BIM-Based Parametric Design Methodology for Modernized Korean Traditional Buildings

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Abstract
With rising social interest in the quality of life and sustainable development in architecture, demands are growing for Hanok, traditional buildings of Korea, as a viable alternative to modernized architecture of Western origin. However, even as the so-called "New Hanok" — which updates the traditional structure with modern design — is gaining popularity among the general public, its design and construction are still a minor practice, in the sense that they rely on a small group of professional carpenters whose practice largely rests on their personal experience. Aiming to build an information system of Hanok that can contribute to the industrialization of its production, this research proposes a new design process for traditional architecture, utilizing a parametric design methodology. This process, based on the understanding of tectonic joints and spatial composition of our traditional architecture, defines a parametric relationship among the structural elements that compose Hanok. The research uses Gehry Technologies' Digital Project and Autodesk Revit Architecture — most useful commercial programs of parametric (and associate) design among today's CAD/CAE/CAM applications — to apply a concurrent parametric design methodology, approaching the project from both "bottom-up" (building initiated by the assembly of smallest elements) and "top-down" (building from partial modifications on a pre-determined whole), to present a new design process for Hanok elements.

Keywords: parametric design; BIM; data structure; modernized Korean traditional buildings; Hanok

1. Introduction
1.1 Background and Goals of Research
With global environmental issues that have direct impact on our daily lives, and the subsequent demand for sustainable developments in architecture, concern for the quality of living is continuously on the rise. Added to this is a social current to imagine a lifestyle beyond uniform and fixed models, and what we now have is a growing interest in Hanok, Korea's traditional architecture well-known for its environmental friendliness.

Of special interest is the so-called "New Hanok," a modernized form of Hanok. A balanced mixture of traditional style and modern space, it has become an object of interest not only within the professional community but also among the general public, with the potential of creating an even greater mass market. Many forms of "New Hanok" are already in existence: Hanok hotels, Hanok public service offices, Hanok apartments, and Hanok hospitals. Recently there are efforts to replace the Hanok's traditional material of wood with others — such as steel or laminated timber — and with these various interesting experiments the future of New Hanok is brighter than ever.

However, there is an obstacle to the industrialization of New Hanoks: the production of traditional architecture, including Hanok, unlike contemporary buildings, relies greatly on a small group of specialized technicians and carpenters, whose expertise is obtained not through systematic education but from on-site experience. Considering that the building industry is primarily characterized by a cooperative process, what is urgently needed is an information system that supports the design of Hanoks, which enables a design process based on systematized and shared data, and the establishment of an IT (Information Technology) infrastructure that will facilitate the mass production of Hanok to make it viable as a contemporary residence type.

Since the mid-2000s, BIM (Building Information Modeling) is introduced in the AEC/FM industry, utilizing the technical developments of the IT industry to integrate the overall process of building from design to construction and management. Answering the demand for sustainability and environment-friendly developments in architecture, BIM enables integrated production and management of data related to a building in its full life-cycle, from initial schematic design to operation and management.

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Moving away from the traditional method based on two-dimensional drawings, a new digital-based environment for architectural practice is created under BIM, where one can extract required information from three-dimensional models which store multiple layers of property information — including the object's function, structure, use, features, limits, and interrelation with other objects. A BIM-based application, inclusive of not only geometric information of a building's elements but also their material properties, can perform such useful services as design automation, real-time data link, generation of details, interference checking and reporting, cost estimation, virtual simulation, and error correction in the design phase by pre-construction inspection (Eastman et al., 2008).

Making use of the recent developments of parametric and associate design methodology, this research is a primary step in building a BIM for Hanok: the introduction of a new parametric design process that constructs information modeling of the Hanok's structural elements.

1.2 Scope and Contents of the Study
In order to conceive an information modeling of Hanok — the first stage in building an information system that can contribute to the industrialization of the Hanok's production — this research proposes a parametric design process that focuses on the tectonic joints and spatial composition of our traditional architecture. Its primary mission is to define a structural typology of Hanok and a parametric relationship among the individual elements that compose a traditional building.

Reflecting the characteristics of Hanok, such parametric design is based on two constraints: 'geometric and dimensional constraints,' defining the dimension and form of each Hanok element; and 'assembly constraints,' which will control the linking of components, consisting of multiple elements.

This research advances in the following phases:
- Survey and analysis on current parametric (and associate) modeling techniques (Chapter 2): An overall survey on current parametric technology — encompassing the integrated processes of digital-based CAD/CAE/CAM — leads to an analysis on its application to AEC/FM industry.
- Logical description of the Hanok's structural types (Chapter 3): by analyzing its inherent design logic, design guide elements are set for a logical description of the structural types of Hanok.
- Introduction of parametric design process of Hanok elements (Chapter 3): a new design process of knowledge-based parametric modeling, based on the interrelationship and joints of Hanok elements is proposed.
- Demonstration of 3D Hanok element library and pre-fabrication (Chapter 4): Utilizing the proposed parametric design method, pilot modeling is implemented, and, to validate the applicability of Hanok element data in actual construction, a DMU (Digital Mock-Up) of a sample element is produced through three-dimensional printing.

2. Introduction on Parametric Design Technology
2.1 Life-cycle Management System
Parametric design, which interlinks information of a building's elements and its upper components (composed of multiple elements), is based on PLM (Product Lifecycle Management).

An integration of CAD, CAE, and CAM, PLM operates on the object's overall life-cycle, from initial requirement analysis to concept design, design development to production, sales to after-sale service, and finally disposal and recycling.

Technical developments made in the manufacturing industry's PLM were applied to the architectural industry in the mid-1990s, and since 2000, further possibilities are explored with the broad use of BIM. Recently, Gehry Technologies produced Digital Project, a package that facilitates the use of CATIA — a PLM system — in the AEC/FM industry, overcoming the difference between the two industries and their respective use of PLM and BIM systems.

Among the programs used in the field of architecture, Generative Component (for Bentley Architecture) and Grasshopper (for McNeel Rhino3D) are graph-based in their application of parametric technology, whereas Autodesk 3D MAX Design is stack-based; Gehry Technologies' Digital Project and Autodesk MAYA, on the other hand, can be classified as an application using the Associative History Parametric method. This research will use Digital Project and Revit Architecture for its demonstration on information modeling of Hanok elements.

2.2 Parametric Representation
Digital modeling, in its aim to generate a three-dimensional representation of a specific object, has evolved from wireframe modeling (where the object's external figure is represented by points and lines) to surface modeling (adding planar data) and finally to solid modeling, which encompasses both interior and exterior aspects of the object. Whereas surface modeling deals only with the list of planes that shape a figure, solid models also include data on the interrelationship among the planes as well as their inner/external features, and hence enable us to calculate the object's volume. Various methods are applied in solid modeling: CSG (Constructive Solid Geometry); Sweeping and Skinning, based on 2D sections; Rounding and Lifting, implementing partial modification of pre-formed figures; Boundary Modeling, which directly operates on points, lines, and planes that define a figure; and FBM (Featured-Based Modeling) (Pottmann et al., 2007).

Among these, CSG, utilizing volume calculation of adjacent objects in solid modeling, makes possible
the modeling of highly complex forms, by dividing them into a combination of geometric shapes. It creates complex forms by Boolean operations — uniting or subtracting neighboring primitives, i.e. simple objects with well-defined boundaries — as systematic tree structure. With its small and simple data structure, CSG can build and modify forms intuitively, and its transfer to B-rep is relatively easy. However, because it works as a combination of primitives, there is a limit to the complexity of a shape it can construct, and outputting a display is quite time-consuming.

On the other hand, FBM is a more advanced solid modeling technique, defining parts as structures of objects with pre-defined properties. By history function — a consecutive command list in the modeling of parts — feature structures of objects can be mutually referred to when required. Although FBM is based on a combination of CSG and Sweeping, it can autonomously define properties in accordance with the desired form, and is different from CSG which can only use fixed primitives (Shah & Mäntylä, 1995; Elliott, 2007).

Considering the tectonic joints and combining principles of the Hanok’s elements, this research utilizes FBM in creating the three-dimensional geometric information of Hanok.

3. Proposing a Parametric Design Process

3.1 Design Guide Factors for Korean Traditional Wood Structures

This research is based on a systematic methodology that defines design in terms of a logical process. Parametric design is in essence a logical description of the inherent composing principles of the various elements that together create a certain form. Therefore, an application of parametric design methodology based on the BIM system enables the structuring of the parametric data of elements that compose a building, generating a logical description of a building’s construction method and composing principles.

The logical definition of the Hanok’s structuring method is especially plausible, when we consider the building principles of our traditional architecture. The tectonic features of the Hanok’s timber construction provide useful criteria in conceiving a parametric definition of its structural types. After presenting a logical description of the Hanok’s structural types, this paper will then suggest a parametric design process that defines the individual structural elements composing its timber structure.

Based on an analysis of the structuring principles of Hanok, 10 design guide factors are defined, which in turn parametrically define the types of Hanok structure. They are: those that determine the size of the building’s floor plan (width and number of bays in the front and on the sides, respectively); and those that define its roof structure and section/elevation (number of floors, composition of Pyungbang — rafter beams — in side section, number of Gidung — columns — in side section, height of Gidung, and horizontal and vertical distances between side Doris).

The various types of Hanok timber structure can be classified by the features of its side section: it is the position of the inner Gidung and its joining with Sukkare that define a specific structural type of Hanok. Therefore, among the design guide factors, ‘composition of Pyungbang in side section’ determines the positioning of Pyungbang that connects inner Gidung and Sukkare. That is, the position of inner Gidung can be described as either a) central placement, b) arbitrary placement, and c) none (no inner Gidung), in which b) requires the description of location and number of Pyungbang elements. When there are two Pyungbangs that connect Sukkare and Gidung in the front, it can be described as ‘front Sukkare Pyungbang 2’.

| Guide | Factor | Name | Explanation |
|-------|--------|------|-------------|
| Plan  | w      | Plan Width | Front length of floor plan |
|       | d      | Plan Depth  | Side length of floor plan |
|       | x      | Grid X     | Width of bays in the front |
|       | y      | Grid Y     | Width of bays on the sides |
|       | s      | Storey     | Number of floors |
| Elevation/Section | d | Disposition of Beams | Composition of Pyungbang in side section (position of inner Gidung, joint method of Pyungbang and Sukkare in side section) |
|       | c      | Section Column | Number of Gidung in side section (incl. inner Gidung) |
|       | h      | Column Height | Height of Gidung (incl. Chosok, Goju-Gidung height) |
| Roof  | pw     | Purlins Width Span | Horizontal distance between side Doris (distance between Ju-Dori and Jung-Dori, Jung-Dori and Jong-Dori) |
|       | ph     | Purlins Height Span | Vertical distance between side Doris (distance between Ju-Dori and Jung-Dori, Jung-Dori and Jong-Dori) |
|       | e      | Eaves      | Length of Cheoma (horizontal distance between outer column and eave edge) |

Using the design guide elements set by this research, a logical description of any Hanok structural type can be generated. A logical description of the design guide elements of the Pavilion of Yaecheon’s Kwon Family (hereafter referred to as Kwon Pavilion) — the example chosen by this research for the parametric
modeling demonstration — is thus presented in the Cartesian Product form of Fig. 1.

\[\begin{aligned}
&w, d, x, y, s, c, h, pw, ph, e,
\end{aligned}\]
\[\begin{aligned}
&= \begin{cases} 3, & (2400, 2400), \{2700, 2700\}, \{l, \text{(central placement, front Sukkare Pyungbang)}\}, \{l, \{3500, 0\}, \{3300, (3000, 1000)\}, \{700, 1000\}\}. \end{cases}
\end{aligned}\]

Fig. 1. Logical Description on Timber-structure Types (top) and Extraction Section Schema (bottom) [Kwon Pavilion]

A study on the allowance limit of variables in Hanok type design guide factors is currently underway. By performing a survey on a larger number of Hanoks and analyzing their structural systems, minimum/maximum values applicable to their structural types will be calculated, and a proper allowance limit of design guide factors will be provided in a following study.

3.2 Parametric Information Chains

In this phase, design guide factors concerning the Hanok structural types defined previously are set as reference planes or points in three-dimensional space, and parametric design of individual structural elements is implemented. Reflecting the Hanok's principles of tectonic structure and spatial composition, the setting of types follows four distinct units: element unit, structure unit, assembly unit, and joint unit.

The relationship among individual elements that assemble a component is defined as a function of parameters. Based on this, a library can be constructed for the Hanok's individual elements — encompassing the smallest element to overall model of Hanok types — which can facilitate the parametric design of Korea's traditional type buildings.

The data structure for Hanok BIM should consider the tectonic and spatial characteristics of traditional architecture, and should define major parameters for elements that compose its structure. According to Hanok elements' hierarchical structure, relative proportion and joint-method among various elements are defined in parametric function based on their key dimensions.

3.3 Parametric Design Process

Design process by parametric and associate relations is based on 'information dependency' and 'constraint dependency.' In the former, the information of lower component is dependent upon upper component: changes in the upper data are followed by changes in the lower data.

The parametric design process of Hanok components suggested by this research is: Guideline Factor Setting → Unit Categorization → Depth Hierarchy Setting 1 (Components) → Reference Setting → Depth Hierarchy Setting 2 (Elements) → 2D Geometry Description → 3D Geometry Description → Instance/Powercopy Setting → Boolean Operation → Document Template Production → Spreadsheet Extraction → Assembly → Pre-Fabrication. (Table 2.)

Table 2. Parametric Design Process of Hanok Components

**Guideline Factor Setting**

Based on an analysis of the Hanok's construction principles, 10 design guide factors are set to define the types of Hanok structure.

**Unit Categorization**

A general categorization of the Hanok's major elements is performed, considering its spatial composition and joint methods.

**Depth Hierarchy Setting 1**

A primary hierarchy among parametric data system of Hanok elements is set: three-dimensional geometric data, relative position and joint information.

**Reference Setting**

Three references are set in defining the geometric and joint information of elements: Grid, Level, and Parameter. Parameters for the description of three-dimensional geometric information consist of input variable and output variable.

**Depth Hierarchy Setting 2**

A secondary hierarchy is set for Hanok elements, based on the closeness and hierarchy of parametric relationships among components and sets of elements. Additional division can be made if required.

**2D Sketch**

A two-dimensional drawing of each element's section is made according to geometric and dimensional constraints.

**3D Geometry Description**

Three-dimensional geometric information is built, applying the various form-building techniques that can describe the specific formal characteristics of each element.

**Instance/Powercopy Setting**

A two-way link is established with property information, based on Grid, Level, and Parameter as established in the reference setting phase.

**Boolean Operation**

Boolean operation (addition, removal, intersection) is implemented on three-dimensional geometric information of joints between elements.

**Document Template Production**

Finalized elements — reflecting the parametric joint information of elements, including joints — are stored as individual file units (parts).
4. Implementation of Methodology

In this chapter, the proposed parametric modeling method for Hanok will be applied to the Kwon Pavilion. As a pilot modeling, it will create a prototype of a parametric data structure for Hanok elements, focusing on the joints and components of its structure.

Among the various commercial BIM programs in use, Gehry Technologies Digital Project and Autodesk Revit Architecture, two representative programs that support parametric modeling techniques, will be utilized. However, since the proposed parametric design process is not subject to any specific application, the methodology suggested by this research is also applicable to other parametric modeling-supporting BIM programs.

4.1 Parametric Associate Relations

Considering the Hanok's tectonic features and especially its joints, references are set as a relative base point to interlink parametric information. This research proposes three references: 'grid,' distance between columns that determine the overall scale of the building; 'level,' providing a horizontal base; and 'parameter,' which describes the three-dimensional geometric information of elements (Fig.2.).

4.2 Structuring of the Model

In order to structure the parametric data of the Hanok's joint elements, this research utilizes FBM, which can define arbitrary parts as a structure of objects pre-defined with specific features. Because FBM provides not only formal dimension data but also a consecutive list of processes that created the resulting form, one can consult the feature structures of the objects by referring to the command history. Since it is also possible to reorder the commands from the history list, it provides a major technical base for parametric design currently under consideration.

- Joints: Parameters are designated to joints of elements, based on their 2D drawings. For the width and height of an element, constraints are applied to use calculations from width and height of Gidung, and, by linking the properties, its three-dimensional geometric information can also be used in other elements.

- Gidung and Changbang (Beam): According to the form of Gidung, with Grid and Level (an element's relative position) as reference, geometric and dimensional constraints are applied to Gidung's 2D drawings. The body of Gidung is produced by applying its height.

- The meeting point between Gidung and Changbang in traditional structures is quite formally complex, consisting of elaborate mortise and tenon joints. Therefore, the element file of Gidung can be generated by removing Sagwae and Jumeokjang — produced in
the previous phase — from the Gidung body through the FBM-based Boolean operation. The horizontal element of Changbang, on the other hand, has a tenon and hence its library file can be generated from the FBM-based Boolean operation of adding (Fig.4.).

- Sukkare and Roof: Roof, the upper major structure of the Hanok, has a three-dimensionally curving shape. In order to fix a relative position in a virtual space, the side Dori's vertical and horizontal location is set as a base point. The curving roof form thus produced is then divided into constant intervals, and points generated from the division that acts as a base point for the addition of Sukkare. By linking the properties of related parameters, the modeling of the Hanok’s roof structure is finalized (Fig.5.).

4.3 Parametric Variations
After producing various elements of Hanok — columns, beams, and elements of roof structure — these elements are then assembled into a Hanok building by applying assembly constraints that reflect its tectonic features, i.e., how its elements are joined.

Because individual elements are linked in parametric relationship, when the data of a certain element is changed information of other parametrically linked elements is also updated, rendering a modified form of the overall Hanok building in real-time. Changes in input variable, as defined in the ‘Reference Setting’ phase of Chapter 3, automatically generates value updates in output variable, parametrically amending all related elements (Fig.6.).

4.4 Spreadsheet Extraction
In the roof structure, Lower Sukkare and Upper Sukkare are classified as the same element but, because of the curving shape of the roof, it has different length and form. One of the strengths of the parametric design methodology suggested by this research is its ability to extract the changing dimensions of elements that are categorically united, according to the form of the roof. The dimensional and geometric information extracted from the parametric model also enables us to proceed to the element’s pre-fabrication.

This parametric design methodology can be applied in the actual building of Hanoks as a new construction method. Currently the traditional structures are built from bottom to top: after the lower structure is finished, the carpenter relies on his/her experience and instinct to conceive the roof structure, and determines the length of the Upper Sukkare on site. The method of this paper, on the other hand, can extract dimensional information of formally un-fixed elements in the design phase, and can help to modernize the building process of Hanok, making it available to a growing market (Fig.8.).

4.5 Pre-Fabrication
This final phase applies DMU (Digital Mock-up) technology to the hitherto constructed Hanok element data — modeled by parametric design methodology — to check if it can be properly applied to actual construction. A preceding phase to CNC production, pre-fabrication verifies and validates the element data of Hanok, to test its applicability to the
Fig. 7. Diagram of the Parametric Design Process for Hanok Elements [Kwon Pavilion]
integrated process of CAD/CAE/CAM, from design to production.

In this research, individual elements created by modeling were transferred to STL format, and printed three-dimensionally by a rapid prototyping device. The validity of the Hanok element data library was verified when the physical models of individual elements were successfully assembled into the Hanok’s structural frame, with fitting joints (Fig.9.).

5. Conclusion

As a primary study in presenting a new design methodology that can support the design of modernized traditional architecture, this research proposed a parametric design process for Hanok. [Fig.10.] Keeping up with the recent changes in the AEC/FM industry — instigated by its integration with the advanced parametric technology of CAD/CAE/CAM — the proposed methodology enables the application of the cooperative design process in the realm of Hanok construction. In other words, a feedback process is made possible in the design of Hanok with the introduction of concurrent engineering between "bottom-up" (building initiated by the assembly of smallest elements) and "top-down" (building from partial modifications on pre-determined types) methods.

One of the characteristics, or limits, of Korean traditional architecture was that its construction was implemented by a small group of professionals. The purpose of this research is to build a systematic data library of Hanok elements, making a technical contribution to the standardization of the construction of traditional architecture.

The parametric design process proposed in this research defines the interrelationship among parameters of major elements that constitute the timber structure of Hanok (Fig.7.). Employing parametric technology, it suggests a new design methodology that can be applied in the planning and design process of New Hanoks.

Furthermore, by integrating the advancements in BIM with Hanok design/construction and aiming for their standardization and automation, the industry of Hanok can finally gain a competitive edge in economic efficiency and contribute to further popularization of New Hanok culture, attractive in its modern interpretation of our traditional architectural culture.

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