Parametric Modeling Methodology for Roof Components of the Traditional Korean House with Focus on Chu-nyeo, Gal-mo-san-bang, and Seon-ja-yeon

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Abstract

The roof of the traditional Korean house, Han-ok, has a curvilinear shape and its design derives from accumulated design principles. Three-dimensional (3-D) object-oriented parametric modeling technology enables the modeling of irregular and atypical geometries by embedding numerically analyzed information. In this study, the authors devised a methodology of parametric modeling for the roof components of a traditional Korean house, such as Chu-nyeo, Gal-mo-san-bang, and Seon-ja-yeon, which have the most complex shapes and 3-D curves. While respecting the conventional drawing method used by craftsmen, the authors re-defined primary factors and systematized the parametric logic considering not only modeling efficiency and accuracy but also user interface and convenience.

Keywords: parametric modeling; methodology; Han-ok; roof component; user convenience

1. Introduction

1.1 Background and Research Objectives

The Han-ok, the traditional Korean house, is characterized by its extremely heavy and large roof. In order to alleviate the heavy image, the roofs of Han-ok generally have curvilinear forms and the edges are slightly lifted, as shown in Fig.1. The 3-D curves are constructed with roof components such as fan-shaped rafters [Seon-ja-yeon] and a corner-rafter support [Gal-mo-san-bang]. All these components have atypical shapes that are difficult to define geometrically; this has been the major barrier to the mechanized production of Han-ok. Therefore, such Han-ok members have been manufactured only by trained craftsmen, as the manufacturing requires both a high level of skill and considerable manual effort. The BIM technology can efficiently reduce such burdens on the production and enable the integrated management of information on the design, construction, and maintenance of Han-ok.

The BIM technology introduced in this study is object-oriented 3-D parametric modeling, which defines a model using the formula among the parameters determining each dimension of relevant components. (Park, 2011)

Accordingly, the final shapes are modified using automatic calculations when the user changes primary parameters; such functionality allows a high level of applicability when put into practice. (Kim and Jeon, 2012) So far, however, existing studies on the components that make the roof curvature of Han-ok have focused only on the orthodox drafting methods or on the implementation of individual 3-D shapes. Therefore, they are not very practical in terms of parametric modeling that accommodates the interchangeable dimensions.

This study intends to re-define the dimensions and factors that are critical for devising the 3-D parametric models of the components that make the roof curvature of Han-ok and then to quantitatively analyze the relations among those dimensions and factors. Through the generalization of these results, a modeling methodology
can be ultimately proposed to accommodate the variety and aesthetics of the roof of Han-ok. This methodology would be the first step towards the modernization of Han-ok and then serve as a basis for the re-interpretation of the orthodox drafting methods of Han-ok.

1.2 Range and Method of Research

The experimental subject in this study is a hypothetical Han-ok with a 5-purlin structure [5-ryang-ga] having a Hipped-and-Gabled roof [Pal-jak-ji-bung] of which the corner rafter and fan-shaped rafters are parametrically modeled. Brackets and aesthetic elements are omitted. The modeling adopts the methodology of 3-D parametric modeling, in which the Han-ok is divided into three groups: the body elements that form the structure under the roof and also control the overall size of the corner rafter and fan-shaped rafters, the roof elements that contribute to the roof curvature, such as the distance between columns and the outer end point of rafters [Cheo-ma-nae-mil-gi], the vertical difference in the curve of eaves [Ang-gok], and the horizontal difference in the curve of eaves [An-heori-gok], the microscopic roof elements that decide the shapes of individual components of the corner rafter and fan-shaped rafters. Next, the inter-relations among these elements are investigated before the relevant parameters are defined.

This study uses Digital Project (Gehry Technology, Inc.) as the modeling tool. Although the Digital Project has been developed using the original program that was used for aircraft, ships, and automobiles and is rather more difficult to use than other 3-D modeling tools, it has the reputation of superior functionality in the implementation of 3-D free-form shapes and is considered to be appropriate for the modeling of the corner rafter and fan-shaped rafters that make the roof curvature with 3-D curved lines.

2. Methodology of Parametric Modeling for Corner Rafter and Fan-Shaped Rafters

2.1 Fundamentals of Parametric Modeling for Corner Rafter and Fan-Shaped Rafters

The corner rafter is the member with a rectangular section cantilevered from the corner of the Han-ok to the 45° direction, and fan-shaped rafters are the members arranged like the ribs of a fan at both sides of the corner rafter. Each member of the fan-shaped rafter has its own shape and size, and the length and curvature increase as it gets closer to the corner rafter.

Fig. 1 shows the corner rafter and fan-shaped rafters in the roof of Han-ok. Because the corner rafter and fan-shaped rafters are the members that determine the roof curvature of Han-ok and have the most complicated shapes, they have special drafting methods that vary among craftsmen and crafts clans. The existing research so far shows the results of depicting the shapes of the corner rafter and fan-shaped rafters by 3-D modeling; however, there is no parametric modeling methodology developed that enables the automatic change in shape. The development of such methodology can provide an efficient design and construction of the Han-ok with the orthodox drafting methods applied accordingly.

The methodology considered for the parametric modeling of the corner rafter and fan-shaped rafters is composed with four principles: the application of traditional building methods, the accommodation of the variety in roof curvature, the consideration of user convenience, and the consideration of compatibility with other BIM tools. Parametric modeling of the corner rafter and fan-shaped rafters is designed to respect the traditional techniques to the maximum by reflecting the traditional building methods of Han-ok while projecting the engineering perspective.

The corner rafter and fan-shaped rafters are available in the most varied forms, depending on the craftman's technique and the user's design decision. While the techniques used by Han-ok craftsmen vary, the method that is geometrically most reasonable and the easiest to understand should be applied and the user's convenience should be considered so that the user can easily understand the techniques of Han-ok and design it.
Although BIM tools have rather different functions and interfaces, the modeling processes of establishing the base point, drafting the shape of the section, and implementing the 3-D form are similar. Therefore, this study intends to develop a modeling methodology by focusing on the principles of implementing geometrical forms.

2.2 Parametric Modeling System for Corner Rafter and Fan-Shaped Rafters

The corner rafter and fan-shaped rafters in Han-ok are the members that construct the roof curvature and unlike the body parts that have simple and linear forms, they have 3-D curved forms. The inner part \([Nae-mok]\) lies inside of the column purlin \([Ju-sim-do-ri]\), the overall size of which is determined from the horizontal distance between the two body elements, middle purlin and the column purlin, and the vertical distance between the two purlins. On the other hand, the sizes of the members of the outer part \([Oe-mok]\) lying outside of the column purlins are determined from the distance between columns and the outer end point of rafters of the roof elements. Further, the 3-D curved form of the members such as the corner rafter and fan-shaped rafters are determined according to the vertical difference in the curve of eaves and the horizontal difference in the curve of eaves of the roof elements.

The system described above is based on the planning and production principles of the craftsman, and only under this system, can the modeling be processed logically with the formative principles of Han-ok applied properly.

The modeling process for each member is described in Fig.5. First, the elements that have to be defined are selected by analyzing the shape of the subject member. Then, the elements are defined mathematically using drafting and production techniques in order to establish inter-relations with other elements and integrate them in a formula.

3. Parametric Modeling of Corner Rafter and Fan-Shaped Rafters

3.1 Establishment of Independent Elements

Before modeling the corner rafter and fan-shaped rafters, the horizontal or vertical distances between the purlins of the body elements and the dimensions of roof elements such as the distance between columns and the outer end point of rafters, the vertical difference in the curve of eaves, and the horizontal difference in the curve of eaves should be determined. The body and roof elements should be established as independent parameters that are not affected by other elements so that when the completed parametric modeling of the corner rafter and fan-shaped rafters and the modeling of other parts is combined, the overall shapes can automatically change on the basis of these independent elements.

In this study, the subject Han-ok is designed to be a 5-purlin structure with a Hipped-and-Gabled roof with a horizontal distance of 1,500mm between the two purlins, a vertical distance of 60 mm between the two purlins, and a distance of 1,500mm between columns and the outer end point of rafters. As the independent elements are defined above, the basic sizes of the inner part and outer part and the end position of various members can be found and the basis for the modeling of the corner rafter and fan-shaped rafters is established.

3.2 Parametric Modeling of Corner Rafter

The corner rafter \([Chu-nyeo]\) is the core member that determines the roof curvature. The modeling of the corner rafter must be completed and its position should be determined before the modeling of fan-shaped rafters can be started. The corner rafter has the shape of a bent stick as shown in Fig.6.; the part outside of the column purlin is called the outer part of the corner rafter, the middle purlin is called the inner part of the corner rafter, and the bending pitch from the top of the column purlin is called the corner-rafter parameter \([Chu-nyeogok]\). The rest of the corner rafter includes the width,
The method of drafting the corner rafter is based on the method of settling the corner-rafter parameter, which varies from craftsman to craftsman. This study uses Hyeon-chi-do-beob, which is the most commonly used method of drafting the corner rafter. (Kim, 2011)

The corner-rafter parameter controls the pitch from the center of the corner rafter to the end of the corner rafter, whose dimension varies with the craftsman, style, scale, and distance between columns and the outer end point of rafters of the building. The vertical difference in the curve of eaves is determined according to the corner-rafter parameter. This study, however, designates the vertical difference in the curve of eaves as an independent element rather than the corner-rafter parameter so that this parameter changes according to the vertical difference in the curve of eaves. In this approach, those who have a limited understanding about Han-ok can easily accomplish the modeling of the roof by controlling the vertical difference in the curve of eaves; this is easier to understand than determining the corner-rafter parameter.

The analysis of the drafting method of the corner rafter shows that the major elements that construct the form of the corner rafter include the corner-rafter parameter, the length of the outer part and inner part, the width, and depth of the corner rafter. The other elements such as the length of the rear part and the shape of the upper part of the corner rafter are additional design elements, for which similar dimensions are used with minor differences depending on the craftsman.

While the length of the inner part determined geometrically from the distance between the column purlin and the middle purlin is the same irrespective of the craftsman, the length of the outer part has a close relation with the vertical difference in the curve of eaves and the horizontal difference in the curve of eaves and varies considerably depending on the craftsman. Since design elements such as the roof curvature are difficult to define using a single formula, these elements are designated as such parameters as their values can be selected from a number of examples so that the user can change the form freely by changing the values.

The distance between columns and the outer end point of rafters is usually designed as the same as or slightly shorter than the horizontal distance between the column purlin and the middle purlin for structural stability; the horizontal difference in the curve of eaves is usually 1/4 of the distance between columns and outer end point of rafters with slight variation according to the craftsman. These are considered as independent elements that are input by the user.

In order to complete the modeling, the user has to input the default values (typically used by craftsmen) for the rest of the elements that change along with the size of the corner rafter. The difference in the height between the corner rafter end and the tip of the rafter in the completed model establishes the vertical difference in the curve of eaves.

3.3 Parametric Modeling of Corner-Rafter Support

The corner-rafter support shown in Fig.8. is the member that supports fan-shaped rafters at the top of the column purlin; the curvature of fan-shaped rafters changes with the height of the column purlin. (Min, 2010)

The height of the corner-rafter support is typically determined on the basis of the wall width, the corner-rafter parameter, or the height of the body of the corner rafter; however, basing the height on the wall width is only an assumption by some researchers and the height of the body of the corner rafter varies from craftsman to craftsman and this variation results in considerable deviations. Therefore, this study designates and expresses parameters on the basis of the corner-rafter parameter.

3.4 Parametric Modeling of Fan-Shaped Rafters

Fan-shaped rafters are arranged between the rafter and the corner rafter like the ribs of a fan. Like the
corner rafter, fan-shaped rafters are divided into two components: the outer part outside of the corner-rafter support and the inner part inside. Each of the fan-shaped rafters has a different form depending on its position. Craftsmen decide the form of each fan-shaped rafter through their own method of arranging the rafters. This study adopts the most widely acknowledged and used method, in which fan-shaped rafters are arranged at 30cm intervals (the intervals of rafter) by drawing perpendicular lines from the first rafter to the curved line of the horizontal difference in the curve of eaves.

(1) Arranging the center lines of fan-shaped rafters

The arrangement of fan-shaped rafters is processed on a horizontal plane, as shown in Fig.9. It starts with the pivot point of fan-shaped rafters, which is [the intersection between the extension of the middle-purlin center line and the outer face of a corner rafter] rather than the center of a corner rafter as its width is considered. A triangular shape is drawn with the three points of [fan-shaped rafters pivot point], [the intersection between the horizontal difference in the curve of eaves and middle-purlin center line extension] and [the intersection between the horizontal difference in the curve of eaves and the corner-rafter face]. A perpendicular line of 30 cm to the horizontal difference in the curve of eaves is drawn beginning from the first rafter of the fan-shaped rafters and a (center line of fan-shaped rafters) is drawn from the intersection; this procedure is repeated until the last rafter. The interval of the last fan-shaped rafter could be considerably shorter or longer than 30 cm, which can be resolved either by adjusting the intervals to be a little shorter or longer than 30 cm or widening the intervals between the second rafter and the third rafter.

(2) Determining the diameter [Seon-ja-tong] of fan-shaped rafters

The next step is to decide the diameter for the inner part of fan-shaped rafters. A perpendicular line is drawn from the line extending outwards from [the midpoint of the fan-shaped rafters center lines] towards the first fan-shaped rafter at [the horizontal projection line of the outer face of the corner-rafter support], which is repeated to the last rafter as shown in Fig.10. The length of each perpendicular line becomes the diameter of fan-shaped rafters.

(3) Drawing the inner part [Nae-mok] of fan-shaped rafters

A vertical line is drawn from [the intersection between the horizontal projection line of the outer face of the corner-rafter support and the line at the midpoint of fan-shaped rafters center lines] on the fan-shaped rafters arrangement plane to the outer face line of the actual corner-rafter support as shown in Fig.11. The distance between a couple of intersections becomes the base length of the inner part, based on which the inner part is completed by assigning the height as the depth of the inner part of fan-shaped rafters [Seon-ja-chum] from the first to the last rafter. There is no definite finding on the depth of the inner part of fan-shaped rafters in existing research. In this study, the depth of the inner part of fan-shaped rafters is fixed to be greater than the thickest diameter of fan-shaped rafters so that the outer part does not protrude from the inner part in case the depth of the inner part becomes smaller than the width of fan-shaped rafters.
(4) Drawing outer part of fan-shaped rafters

The outer part is drawn after drawing the inner part of fan-shaped rafters. As shown in Fig. 12., a vertical line is drawn from [the end point of the outer-part center line on the fan-shaped rafter's arrangement plane] towards the roof curve to find the intersection. The line linking this intersection and the upper center line of the inner part of fan-shaped rafters becomes [the upper center line of the outer part]. A circle with the diameter equal to the width of each fan-shaped rafter is drawn at the 1/3 point from the inside to the outside. Another circle with the same diameter is drawn at the 2/3 point and the last circle with a diameter that is 2/3 of the width of fan-shaped rafters at 30 mm outwards of the endmost point is drawn. The final form of the outer part is completed by drawing a solid having these three circles as its sections.

Finally, the end part of the outer part is cut by approximately 3 cm to be slanted inwards, which completes the modeling of fan-shaped rafters, as shown in Fig. 13.

3.5 Application of Parametric Modeling

The shape of a completed model of the corner rafter and fan-shaped rafters changes automatically as the parameter values established during modeling are adjusted (Fig. 14.).

The application of such a parametric modeling methodology could facilitate easier completion of the Han-ok modeling, since the shapes of the corner rafter and fan-shaped rafters change automatically to match the overall size of a particular Han-ok.
traditional drafting methods, the accommodation of the variety in roof curvature, the consideration of user convenience, and the compatibility with other BIM tools. In this methodology, the components of Han-ok are categorized into three groups of elements—body elements, roof elements, and microscopic roof elements—the inter-relations among which are defined as formulae in order to construct a parametric model of the Han-ok roof curvature that changes automatically in response to various factors, such as vertical and horizontal distance between purlins and vertical difference of the curve of eaves etc. While implementing the drawing principles used by craftsmen, the authors adjusted some parameters and drawing orders to improve the user interface and convenience.

This study is the first step towards the mechanized production of Han-ok by facilitating systematic design and standardization using new technology while accommodating the variety in Han-ok. Further, the process of defining inter-relations among members and formulating logical descriptions about them would enable us to re-interpret the traditional principles of Han-ok. Based on these results, further research should be carried out for the other members that also contribute to the roof curvature.

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References