to the target element and reflecting the actual construction or modeling principle. In addition to arithmetic operations, conditional statements such as "if" can also be used to define the value through the formula for when conditions are met. For example, Users can reconfigure most simple functions, such as the visibility of the target element or specifying its material. Therefore, complex shapes can be easily created by adjusting a few independent parameters by defining dependent parameters with various formula expressions.

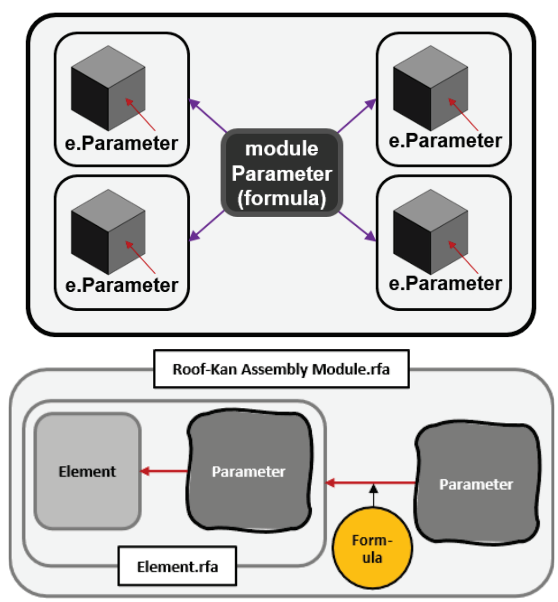

Figure 5: *Concept diagram of Parameter and Formula*

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The roof-*Kan* combined module proposed in this study comprises multiple parameters and families within a single family, and their correlation allows the creation of each roof shape.
The edge and middle *Kan* modules can implement five and three-purlin structures and connect the roof type and the *Kan*. The operation of parameters is defined as an essential element of each direction's length, material, and component name within the module family, while the parameters specified within the module family are again defined as a formula of the parameters defined in the module.
For example, creating a *Matbae* roof with a three-purlin structure can be replaced with the logic of defining two independent parameters, one with the roof shape (Name) as *Matbae* (Value) and the other with the number of purlins (Name) as three (Value) in the edge-*Kan* module. Once the value of "*Matbae* roof with a three-purlin structure" is created, the value shapes the defined roof through the formulas previously specified for each component. Also, each roof shape is differentiated by the presence and position of each component; therefore, the roof-*Kan* combined module is created with type parameters [10].

3.2 LAYOUT LOGIC FOR ROOF-KAN COMBINED MODULE

The initial layout of the module begins by defining the main facade of the building based on the number of the body module in perpendicular and horizontal directions, which is already placed in the previous steps. For the roof-*Kan* module to be placed on the top of the body module, the building must be hypothetically divided into an independent l-shaped building, *Chae*. A main and subordinate *Chae* is distinct by a change in the number of *Kan* in the vertical direction of the main facade.

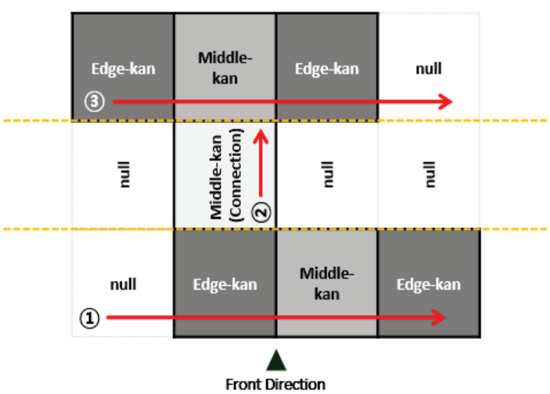


Figure 6: *Arrangement process of Roof-Kan Assembly module*

Once the buildings are separate, the roof frame module is placed from the lower-left *Kan* of each *Chae,* where the coordinate is set to 0, 0. The module first decides whether it is an edge-*Kan* module or a middle-*Kan* module based on the existence of the adjacent module, then it is placed from left to right accordingly in the independent *Chae*. The rest of the independent *Chae* repeats the same process to complete the placement of all roof frame modules.

The rules for placing the roof-module combinations in each *Chae* are further divided based on the number of *Kan* in the front facade. If the building has three or more *Kan*, the initial module will be an edge-*Kan* with a defined roof shape while hiding the *Daedulbo* and *Jongbo*. And the module type of the second *Kan* is determined according to the existence of a *Kan* to the right.
For the first middle-*Kan* module of the second *Kan*, all the parts of the *Jusimdori* level are generated, while the *Dadulbo* and *Jongbo* on the left are hidden for the rest of the middle-*Kan* module. Finally, the right edge-*Kan* of the *Chae* is placed while hiding the *Dadulbo* and *Jong-bo* on the left to complete the placement of the module. This process minimizes the error in the quantity data and ensures there are no overlapping elements once the entire roof-*Kan* module is placed.
Only the edge-*Kan* module is placed in the building with two *Kan* in the front facade. The first module generates all the *Daedulbo* at the *Jusimdori* level, while the second module hides the left *Daedulbo* and *Jongbo*. In the case of a building with only one *Kan in the* front facade, only one module is placed.

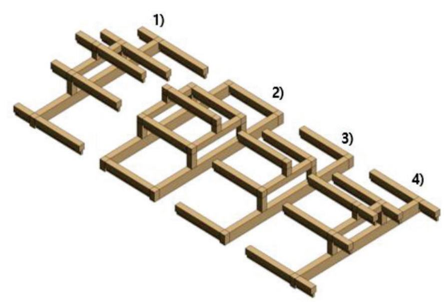


Figure 7: *Arrangement Process of Edge-Kan and Middle-Kan Module*

A middle-*Kan* module is generated to create the connecting edge in the corner of the house where two or more *Chaes* meet vertically. The additional elements must be created outside of the module range in this process.
The current module placement has each *Chae* as an independent state; therefore, the *Chaes* must be connected with purlins. The connection process of *Chaes* is followed. First, a main *Chae* and a subordinate *Chae* are determined, then the subordinate *Chae*'s middle-*Kan* module generates the connecting purlins. Once the connecting purlins are created, the cornered house is completed, adjusting the height of purlins according to the hierarchy of the *Chae*. The *Matbae* roof requires the purlin extension that goes beyond the boundary of the roof-*Kan* module. However, the edge-*Kan* module that determines the roof's shape is always placed at the beginning and end of the *Chae*, and the purlin extension is created outside the *Chae*, so it does not affect the adjacent *Kan*. Therefore, the purlin extension for the *Matbae* roof is made outside the boundary of the roof-*Kan* module using the same logic as the middle-*Kan*'s connecting purlin creation.
On the other hand, for the *Woojingak* roof, the *Chunyeo* extends to the *Jongdori*, which means the *Jong-dori*, *Daegong*, and *Jongbo* need to move inside the *Chae*. This means it can affect the adjacent *Kan*, but this is

resolved by separating the constraints of the *Daedul-bo* and *Jongbo*.

3.3 COMPLETION OF ROOF PLANNING AND MODELING

The roof planning process takes place after the completion of the body plane planning, with the lower *Jusimdori* level fixed, where the body and roof intersect. Therefore, the user can independently define the roof type, scale, purlin structure, and the rafters' curve. During the roof-*Kan* module placement, the program automatically identifies the designated plan below and creates the user-interface presenting the pre-view of the floor plan and the section for the user to decide which floor or *Chae* to work on.

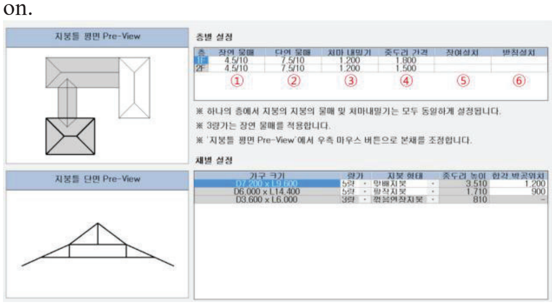
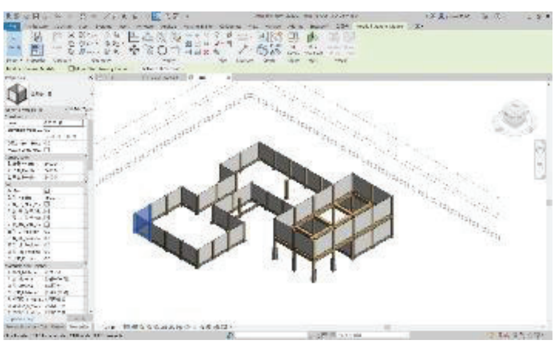


Figure 8: Pre-view of roof planning UI

On the 'floor' part of the UI, the users can type-in the desired values of the angle of rafters, overhang depth, and purlin spacing and etc. However, the range of these values is pre-set based on the analysis of existing *Hanok* to prevent users from creating an impractical roof. On the other hand, users can determine the roof type, the purlin structure, and the location of the bargeboard on the '*Chae*' part of the UI. This process allows users to determine the roof type of each *Chae* independently while suggesting the appropriate purlin structure according to the scale of the body structure. The purpose of this program is to reflect the principles of the *Hanok* construction while promoting efficient modeling.



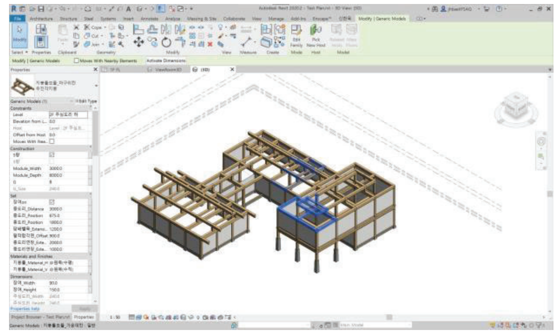


***Figure 9:** Before and after the roof-Kan module placement*

4 CONCLUSIONS

It is crucial to solve the difficulties of *Hanok* design for the growth of the Modern *Hanok* industry. The roof of *Hanok*, in particular, requires a curved roof with a combination of various wooden structures, which is the biggest obstacle in the design process of *Hanok*. Therefore, this study regarded the roof frame as an independent structure, breaking out of a general notion that the roof frame is a subordinate structure of the body, and proposed a roof-*Kan* combined module.

The significances of this research are as follows. First, it defines criteria for separating the body and roof parts by focusing on the module-based design methodology. In addition, it distinguishes information that has already been determined in the preceding stage, information that is automatically generated through it, and information that needs to be redefined by the user and aims to improve design efficiency by accumulating data.

Secondly, it provides a basis for constructing a cornered roof efficiently. Considering the timing of placing the roof-module combinations, the modules were divided into middle-*Kan* and edge-*Kan*, and an effective methodology for placing the modules between *Chae* and between adjacent *Chae* was proposed.

This study is part of developing a Modernized *Hanok* design tool that can be easily used by non-experts who are not familiar with *Hanok* architecture. This tool is expected to provide a better *Hanok* design environment by accumulating information from the plane, elevation, and cross-section plane of the building to the details of each member.

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