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# PARAMETRIC MODELING TECHNOLOGY FOR APPLYING HBIM TO KOREAN TRADITIONAL WOODEN ARCHITECTURE

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**KEY WORDS:** HBIM, Korean Architectural Heritage, Joint and Splice, Joints, Virtual Modeling

**ABSTRACT:**

The objective of this study was to apply parametric modeling for Korean traditional wooden buildings including joints using a script-based modeling engine. Korean traditional wooden buildings have complex structures composed of numerous members called joints and they are difficult to identify from the outside of the building. Therefore, creating the joints for the virtual modeling is essential to fully understand them. This study applied parametric modeling using the relationships and connectivity of each member.
First, this study aims to create a single building by generating as many parametric models based on the drawings as possible, and supplementing with scanning models that are too complex to shape parametrically. Subsequently, various joint types were classified based on literature and drawings, and the parameters of each member were designed and systematized to apply to the building model. The methodology of this study can generate low-capacity models because it is based on scripts, unlike Scan-to-BIM and visualize various restoration plans for non-existing architectural heritage and virtual replication of traditional wooden buildings. Moreover, it can be utilized as a procedural modeling tool to create buildings at heritage by area including the surrounding landscape, and gradually applied to curved members using mechanical design.

## 1. INTRODUCTION

The most significant objective of this study was to implement a seemingly indistinguishable joints by applying a parametric design in a script-based modeling engine. Joints are essential to virtually modeling Korean traditional wooden buildings because they are structurally important in bearing the load of the entire building and have historical significance, reflecting the architectural period and use in the design. In Korean traditional wooden buildings, joints become more complex in shape as they expand to accommodate the increasing number and size of members. By applying parametric modeling, it is possible to create high-quality, low-capacity 3D models that contain information on the connectivity of each member and joint type, which are also helpful in understanding the complex structure of traditional wooden buildings.
The members of joint form the structural frame of Korean wooden building. Among them, the horizontal members joining the top and bottom of the column bear tensile and compressive loads, and they prevent the deformation of the column rows and maintain the frame of the building. Moreover, it is possible to expand the scale of building by joining each member in longitudinal, transverse, and vertical directions (Jung., 2010). The joints not only play a structural role but also express the beauty that people have pursued throughout history. Depending on the passage of time or the purpose of the building, the aesthetic elements are reflected in the joint types or scale. In other words, it is possible to infer the construction period, purpose, and user of the building through the details such as the shape of the building, the arrangement of the rooms, and the joints.
The parametric modeling scripts of this study were written in two ways: for buildings and for the joints. Parametric modeling is utilized when creating each individual member of a building and calculating the surfaces where the members join in order to implement the shape of joints. Furthermore, this study used scanning to supplement the parts that are composed of multiple curves or have added artistic elements.
The following is the procedure for creating a virtual model of a building with joints:

1. Create a model using a drawing-based building modeling script
2. Add the members obtained by scanning
3. Modify or replace members using the joint modeling script template

When using this methodology, automated modeling can be attempted for areas where existing and non-existing buildings are mixed. This methodology allows for the automated modeling of large number of buildings with various shapes by selecting the style of architecture commonly used at the time of construction based on the historical facts of non-existing buildings and adjusting the parameters. Moreover, it can be used for the preservation and maintenance of architectural heritage, archiving by building HBIM libraries and creating digital content because it can realize the joints that cannot be identified just by scanning without dismantling and it can be used to suggest various virtual restoration plans.

## 2. RELAED WORKS

Yen et al. aimed to manage the member information of traditional Chinese wooden buildings through 3D modeling and metadata. They implemented members of various sizes and shapes and defined the relationships between different members (groups) using metadata(Yen et al., 2013). However, this study was limited to the caisson ceiling of the Confucius Temple in Taipei since members were realized by the 3D scan. Further classification and structuring of the member types are required to apply to other buildings.

Kanasaki and Tanaka verified the possibility of applying Tugite and Shiguchi, traditional Japanese wood joint systems, to fields other than architecture by implementing them in a digital environment. They analyzed about 200 types of Tugite and Shiguchi and made them generalizable to be producible digitally by adapting them to the digital environment(Kanasaki and Tanaka, 2013). However, the analysis on the meaning of the joints in the building and the organicity between jointed members and building was insufficient, and it was limited to the analysis of joint types.

Zhao et al. proposed an optimization algorithm for the parametric design and robotic fabrication of dougong, one of the traditional wooden components of Chinese architecture. This analyzed and standardized the shape, proportion, joinery rules, and joint shapes of the dougong’s constituent members(Zhao et al., 2020). Jiang et al. studied the dougong of the Yingxian Wooden Pagoda developed an intelligent algorithm that could infer the dimensions of member and joint types that were not identifiable due to complex stacking structures(Jiang et al., 2020). However, both studies simplified the shapes of members to apply parametric modeling to the joints and ~~the~~ decorative elements. In addition, they did not investigate various joint types, nor the relationship between the size of the dougong and other members in the building.

Lu et al. aimed to establish an HBIM schema for Chinese architectural heritage in Taiwan based on members. In particular, they categorized traditional Minan-style buildings into structural members that supported the weight of the roof or the building itself and non-structural members. The study analyzed the members that constituted the connection parts, such as rafters, beams, dougong, and columns(Lu et al., 2018). Moreover, Cheng et al. developed a more efficient process for modeling the entire building and inputting various information about the dimensions and parameters of members. They created families with parameters or user-defined components based on the shapes of members that appeared repeatedly, such as tong (main beam), dou (supporting bracket), and ying (roof beam). Conversely, members with complex shape, such as tuomu (angle bracket), guatong (gourd-shaped supporting bracket), roof, and fence, were grouped and set up as a family without parameters or user-defined members(Cheng et al., 2021). These two studies are significant in that they proposed an efficient process for modeling historic buildings by distinguishing different types of members. However, they did not delve into the types and examples of how each member was jointed and their respective shapes in detail.

Many attempts have been made in East Asian countries with abundant wooden buildings to efficiently digitize and manage the complex systems that joint various members. However, previous studies were limited in applicability, as their methodologies focused only on the joints themselves or were limited to specific buildings, and failed to implement or identify various joint types. Thus, this study aimed to demonstrate the process and results of implementing various joints in Korean traditional wooden buildings by applying parametric design to the virtual modeling process of Suwon Hwaseong Fortress and Hwaseong Temporary Palace.

## 3. METHODOLOGY

This study aimed to implement a low-capacity data model based on parametric design to apply HBIM (Historic Building Information Modeling) to architectural heritage, specifically implementing joints with complex shapes. Unlike the typical Scan-to-BIM method, which produces a large-capacity model due to the characteristics of Korean wooden buildings that join small and large members, this method replaced straight-shaped members and joint members in the existing scanning model with parametric modeling. This approach offers great potential for extensibility and applicability, such as inferring various shapes for unidentifiable parts and creating virtual restoration plans, without dismantling architectural heritage. To test this potential, parametric modeling was applied to Suwon Hwaseong Fortress and Hwaseong Temporary Palace.

### 3.1 Framework of Digital Architecture Creation

Suwon Hwaseong Fortress and Hwaseong Temporary Palace are architectural heritage sites in South Korea. The temporary palace, built for political and administrative purposes, is surrounded by the buildings in Hwaseong, including the rampart. Hwaseong was registered as a UNESCO World Heritage in 1997 in recognition of its excellent military structure utilizing regional terrain and the technological exchanges between East and West. Moreover, since the entire process of construction, including architectural drawings, drawings of the construction machinery, and the dimensions and quantities of materials used, is documented in the “Hwaseong Songyouk Eugye”, they have been maintained and repaired based on these reports, which is a unique characteristic(Cultural Heritage Administration, 2023).

Korean traditional wooden buildings are composed of numerous members that are either identical in shape or have variations within a predictable range. These members exhibit different joint structures depending on the era and environment. To efficiently model these complex structures in a virtual environment, this study proposes a script-based parametric modeling approach. By defining templates for various members and modifying parameters through the use of scripts, it is possible to accurately recreate the members with the same dimensions as the real architectural heritage in a digital environment.

This study divided members into those that could be fabricated by parametric modeling and those to be acquired by scanning. If a member has a simple shape, such as a cube, cylinder, trapezoid, or a combination of these, a primitive model was created using functions in the engine, and a member-specific template was prepared. Members with high LOD, such as roof tiles, ikgong(structure type with bird’s wing shaped bracket arm) and hwaban(a member to support a purlin support carved pots, lotus flowers, lions, etc.), which were composed of curved lines or detailed decorations such as carving, were modeled through scanning. Scanning models also can be easily modified by applying parameters to the position, rotation, and size in the script. Creating a parametric HBIM model reflecting the complex joints characteristics of Korean wooden architectural heritage proceeds as shown in Figure 1:

1. Create a parametric model using a script template based on the drawings of the architectural heritage
2. Add the Scanning model for high LOD (Level of Detail) members created through scanning to the building
3. Apply the parametric model of the joints to the building model

   Complete the model by adding information such as repair history and material for each member

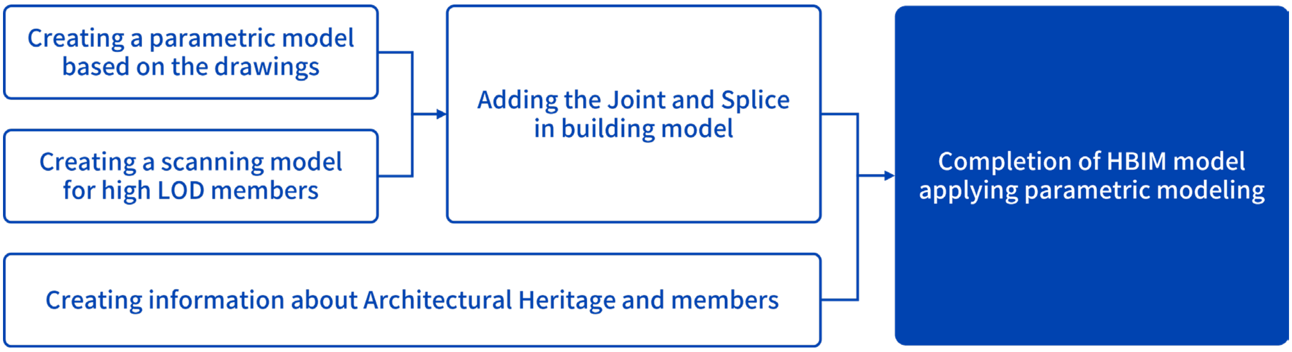


**Figure 1.** Process of parametric modeling for HBIM application in Korean traditional architecture


**Figure 2.** Code system of script templates for joint and splice

### 3.2 3D Modeling Process of Joint and Splice

In traditional Korean wooden buildings, it is possible to identify the structural system by considering the mechanical properties of the joints among the members. The joint can be divided into two types: "joint," which indicates the joining of orthogonal members, and "splice," which represents the joining of members in the same direction. However, since they are not directly visible from the exterior of the building, precise dismantling and measurements are required to understand the structure. Therefore, parametric modeling was utilized as a method to identify the shapes of joint members and the joint method in wooden buildings without the need for physical measurements after dismantling.
The process for parametric modeling of joints is as follows:

1. Prepare drawings to identify the shapes of joints and design parameters
2. Create a reference drawing based on various sources, including actual measurement drawings and research reports.
3. Generate a parametric modeling script by setting parameters and member details in the drawing.

Before preparing the parametric modeling script, this study coded various elements such as parameter, joint members and methods. Since the modeling engine used in this study was additive, each member in the wooden bracket part was individually modeled. In addition, joints and splices are made in various parts of Korean wooden buildings, such as the body, bracket, and frame structure, and the members used vary depending on the part. It's important to distinguish between different cases, even if the joints method is the same in other part. For example, the "joints between a column and cornerstone" and the "joints between a beam and a purlin" are not the same. The script, written in text, can be difficult to understand intuitively and can cause confusion. Therefore, we established a system to clearly classify the code.
In the script, as shown in Figure 2, the template name is determined by assigning codes in the order of **major classification, sub-classification, minor classification, and micro classification**. However, the number of micro classifications varies depending on the joint type, and this is indicated by connecting them with a hyphen (-), which shows that the classification is not based on the distinction of major/sub/minor/micro classifications.

**The major classification** refers to the parts of the building. It followed the classification in "Condensation Method of Traditional Korean Wooden Architecture (2010)" and the member code of KOFTA (Korea Foundation for the Traditional Architecture and Technology). **The sub-classification** refers to members that are joined. In most cases, the previous member code is used. However, when two types of members are used, such as "joints between a beam and a purlin", the initial of each member code are used. **The minor classification** refers to the type of joints, and the suffix of all minor classes is construction, so the code is also in the form of 0C. The joint types that are not specifically classified are assigned to "other construction (OC)". **The micro classification** indicates the joint method (name), and unlike the previous classifications, it is a three-letter code. The initials of the joint and splice are used as suffixes (e.g., 00J and 00S, respectively).
In addition, parameter codes were established to systematize the parameters assigned to the necessary members and elements based on the joint method used, such as fist cog joint, butterfly joint, and point joint. Typically, the total length of a member or element is set as a parameter, with the length along the X-axis representing the width, the length along the Z-axis representing the depth, and the length along the Y-axis representing the height. These parameters are generally considered to be constants. However, some parameters, such as w, d, and h, are defined using mathematical formulas as they are related to other parameters.
It was necessary to structuralize the used functions and scripts to write scripts for parametric modeling, along with defining the parameters, members, and wooden bracket codes. The script uses functions to define rules and parameters, functions to define member shapes, and functions to define the scale or position of members. The script, which used many different functions, was structured as follows for readability and work efficiency.
The script structure consists of two cases: 1) "cases of the same shape and different positions" and 2) "cases of the same shape and different positions and rotations". In the former case, the first rule defines different positions, and the second rule defines the shape and size of the element corresponding to each position by writing the positions as parameters. In the latter case, the first rule defines different positions, the second rule defines the shape by writing the position and size as parameters, and the last defines different rotations of the element corresponding to the first two rules.

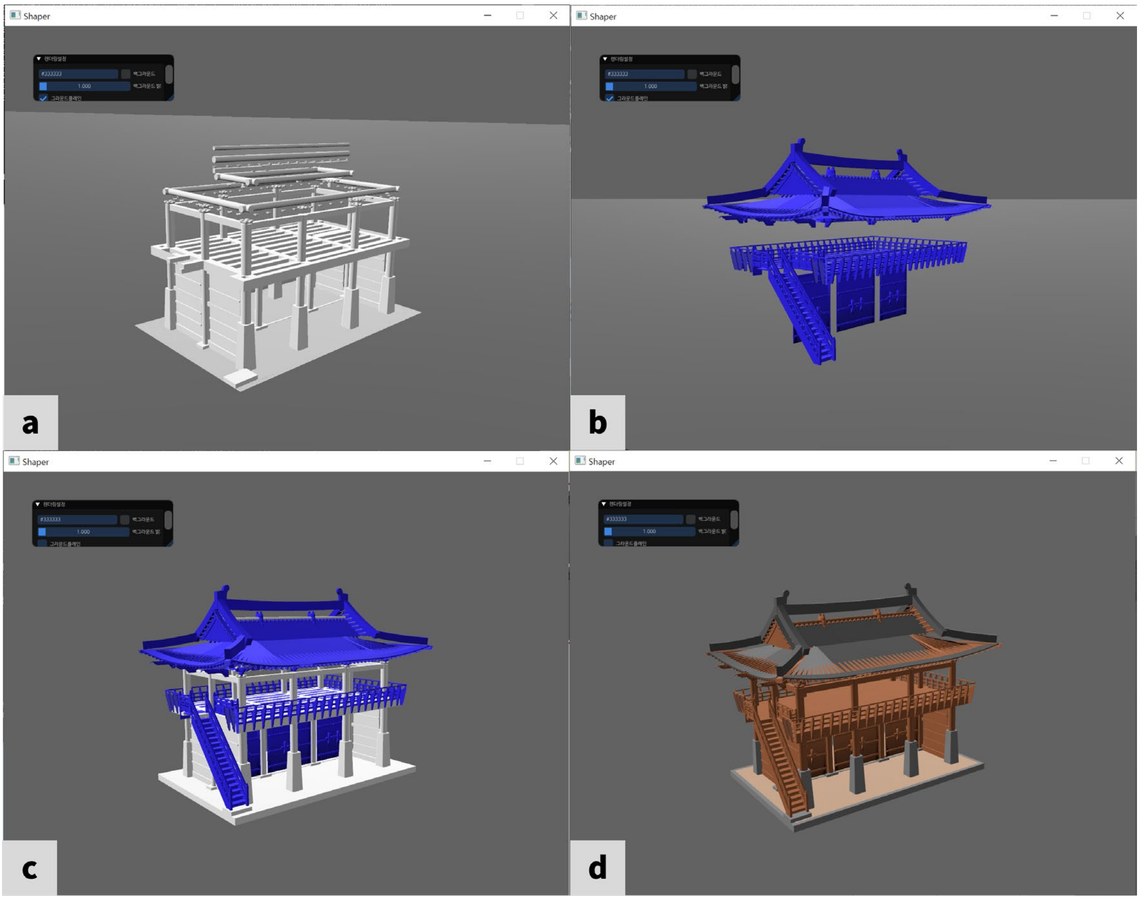


**Figure 3.** Images of the Shinpoongru in Hwaseong Temporary Palace.
(a) Models by parametric. (b) Models by scanning. (c) Combining from (a) & (b). (d) applying colors.

| Purpose | Script Example | Description |
|---|---|---|
| Same shape but different positions | rule CAtop = {<br>CAtop_T (0, CAh2, 0)<br>CAtop_T (0, CAh2, CAD*2/3)<br>}; | - Define the upper part of columns with different translate values. |
| | rule CAtop_T (tx, ty, tz) = {<br>box (1, 1, 1)<br>translate (tx, ty, tz)<br>size (CAW, CAh1, CAd1)<br>CAtop_T_<br>}; | - Define the shape of a CAtop<br>- Define it as a cuboid first<br>- The position is the same as the previous “CAtop_T (tx, ty, tz)”<br>- Define size |

**Table 1**. Example of script structure for creating joints: modeling scripts when shape is the same but positions are different.

Table 1 contains a portion of the scripts used to create the shape of a single-groove at the top of a column. The single-groove shape is characterized by a "—" shape, and requires boxes with identical shapes to be placed parallel to each other with an empty space in the center. Therefore, when modeling boxes with the same shape but different positions, the script is written as shown above.

### 3.3 Results

The proposed study aimed to identify the joint methods and shapes of traditional Korean wooden buildings and suggest parametric modeling as a method for their implementation. The self-developed script-based modeling engine was used for this purpose, allowing for parametric modeling by setting the relationship between members as parameters. In other words, the parametric modeling can be performed by adjusting the parameters to implement the chosen joint method in various dimensions and shapes while considering the relationship between each member in the building.

Figure 3 shows the process of HBIM modeling for Shinpoongru in Hwaseong Temporary Palace, utilizing both parametric and scanning modeling. The building was divided into two parts: parametric modeling (a) and scanning modeling (b), which were implemented based on the characteristics of their members. The two models were then integrated (c) to complete the overall building shape, and appropriate colors were applied to each member to create the final appearance (d). By adding ‘joint and splice’ details to the model, a BIM model that accurately reflects the intricate joint characteristics of traditional Korean wooden buildings can be produced.

To implement the joint, the next step was to create drawings by referring to various sources such as actual measurement drawings and research reports of existing wooden architectural heritage. Figure 4 depicts a drawing of the half fist cog splice between left and right lintels in the single-groove joint at the top of the column, as well as the tenon joint between the lintels and the column. To design the parts as parameters of a model, this study divided the elements of the members to be fabricated in an additive way and wrote scripts accordingly. After writing a script and entering it into the engine, the results shown in Figures 5 and 6 were generated. Various configurations can be created by adjusting parameters in different ways, while maintaining joint methods and shapes (Figure 7~10).

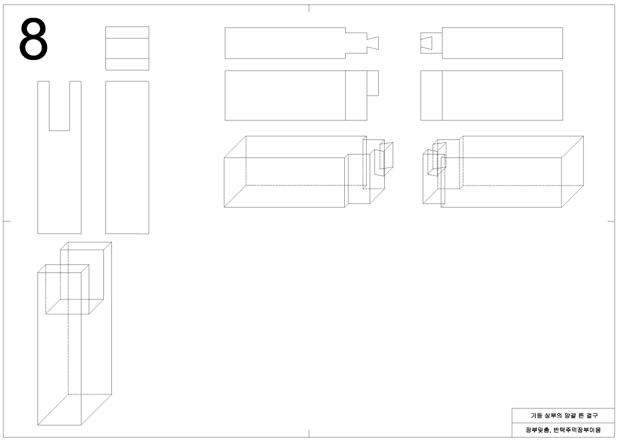


**Figure 4.** Drawing of "the single-groove joint at the top of the column – the tenon joint & the half-fist-cog splice"

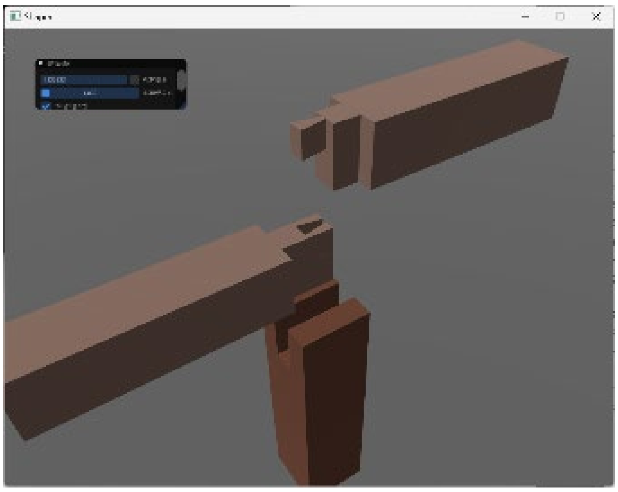

**Figure 5.** An implemented image before combining "the single-groove joint at the top of the column – the tenon joint & the half-fist-cog splice"

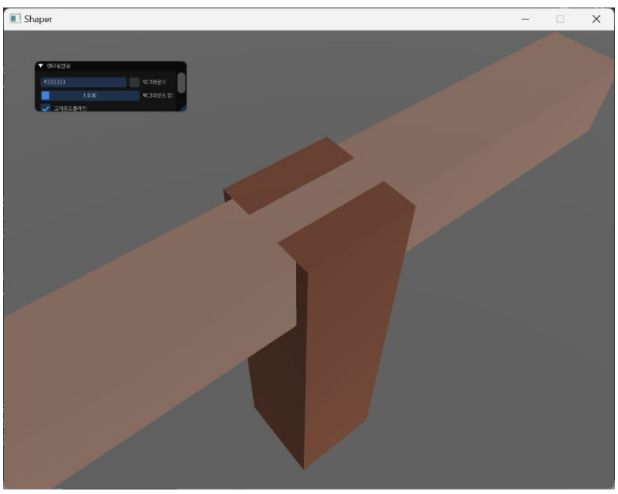


**Figure 6.** An implemented image after combining "the single-groove joint at the top of the column – the tenon joint & the half-fist-cog splice"

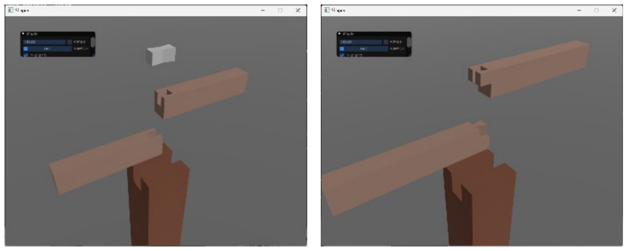

**Figure 7.** The examples of "the single-groove joint at the top of the column – the whole-tenon joint & the butterfly splice(left), the whole-tenon joint & half-fist-cog splice(right)"

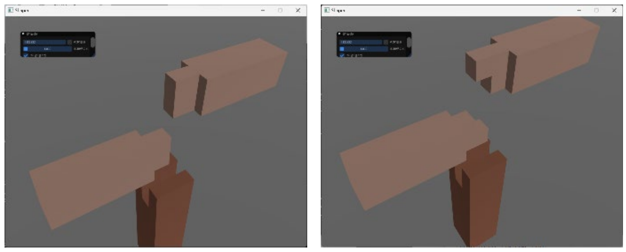

**Figure 8.** The examples of "the single-groove joint at the top of the column – the tenon joint & the plain splice(left), the tenon joint & half-lapped splice(right)"

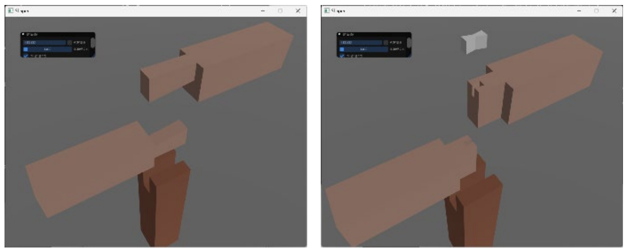

**Figure 9.** The examples of "the single-groove joint at the top of the column – the tenon joint & the hooked-scarf splice(left), the tenon joint & butterfly splice(right)"

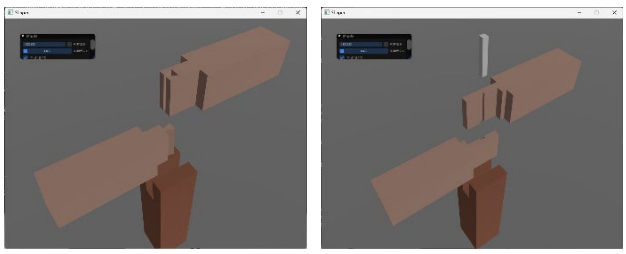

**Figure 10.** The examples of "the single-groove joint at the top of the column – the tenon joint & the fist-cog splice(left), the tenon joint & notched cross-lap splice(right)"

## 4. CONTRIBUTION

The script-based modeling engine in this study allows for the arrangement of existing models established through scanning, and implement primitive models using functions. The former is useful for utilizing existing digital model data, while the latter is ideal for large-scale automated modeling. Suwon Hwaseong Fortress and Hwaseong Temporary Palace, the buildings targeted in this study, do not refer to a single building but rather indicate groups of buildings constructed for various purposes. Automated modeling can be applied to implement the historical Suwon district, which includes the Hwaseong Fortress, Hwaseong Temporary Palace, and non-existing private houses. By adjusting parameters to apply the architectural styles that were frequently used for constructing private houses at that time, a large number of buildings with various shapes can be modeled.

Moreover, the methodology of this study can be applied to other models, besides Suwon Hwaseong Fortress and Hwaseong Temporary Palace. The current building modeling scripts often import and place modeling members generated through scanning. However, as mentioned earlier, since it is impossible to identify detailed joints and splices, the scanning members do not express joint methods. Therefore, if joints implemented by parametric modeling are applied to this model, the corresponding members will be replaced with parametric modeling members. If it is a script model implemented as a primitive, it will be merged and modified to apply the parametric joint method.

In Korean traditional wooden buildings, the structural system that takes into account the building's mechanical properties can be identified through traditional joint types. However, since joints are not directly visible on the building's exterior, they cannot be scanned, and modeling joint parts requires dismantling or detailed drawings for each member. Therefore, parametric modeling was chosen for this study, as it can be used in various contexts, such as inferring different joint methods without dismantling traditional wooden buildings, proposing various virtual restoration plans, and utilizing remaining archival documents or drawings, including those related to cultural heritage.

## 5. CONCLUSION

This study proposed parametric modeling to realize unidentifiable joints in the application of HBIM to Korean wooden architectural heritage. The existing virtual models implemented by Scan-to-BIM do not reflect the detailed shape and method of the joint parts. Therefore, this study aimed to improve the limitations of BIM for Korean architectural heritage by designing parameters using the relationships between members. However, it has been applied only to straight members. The carving mainly applied to bracket members is a subjective design by carpenters for aesthetic effect, so it is difficult to systematize and model the parameters, which is one of the limitations.

However, it is possible to partially apply parametric modeling in this case by modifying the size parameters of the scanning model based on the outline. Parametric modeling can be extended to the mechanically designed structural parts, even though it is a curved member, such as the bending of the eaves, if the model does not include subjectivity. Furthermore, if the proportions of the entire building are established as a criterion, such as an element called a “compartment”, parametric modeling can be attempted for all members interacting within the building.

Since various joint types could be implemented by changing simple parameters in this study, it’s a useful visualization method for inferring unidentified joints. It is also possible to conduct large-scale modeling including joints with minimum evidence because it enables automated modeling at the member level. Therefore, it helps to understand the connections among the members within the joint through the use of parameters. Consequently, all model data can be utilized for the preservation and maintenance of architectural heritage, as well as for archiving through HBIM library construction, and digital content.

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