APPLICATION OF DIGITAL CATALOG USING PARAMETRIC MODIFICATION: Morphological variations in design through the traditional Korean joinery

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December 2010

Submitted towards the fulfillment of the requirements for the Doctor of Architecture Degree

School of Architecture
University of Hawaii

Doctorate Project Committee
Hyoung-June Park, Chairperson
David Rockwood
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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawaii at Manoa.

Doctorate Project Committee

Hyoung-June Park, Chairperson

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"In their hearts humans plan their course, but the LORD establishes their steps – Proverbs 16:9"

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ABSTRACT

APPLICATION OF DIGITAL CATALOG USING PARAMETRIC MODIFICATION:
Morphological variations through the traditional Korean joinery

By

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Key words*: Morphological transformation, Digital Catalog, Parametric modification and Korean joinery system*

The purpose of the study is to explore the idea of morphological transformation in building components and its design iteration through the parametric changes and rearrangements of components. The parametric conditions in Building Information Modeling (BIM) allow flexible changes in form, dimension and assembly of the components. The unique setting of working with the components, BIM software allows its users to easily modify the general characteristics of components through their parametric changes (Lee, Sacks and Eastman, 2006). With traditional Korean joineries as the main components within the digital catalog, parametric modifications of each component will be able to perform morphological transformation of a building that is being designed.

Traditional Korean architecture is referred to as "moving architecture," due to the efficiency and economy in its constructing process that allows the reuse of building components with varieties of flexible joinery system in assembly and disassembly process and prefabrication method.[1] With the application of Building Information Modeling (BIM), the digital catalog of all

[1] Jung, Yun-Sang. 2006. A study of *Joineries in Wooden Structure and its analysis* in Seoul, Korea. Research Documentation, traditional Korean architecture study group.

the 44 components of Korean joinery system is developed to be the main source in the design of a prototypical structure and its morphological transformation. Based upon the components of three primary bracket styles (*Jusim-Po, Ik-Gong and Da-Po*) of traditional Korean joinery system in the catalog, the parametric modifications of the components and their rearrangements are performed for various design iteration. This paper demonstrates the design process of morphological transformation using parametric modifications in BIM environment through the parametric changes in Korean joinery system.

In this paper, all forty four components of Korean Joinery system become a series of modules in a rule-based (parameters and constraints) catalog for the parametric changes and the rearrangements among the components within Autodesk Revit environment. Since the catalog contains the components created from various joinery conditions, any single module or the combinations of the multiple modules from the catalog can be employed for easy fabrication, removal, reattachment and action as a structural element as well as sub-structures after its usage. The catalog allows a user to assign various parameters to the variables of each component according to its usage. By assigning different parameter, the component has flexibility for generating various joint connections.

The research provides various transformation outcomes of a prototype structure with the modification of the components. The original prototype shelter design transforms into different furniture for public usage or individual resting units. According to a given design condition or site context, the prototype structure becomes transformable and reusable with various combinations of configuration among its components and their parametric changes.

CHAPTER 1

INTRODUCTION

1. DEFINITION

The following are several definitions of *morphology and parametric* in the New Oxford American Dictionary:

Morphology

"1. the branch of biology dealing with the form and structure of organisms.

2. the form and structure of an organism considered as a whole.

3. *Linguistics*.

   a. the patterns of word formation in a particular language, including inflection, derivation, and composition.

   b. the study and description of such patterns.

   c. the study of the behavior and combination of morphemes.

4. the form or structure of anything

5. the study of the form or structure of anything"[2]

Parametric

"1. Mathematics.

   a. a constant or variable term in a function that determines the specific form of the function but not its general nature, as *a* in $f(x) = ax$, where *a* determines only the slope of the line described by $f(x)$.

   b. one of the independent variables in a set of parametric equations.

2. Statistics. a variable entering into the mathematical form of any distribution such that the possible values of the variable correspond to different distributions.

3. Computer. a variable that must be given a specific value during the execution of a program or of a procedure within a program.

4. Characteristic or factor; aspect; element."[3]

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[2] New Oxford American Dictionary.

2. PURPOSE AND SCOPE

The main purpose of the project is to experiment with the parametric modifications in component constructing process and its application in building design through the morphological transformation – therefore different configuration of iteration becomes possible for flexible design approach. The project will incorporate the unique varieties of traditional Korean joinery system as its main component group. The advanced tectonic principles of individual components embedded in traditional Korean joinery system effectively led to an easy assembly and disassembly, fast construction, easy relocation of a structure and the reuse of components.[4] Traditional Korean architecture is not a one massive structure but multiples of individual components assembled together.[5] In various documentations displaying the repairing work in traditional Korean architecture, the quality of Korean joinery system in its mechanisms has proven to be very efficient in assembly and disassembly method, enhances the reusability of the material, and easy relocation of a building.[6] In the computerized modeling of components found in traditional Korean joinery system with its parametric changes, a total of 44 existing components and 136 new components will be valuable in the digital catalog for their effective use in morphological changes – the digital catalog and its 180 individual components will serve as an important design tool to propose various iteration of shelter design and its sub-structures.

The project is an overview of the process of generating a morphological transformation through parametric modifications in each component. The parametric data will be combined and make a set of individual components under one library, the "digital catalog." Research conducted on traditional Korean joinery system, parametric modifications and their application, uses and rational relevance, morphological variations, computer modeling and design iterations will be the overall scope of the project. This paper suggests the parametric modifications of traditional Korean joinery system and the exploration of the application possibilities using parametric and associate design methods.

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[3] New Oxford American Dictionary.

[4] Chong, Im-Guk. "*The Style and Structure of Korean Architecture.*" Seoul, Korea: Il-Won-Sa Press, 1974.

[5] Jung, Yun-Sang. 2006. A study of *Joineries in Wooden Structure and its analysis* in Seoul, Korea. Research Documentation, traditional Korean architecture study group.

[6] Kim, Dong-Hyun. "*Korean Wooden-Architecture Methodology*." Seoul, Korea: Bal-Un Press, 1993.

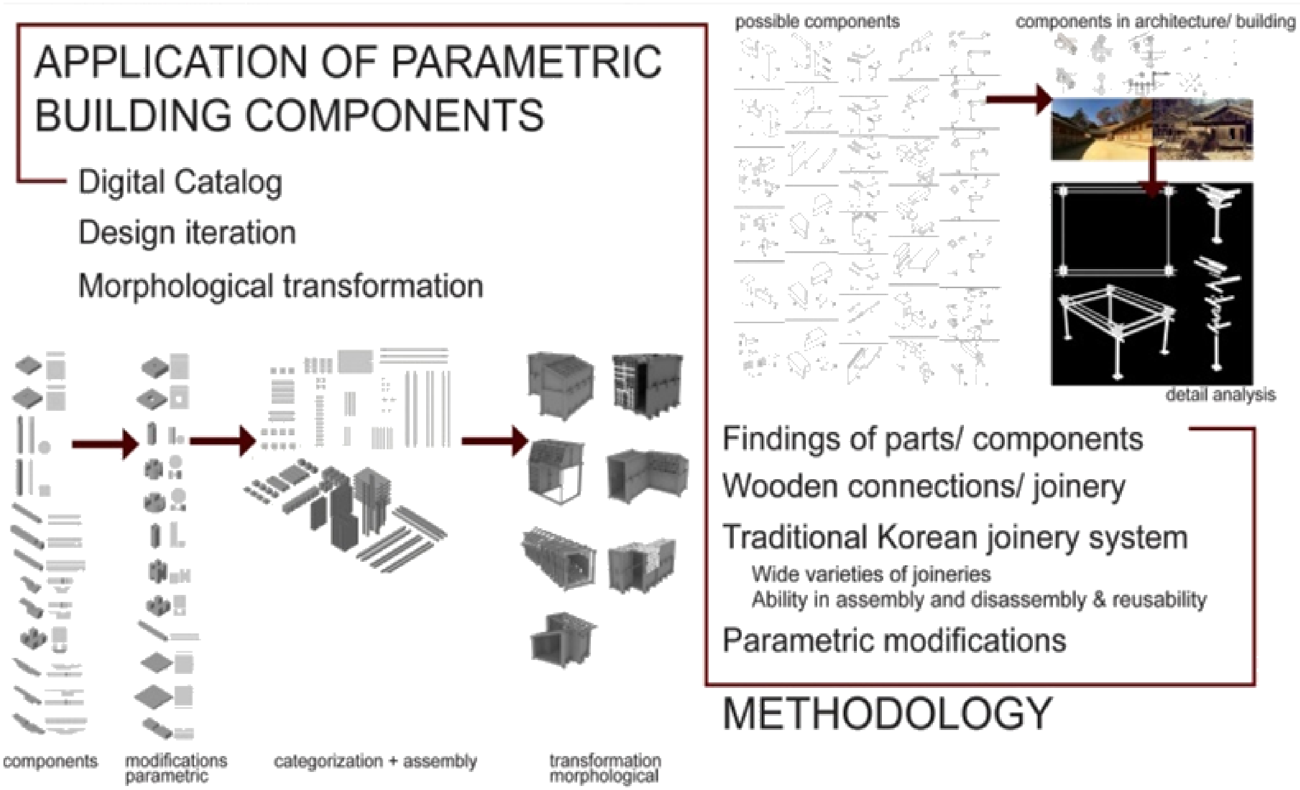

Figure 1. 1 Overall objective of the project

The core purpose of the project is to study the possibilities of morphology through parametric modification using BIM software. In a purely morphological sense, the following items will be omitted in the project though traditional Korean joineries are selected as main source of component group:

1. Any cultural aspects in material, form and design
2. Structural performance of the components and building designed
3. Aesthetic values within the traditional Korean joineries

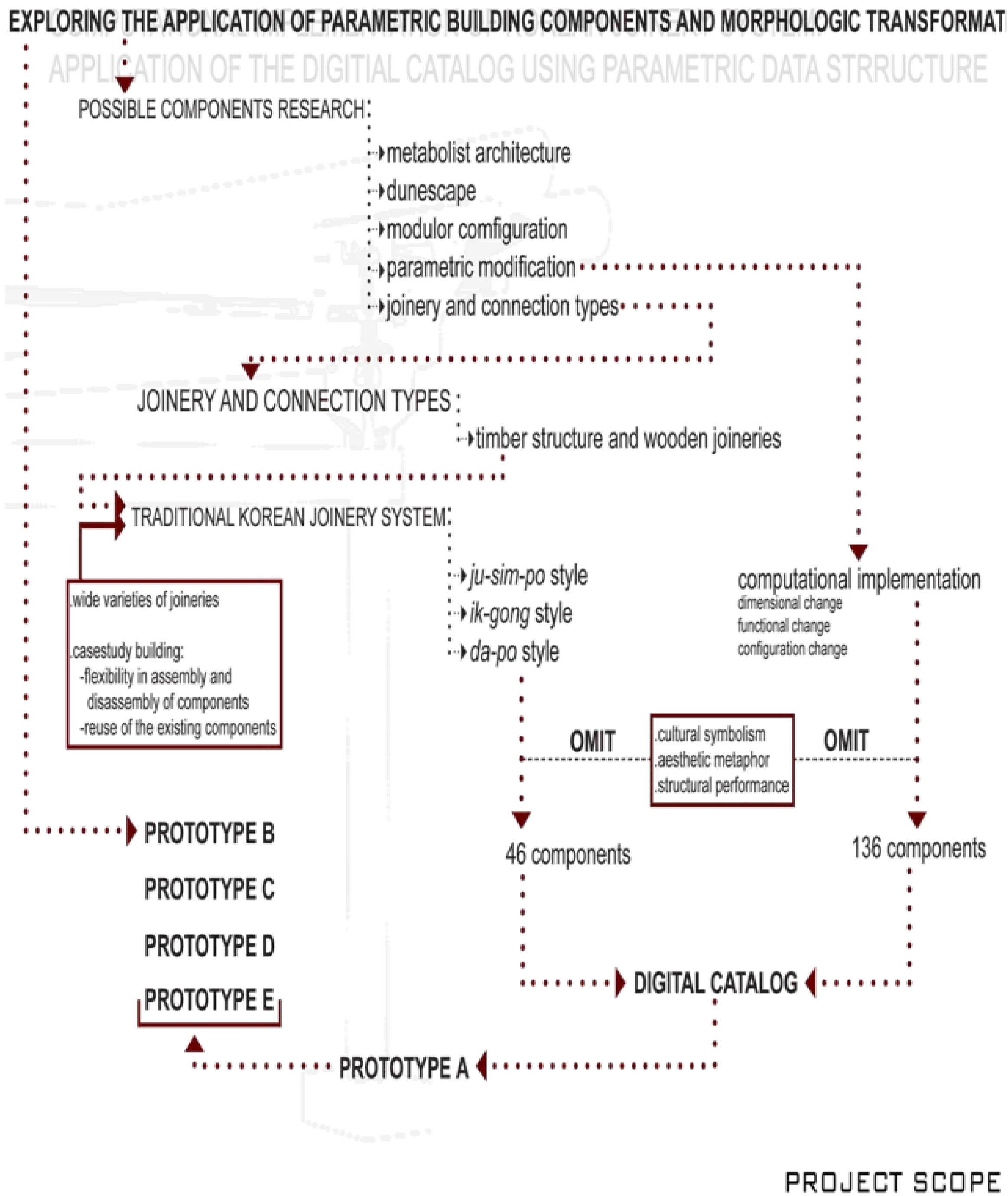

Figure 1. 2 Overall scope of the project

3. OBJECTIVE

The objective of the project is to perform the morphological transformation of a structure, through implementing parametric modifications in the components group within digital catalog. Exploring the digital parametric modeling and its computational implementation of traditional Korean joinery system will be the primary object to pursue possible transformation of a rational application in prototype building design through the reusability and reconfiguration of the components.

The project will be an in-depth study on the mechanisms embedded in traditional Korean joinery system and its parametric changes through the BIM environment. The project ultimately aims to create a digital catalog with combined components of the existing and newly developed components through its parametric modifications. The catalog will be designed through comprised results from various experimentations made on existing joinery conditions. Also, a series of modules using traditional joinery system will be analyzed and studied to forefront the mechanisms of joinery system to propose morphological variations in design work that can easily be fabricated. The D. Arch project will ultimately aid the future interests and contribute to the body of knowledge by exploring the parametric norm and its application in various traditional Korean joinery systems as well as the possible potential in rational application in design process.

Analysis on Korean joinery systems will be produced in written and drawing format, including charts and diagrams. Experimentations will be done in various computer generated models such as 3-D Rhinoceros, Autodesk CAD and Autodesk Revit. To support my ideas, quantitative research on Korean joinery system, fabrication of a traditional building and module system will be collected thoroughly. Base research will be focused on parametric modifications and traditional Korean structure and its joinery system. The base research is the most important part of my D.Arch project, so critical research will be dedicated to traditional Korean joinery system and its assembly units and parametric changes of the components. Finally the iteration of design through the implication of digital catalog will be presented.

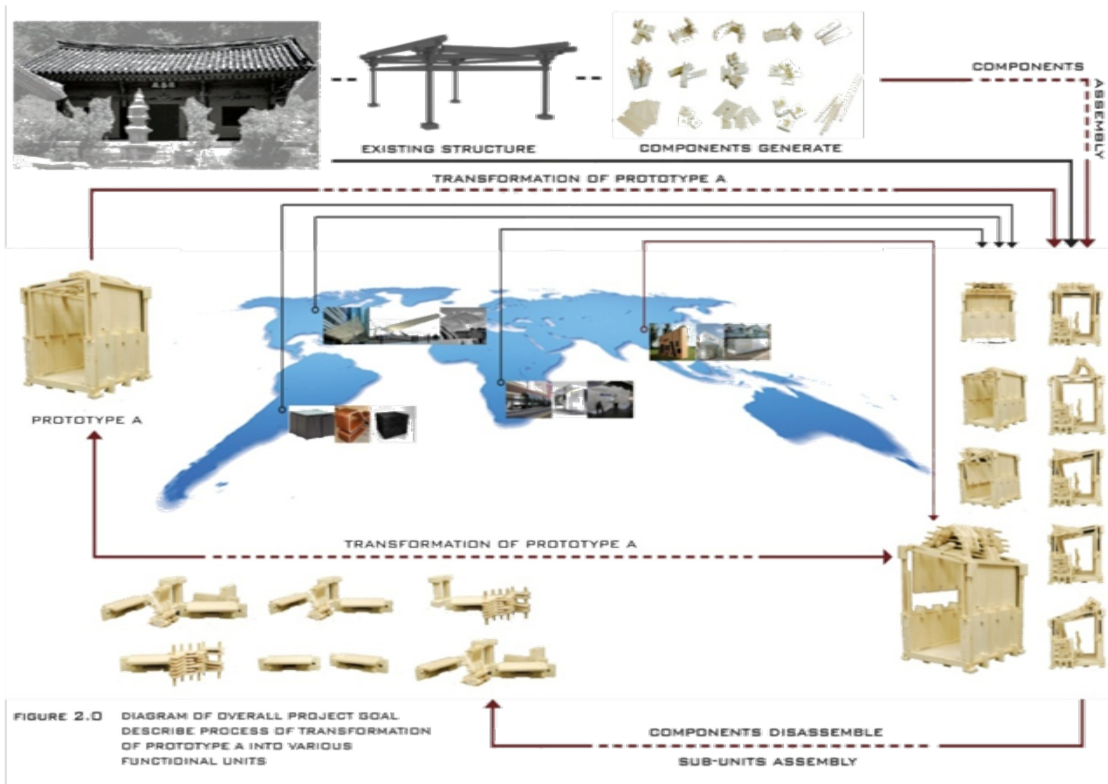

Figure 1. 3 Overall project goal

4. METHODOLOGY

Research

To generate a digital catalog, in-depth research on existing traditional Korean architecture needs thorough analysis. Amongst the type of wooden structures and joinery types, traditional Korean joinery systems were selected as the based system to be studied, because of its wide varieties of joinery types and cases founding in reusing, relocating and reassembling of the components.

Components and categorization

Traditional Korean joineries will be categorized according to their functions in traditional Korean architecture, and its parts are generally categorized into four main groups: floor, column, bracket and roof. Based on the function of joinery, they will be categorized under those four groups.

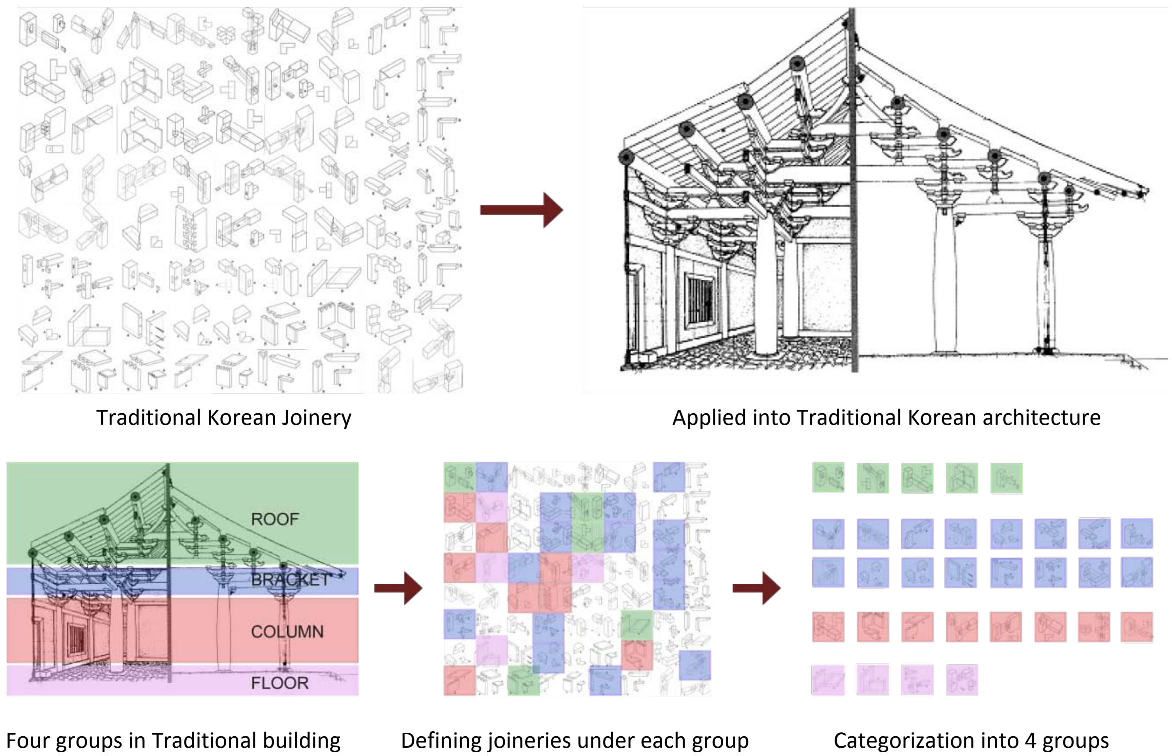

Figure 1. 4 Categorization / grouping of joinery according to its function in traditional Korean building structure

Figure 1.4 shows the application of traditional Korean joinery into a building structure. Joineries were categorized under four groups that are based on the function of joinery and its use in existing building structure. Categorizing the joinery based on function was to adequately relate the component group into building components in the future studies and also to keep the existing function of the joinery. Categorization of joinery resulted in focusing on a specific unit in traditional Korean architecture, which is the bracket system of traditional Korean architecture. Bracket systems were selected in traditional Korean architecture to generate components. As stated earlier, the *bracket system* contains four main groups of traditional Korean building structure: floor, column, brackets and roof. The three main types of bracket systems found in traditional Korean architecture are *Ju-Sim-Po* style*, Ik-Gong* style and *Da-Po* style of bracket system. A case study of an existing building containing the three different type s of bracket system needs to be done to understand their time frame and functional aspects. Each style of bracket system was highly favorable throughout Korean history. Acknowledging the existing joinery and categorizing them into a systematic, rule-based catalog are crucial in the project.

3-D Model and Parametric Application

Once all of the components in the main bracket systems (*Ju-Sim-Po, Ik-Gong* and *Da-Po*) have been discovered and listed as the main components, constructing them into the 3D computerized environment are necessary for their parametric studies. Building the 3-D model was done in the Autodesk Revit environment. Revit Architecture is one of the BIM based digital application tool that is widely in use in modern architecture. Using the Revit Architecture will best utilize the digital catalog and its possible potential for future use. In the Revit Architecture environment, both 2-D and 3-D modeling are possible through the data structure of BIM software. While 2-D drawings are being produced, 3-D modeling is also being constructed at the same time.

The concept of working with components in BIM environment enables the user to construct his or her own individual components as separate entities from the built-in components in Revit. By assigning the parameter, components can have flexibility in its dimensional, geometric and assembly modifications.

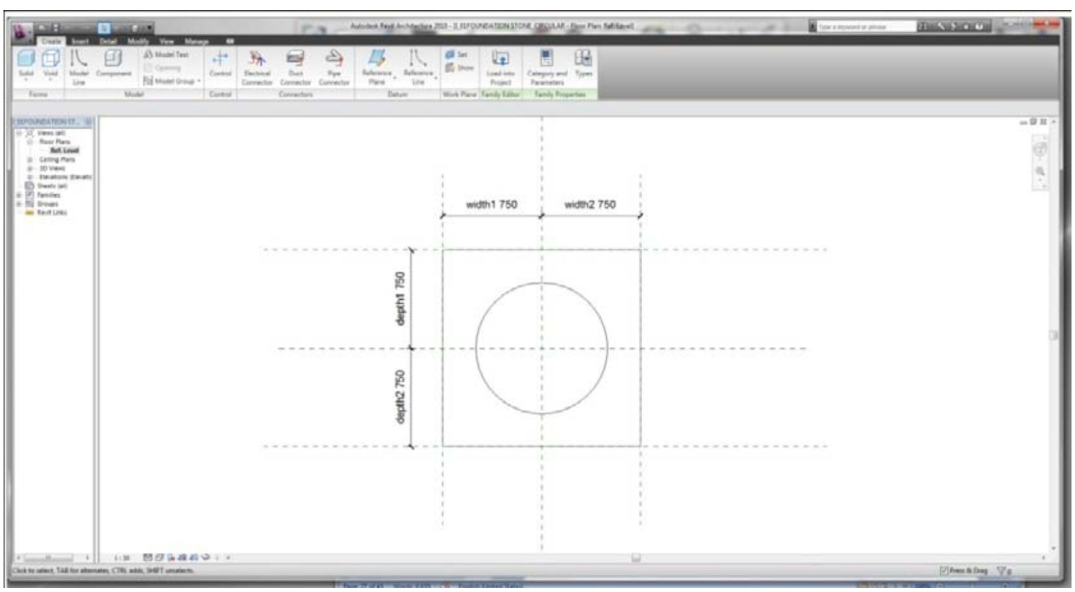

Figure 1. 5 Revit Architecture Interface

5. LITERATURE REVIEW

This section of the chapter explains the various scholarly literature and ideas related to the project topic *computational implementation* and the idea of *assembling & disassembling, reusability in components* and *morphological transformation of a building.*

5.1 Parametric Modifications

With the rapid development of advanced information technology, BIM (Building Information Modeling) applications in the profession of architecture have become very effective in the process of generating and managing building data during its life cycle.[7] Typically the process uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The process produces the BIM as a new method of project delivery from the genetic 2-D CAD drafting to digital based program, which encompasses building geometry, spatial relationship, geographic information, and quantities and properties of building components.[8] An overall data structure of BIM makes the combined analysis of 2-D drafting, documenting specification, constructing, check and 3-D model simulation became possible. BIM-based applications can assign specific information of components and grouped them as a type family in working environment. A library of various family types linked together to simulate changes and modifications was made in each parametric data. Parametric models can provide important geometric flexibility and support an iterative design refinement process. The nature of parametric modeling requires the constraints in its dimension, geometry and assembly. The dimensional constraint, the most basic constraint, required the parameters in its length, width and depth of the components. By assigning the parameter, components can now be flexible in its dimensional modification.

Therefore, the possibilities of parametric design using BIM system for industrialization of traditional Korean joinery system and basic foundation of the data schema and the information flow between parametric and multi-disciplinary tools. Figure 1.6 represents the type of parameters constraints in Revit architecture interface. The three most common types are dimensional constraints, geometric constraints, and assembly constraints. The three constraint

[7] Lee, G., sacks, R., and Eastman, C. M. (2006). *Specifying parametric building object behavior (BOB) for a building information modeling system. Automation in Construction,* 15(6), 758-776.

[8] Holness, Gordon V.R. *Building Information Modeling Gaining Momentum.* ASHRAE Journal. Pg 28-40. June 2008.

groups have various control conditions. The following are the BIM based digital application software:

- Graphisoft ArchiCAD
- Vectorworks ARCHITECT
- Bentley Architecture
- Autodesk Revit Architecture[9]

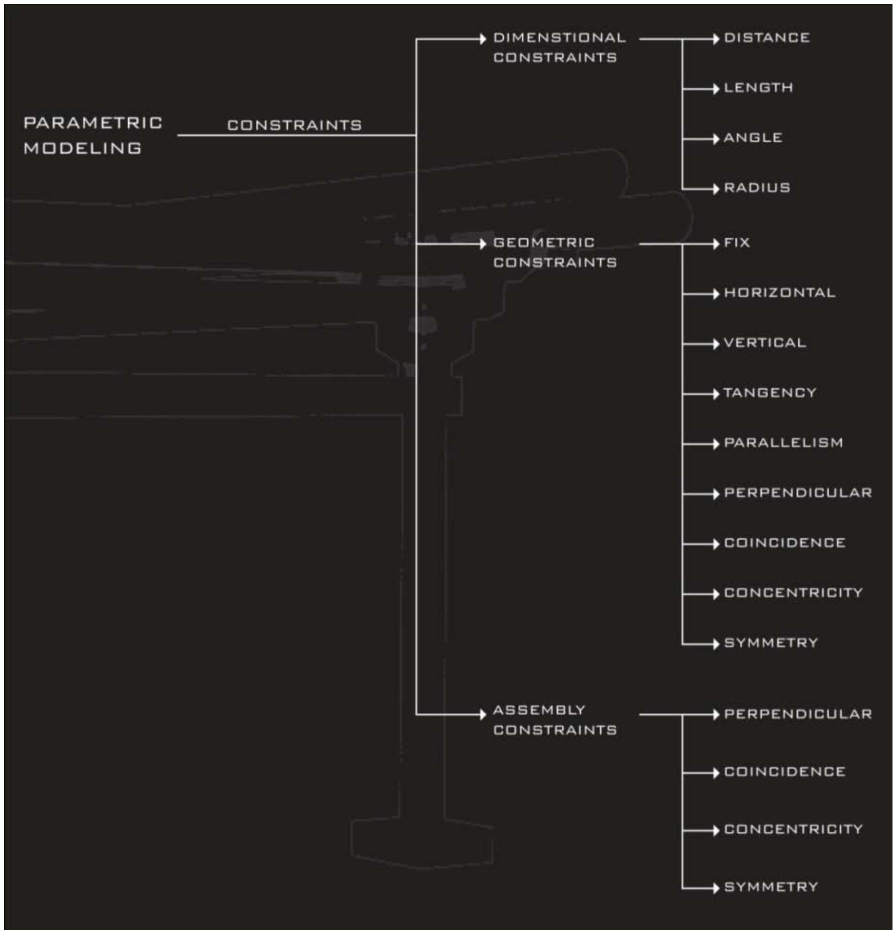

Figure 1. 6 Parametric Modeling: diagram of constraints

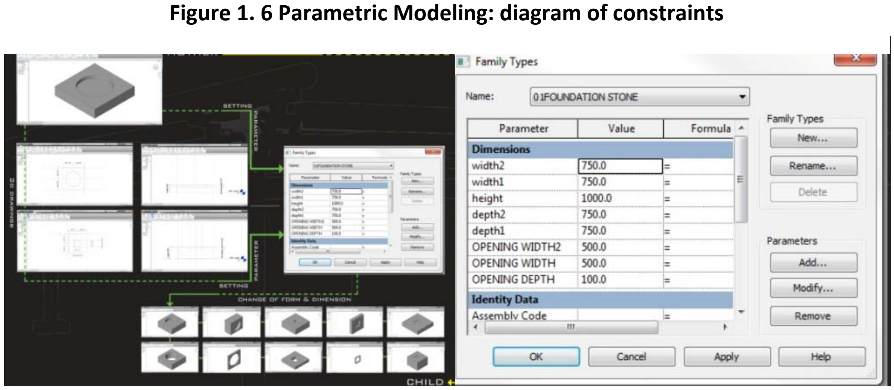

Figure 1. 7 Parametric modifications through dimensional changes

9 Kim, Jae-Yeol., Park, Jung-Dae., Lim, Jin-Kyu., Kim, Dong-Wook. *A Basic Study on the Parametric Data Structure for Modernized Korean Traditional Buildings.* Thesis 2004.

Graphisoft ArchiCAD

Introduced in 1984 and currently in its ninth version, Graphisoft ArchiCAD was the first product among the BIM software solutions to create a visual model. ArchiCAD's bidirectional associative models keep all the data in one PLN file that can hold a 60,000-square-foot building, including all construction documents. ArchiCAD uses the GDL (geometric description language) model creation language, which contains all the information necessary to completely describe building elements as 2-D CAD symbols, 3-D models and text specifications for use in drawings, presentations and quantity calculations.

Vectorworks ARCHITECT

Offered for both Macintosh and Microsoft Windows platforms, Vector works Architect is an excellent BIM program that has been around the longest. Vectorworks probably has the most routines dedicated to architecture and construction. It is very popular and more widely used in Europe than in the United States.

Bentley Architecture

The architectural application within Bentley's multidisciplinary suite of application, Bentley Architecture is an object-oriented product. Like its companions for structural and building system engineering, Bentley Architecture is based on the MicroStation platform. Because MicroStation has the second largest number of installed seats, there is a large pool of operators from which to draw from. Bentley Architecture includes full top-quality rendering and animation from within its user interface and also provides capabilities for modeling, visualization, and reporting, schedules, cost and program analysis.

Revit Architecture

Conceived by programmers who created the 3-D software for the mechanical design industry, Autodesk Revit Architecture applied concepts from the 3-D software to create a solution tailored for architecture and construction. Revit is truly bidirectional in that any change to any object or any document view, including views on sheets ready to plot, is expressed in all documents and views. Many large architectural firms do their pilot projects with Revit Architecture.

5.2 Metabolist Architecture

Started in 1959, the metabolist movement is envisioning a city of the future inhabited by a mass society that is characterized by large scale, flexible and extensible structures that enable an organic growth process.[10] In this case, the traditional laws of form and function were obsolete. The Nakagin Capsule Tower by Kisho Kurokawa in 1972, the first metabolist architecture building, was built with 140 prefabricated module units that can be replaced, added and removed. However, none of the units were neither replaced nor added, due to the building's size limitations and maintenance problems. The fundamental idea of the transformable building design was well captured through applying module units onto the core structure to enable an organic growth of a building (Fig.1.8). Module units were prefabricated concrete cubes with a built-in bed, bathroom unit, television, radio and alarm clock. The capsule interior was pre-assembled in a factory. The idea of the Metabolist movement was very difficult to implement due to the pragmatic issues of structural performances control. Most Metabolist group of people failed to turn the Metabolist architecture's theory into real architecture. Failure of Metabolist architecture was mainly due to the limited technology at the time: assembling and disassembling mass prefabricated units into a permanent structure were very challenging due to structural performances and its materiality. Architects were faced with limitations in size and material options. Fully-furnished prefabricated interior space also limited the spatial configuration of units; the interior space lost its flexibility compared to exterior changes of a building. Although the Metabolist movement generally failed, it initiated the drive of developing buildings with the quality of organic growth in 21st century architecture.

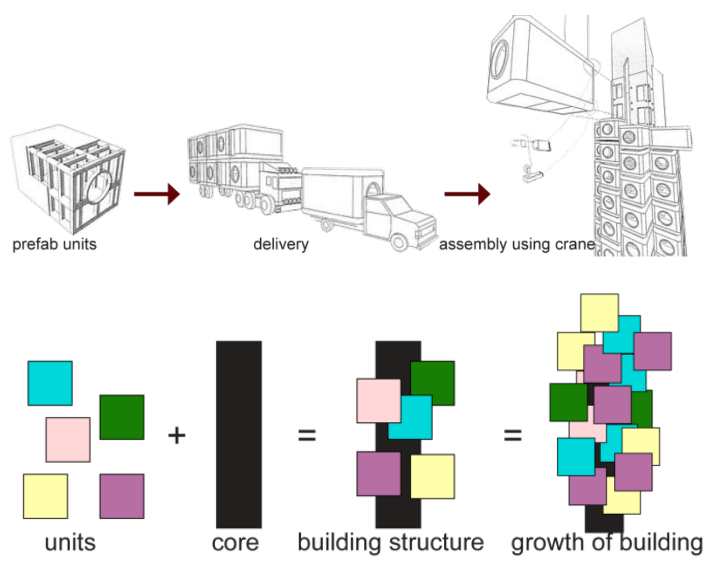

Figure 1. 8 Nakagin Capsule Tower assembly units and diagram

[10] Wikepedia Encyclopedia. *Metabolist Movement*. Wikepedia Encyclopedia. http://en.wikipedia.org/wiki/Metabolist_Movement. (accessed Sept. 9th 2009)

5.3 Dunescape

Dunescape by SHoP Architects is comprised of over 6,000 individual 2X2 cedar strips with a vinyl surface that bends and folds to accommodate various spatial configurations.[11] Through applying the multiples of identical material and its joining/connection method, SHoP Architects created an architecture that can now change its form, function and program. The structure's form can change to accommodate various programs and functions for its users. Flexibility in form not only made varieties of programs available but also maximizes the spatial experience for its users. Unlike the Nakagin Capsule Tower, Dunescape focused on a composition of small components.

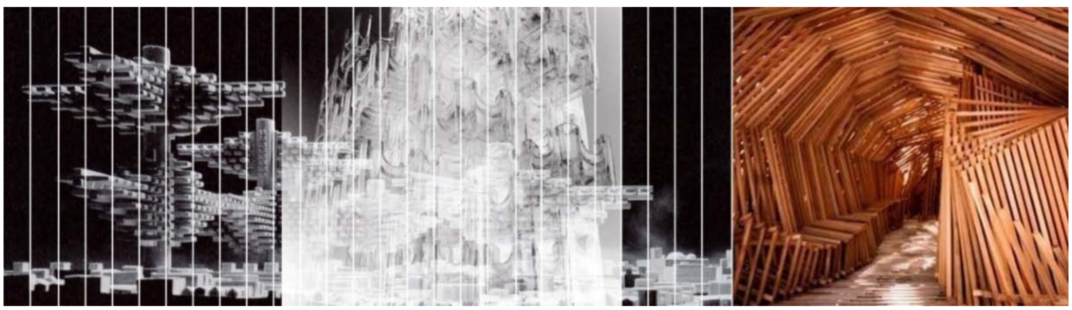

Figure 1. 9 Metabolist Architecture (left) and Dunescape (right)

To state which structure best displayed its transformation process compared to other structures is rather difficult, because their concepts are rather similar to one another. However, the Nakagin Capsule Tower differs from Dunescape by being relatively large in size and scale compared to Dunescape; hence the quality of flexibility varies between the two structures. This discussion introduces a couple of questions. Does the **size of a building restrict the building's flexibility in changing the building's form? Can the building obtain such flexibility without any restrictions in its size and scale?**

The Dynamic Tower design proves that even high-rise structures can obtain such flexibility in form and motion and that even a large and mega building can be flexible to a certain degree in changing its form. However, with the available technology and materials, the size of a building does matter in terms of how much flexibility the building can attain. The Nakagin Capsule Tower and the Dynamic Tower successfully obtained their flexibility in their exterior façades. However, these two towers were focused in relatively large units as compared to Dunescape.

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11 Shop Architects. *Dunescape at P.S.1 MoMA*. Shop Architects. http://www.shoparc.com/#/projects/type. (accessed Sep. 12, 2009)

Therefore, the pre-fabricated interior spaces could not be personalized, and exterior changes were also limited, so the actual spatial experience does not have any flexibility at all. While the building's overall size does not matter, the size of pre-assembled components and the number of the components in a structure do affect the quality of flexibility. Depending on which parts, units, and components and their size, the building can become flexible not only through its form but also through its spatial experience. My project is very similar to Metabolist architecture and Dunescape, yet it focuses specifically on the modules of independent small components. If the Nakagin Capsule Tower is considered as practicing organic growth of macro components in a building (the units which to added or subtracted from the core is relatively large compared to Dunescape) and Dunescape is considered as the middle ground due to the size of its structure, then my project's focus can be viewed as studies of micro components in a building structure (either equal or even smaller components than those used in Dunescape). The project focuses on studying microscopic building components to have flexibility over form, function and program change to attain overall changes. **The goal is to achieve the quality of spatial, functional and programming changes through assembly and disassembly, adding and subtracting of individual building components.** Why micro? Micro elements have much more potential in developing total reusable components. Large units shown in the Nakagin Capsule Tower and Dynamic Tower have the restrictions in structural performances, form generation and assembly and disassembly. Micro components not only display their exterior changes but also varying spatial experience and dismantling of the structure. By studying the detailed elements of the components in a building and how individuals influence the overall assembly of the building, total reusable building components can ultimately change a building. Although many of the structural components and individual elements in modern architecture became more efficient and specialized to attain module units, these aspects are purely objective. These components and individual elements still need to be pre-fabricated according to the designer's requirements. Therefore, module units being produced in the field of architecture are *one of a kind*. Specific prefabricated components are designated to assemble into *only one* specific building for *one* specific purpose at *one* specific location. They cannot be applied nor reapplied into other buildings or even different locations in the same building structure. This current situation introduces the question of how to make these components become standardized and maximize their application for multiple building designs. Other questions to consider are what need to be done to create micro-components and based on what and where does experimentation start from?

To find possible micro-components, I have listed down the crucial characteristics of the individual members: they **need to be easy to fabricate, be able to assemble and disassemble in relatively short amount of time, work in a module to be flexible in size and form and ultimately be able to perform a growth state of a building.** To have such characteristics, system requires the following:

- **Multiples of individuals** put together instead of one large mass (focus on the small multiples rather than one big component to obtain flexibility)
- Multiples of individuals abide by a **set of rules, guides and systems**
- Individuals must have a flexibility in **assembly and disassembly** (advanced connect/joint methodology)

Based on the list above, I have concluded that creating total reusable architectural components can be achieved through collaboration work of two fields: **Modular configuration and Joinery system**.

5.4 Modular Configuration

The word module originated from the Latin word modulus (mode + ule). Module is a separable component, frequently an interchangeable component with others for assembling into units of different size, complexity, or function.[12] The modular system is a set of rules and dimensions that abide by its own theory. For example, Le Module is based on human dimension – a set of coordinated dimensions with which to design the architecture based on the body dimensions of a six-foot man. Through this system, Le Corbusier sought to reconcile the physical needs of the human body through the use of two sets of dimensions, which are based on a Golden Section of the height of a man and that of his navel. From this, he produced a number sequence from 27cm to 226cm in increments of 27cm and 16cm.[13] The beauty of the modular system in architecture is that you can replace or add any one component without affecting the rest of the system. Modular systems can reduce the construction time and cost through incorporating off-the-shelf components and the selection of standard prefabricated parts. Le Corbusier's Le Modular is the measurement system that Corbusier proposed as the basis for determining architectural characteristics based on the proportions of the human body

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[12] Dictionary.com. *Module.* http://dictionary.reference.com/browse/module (accessed Sept. 12, 2009)

[13] Ambrose, Harris & Stone. *The Visual Dictionary of Architecture.* AVA Publishing SA 2008. Pg.174

dimensions. The modular system is now becoming a famous design tool due to its achievement in augmentation and exclusion. From architecture to furniture design, numerous numbers of modular assemblies are being created. Each and every modular unit is designed to carry out the idea of distinctive, unique, adaptable and variable solutions.

Born in 1928, American artist Sol Lewitt is linked to various movements such as Conceptual art and Minimalism.[14] For the five modular structures (Fig.1.10) by Sol Lewitt, each of them occupies the same ground plan. They rise in single steps to a height of five units; the fifth structure is uniformly 5 units tall. The sculpture became a modular structure, a constructions that repeat and bring into order a single unit following the principle of geometrical progression. Sol Lewitt's modular structure based on the rectangular structures in 1960s created varieties of extra movements in modular configurations using open and close rectangles.

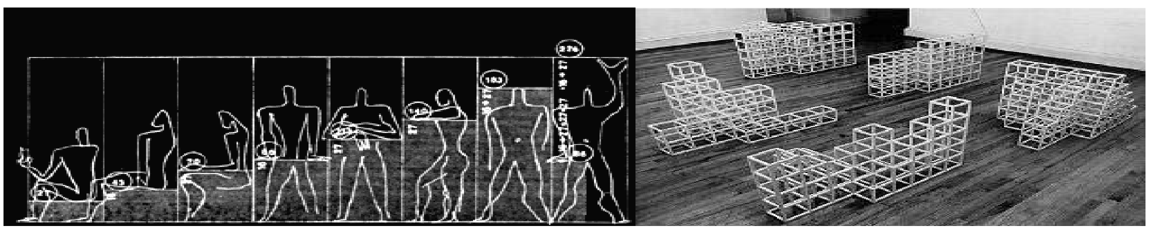

Figure 1. 10 Le Modulor (left) and Sol Lewitt modular structure (right)

Figure 1. 11 Variations of incomplete open cubes

Based on the idea of Cubical Modular structure, figure 1.11 shows the variations in open cubes and its possible configuration methods. The idea of creating a modular structure through a simple geometry by Sol Lewitt well defined the conceptual movement of minimalism and its modular structures.

14 McNay, Michale. "Sol Lewitt Obituary," The Guardian, April 11, 2007.

5.5 Joinery and Connections

Joinery and connections are involved when two or more objects are put together. In a building construction where thousands of different parts are assembled together, joinery and connection of individuals become some of the critical conditions, as structural failures occur due to wrong joineries and connections between two structural members. However, depending on the types and conditions of joinery and connections in a building components (such as connections of walls, floors, structural members and building envelop), the building can achieve such state of flexibility. Depending on how rigid or flexible each connection may be, building parts can move either freely or rest at a permanent condition. **The most critical study in this project is to create a system that can be easily fabricated and flexible in terms of assembly and disassembly of parts in a building envelop**. Therefore, researching the useful joinery and connection method is one of the vital research goals in this project. From the common types of construction and its materials (concrete, steel and wood), the wooden timber structure has the most flexibility in terms of assembly and disassembly. It also has a relatively easy fabrication method compared to concrete and steel structures, due to the construction method using various joinery system and the natural characteristics of its material: lightness, flexibility and resistance to tensile stress.[15] Concrete is very strong in compression and weak in tension support, due to its rigid characteristics; concrete often cracks in tension support. Steel is strong in tension but weak in compression. The connections used in both concrete and steel components required either a bolted or welded-down connection that restricts its flexibility in terms of disassembly. Reinforced concrete is very efficient in both compression and tension force; however, joinery and connection become heavy and require permanent connection as in concrete and steel framing structure. Also the permanent casting of the steel member inside the concrete minimizes the reusability of the material after its use. Wooden materials are relatively strong in both compression and tension support. Also, traditional timber structures are often connected through various joinery systems that do not require a permanent connection between members hence acquiring the quality of assembly and disassembly of the structure.

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15 Kiyosi, Seike. "*The Art of Japanese Joinery*." New York: Weatherhill Tankosha Press, 1977.

CHAPTER 2

RESEARCH DOCUMENTATION

The following chapter explains the overall research on traditional Korean architecture, mainly focusing on the traditional joinery systems and their bracket structures. The purpose of the research on the brief history of traditional Korean architecture was to give basic knowledge on traditional Korean architecture and its history. The chapter investigates the three types of bracket systems and categorizes joinery.

6. TRADITIONAL KOREAN ARCHITECTURE

Chinese architecture influenced traditional Korean architecture throughout different periods of its history. Although the two styles looked almost identical, traditional Korean architecture had been modified and developed to best fit into the context of Korea, hence, created its own unique styles and identity as Korean architecture. The exact date of the first appearance of Chinese architecture in the Korean peninsula is still uncertain. However, the date has been estimated to be as early as 100 C.E. through examining various records in historic documents and monumental footprints.[16] Among the three kingdoms during the Three-Kingdom-Period (Go-Gu-Ryo, Silla and Baek-Jae) in Korea from 57 B.C.E. to 668 B.C.E., Go-Gu-Ryo was the first adopter of Chinese Architecture, due to its close geographic proximity to mainland China. The geographic area of Go-Gu-Ryo is located in today's location of most parts of North Korea and some parts of Mongolia. Go-Gu-Ryo accepted the influences of Chinese culture and styles of architecture far before the other two kingdoms. Historic periods that significantly influenced traditional Korean architecture were the Silla Dynasty, Go-Ryo Dynasty and Jo-Seon Dynasty.[17] Buddhism and Confucianism influenced the three dynasties and their styles of architecture.

The three main types of traditional Korean wooden structures are *Ju-Sim-Po* style, *Ik-Gong* style and *Da-Po* style. In the *Ju-Sim-Po* style of bracket system, groups of members or brackets are situated only on top of columns. The *Ju-Sim-Po* style is the earliest type of bracket structures used in Korean wooden structures. *Ik-Gong* style of bracket system is very similar to

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16 Kim, Dong-Hyun. *Korean Wooden-Architecture Methodology*. Seoul, Korea: Bal-Un Press, 1993. Pg. 35

17 Kim, Ji-Min. *Confucius Architecture in Korea*. Seoul, Korea: Bal-Un Press, 1993. Pg.23

Ju-Sim-Po, yet it is much simplified version. By using the members call *Ik-Gong*, numbers of beams are reduced to two instead of the three to four members shown in *Ju-Sim-Po* style. In the *Da-Po* style of bracket system, the brackets are situated not only on top of columns but in between spaces of columns as well.

Figure 2. 1 Historic timeline and influence of Korean Architecture

Especially in the case of traditional wooden structures of Korean architecture, having flexible joinery and connections in building components makes effectively relocating the building to another site much easier by allowing the components to be dismantled Traditional Korean architecture does not involve any steel connectors, rather it involves purely joined components through various types of wooden joinery system. Traditional Korean architecture has always been the linkage between Chinese and Japanese architecture but is much unknown in the Western architecture. The purposes of referencing the traditional Korean joinery system as the main source of the project and computerization with parametric environment are in the following:

- I am very interested in the wide varieties of joinery types found in traditional Korean wood craftsmanship. The numerous joineries are well categorized into three main types of joinery: *Mat-Cheom (interlocking), Ee-Eum (over-lapping) and Jang-Bu (piercing)*. Categorized by joinery types, the grouping of each component was very effective.
- Original documentations show many cases of the exact components being reused during the repairing and relocating processes of the historic buildings in Korea. These cases prove the high level of reusability of the materials and components in the traditional Korean joinery systems.

Many studies relating to the traditional Korean joinery system had been done, but most of them focus on the topics of renovation and reconstruction, and they focus on regulations, guides and rules on how to fix existing condition of joineries.[18] Although few research organizations such as Interlocking (Zza-Mat-Chum) and the City of Jeon-Ju in South Korea started to apply the traditional Korean joinery system into a furniture design process, applying the system to modern building components is yet to happen. As a Korean-American, I want to contribute to the field of Korean architecture by exploring and researching the traditional Korean joinery system to further develop the mechanisms of joinery and connection method to create a digital catalog. By obtaining and researching the original text written in Korean, I want to contribute to Western architecture by making the traditional method of construction and detail joinery system of Korean architecture available to English speakers. Also, the study on how architects can use the traditional Korean joinery system for designing future buildings is very original in a sense that the research is moving towards the innovative concept of evolving architecture rather than focusing on repairing what already exists. The study not only has potential application in future design but also compliments the traditional and cultural aspects of traditional Korean architecture. The project will contribute to both Korean and Western architecture. **However, please note that the intent of my study lies in the mechanisms of traditional Korean joinery system and not those of aesthetics, cultural aspects and metaphoric meanings of traditional Korean architecture.**

Traditional Korean joineries can be divided into two common categories: overlapping (Ee-Eum) and interlocking (Mat-Cheom). The Ee-Eum type of joinery overlays on top of each member in same direction, and lap joints are examples of Ee-Eum joints. The Mat-Choom type of joinery interlocks various members, and examples of Mat-Cheom joints are Mortise and Tenon joint, Dado joints, and Rabbet joints.[19] From foundation to building completion, traditional Korean wooden structures use tens of Ee-Eum and Mat-Cheom joineries. Some act as a load barrier, distributor, or both; and some are used for aesthetics. Multiples of simple joineries are put together to create a strong structural member in traditional Korean buildings. Also, due to the simple connection methods of the individual components, traditional Korean buildings can be constructed quickly with easy assembly and disassembly.

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18 Jung, Yun-Sang. 2006. A study of *Joineries in Wooden Structure and its analysis* in Seoul, Korea. Research Documentation, traditional Korean architecture study group.

19 Yoon, Won-Tae. *Traditional Earth House Structure and its practice.* Kyung-Gi, Korea: Cultureline Press, 2004. Pg 118 & 121

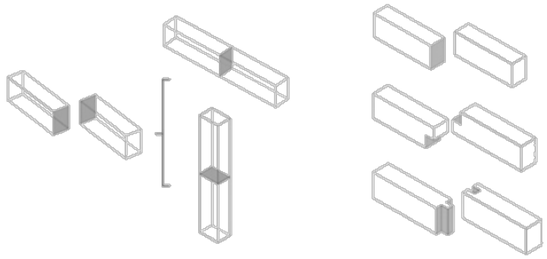


Figure 2. 2 Example of overlapping (*Ee-Eum)* joinery

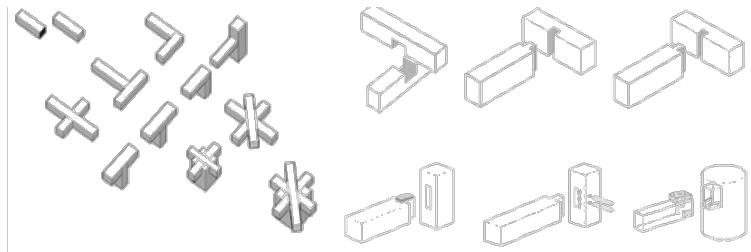
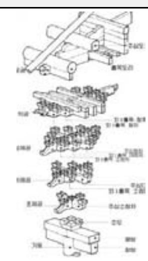
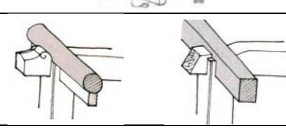
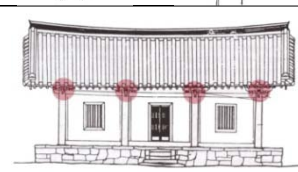
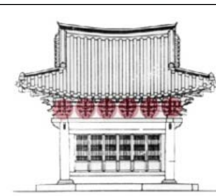
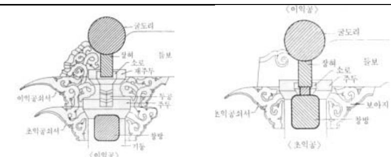
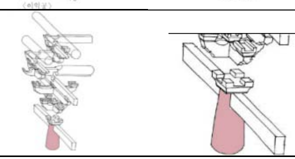
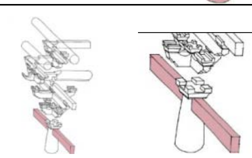
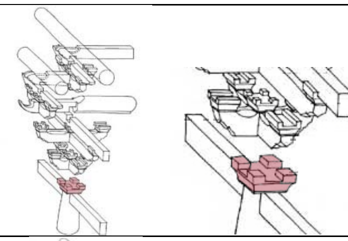
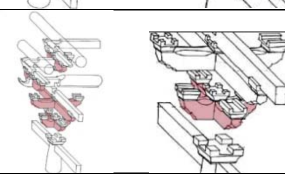
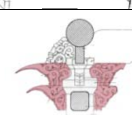
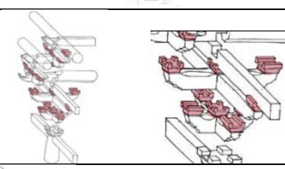
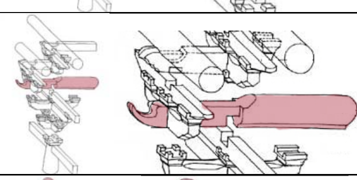
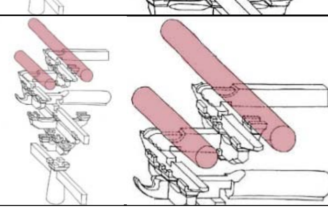
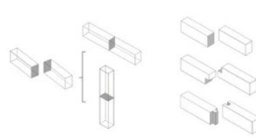


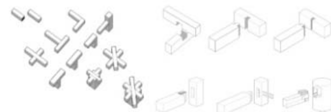
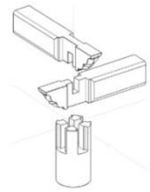
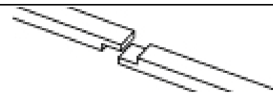
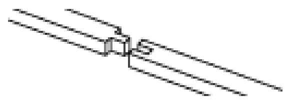
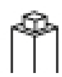
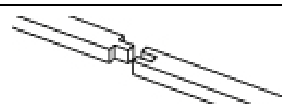
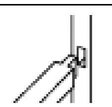
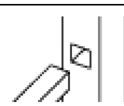
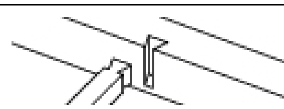
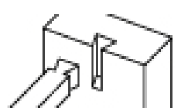
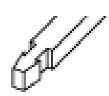
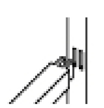
Figure 2. 3 Example of interlocking (*Mat-Cheom)* joinery

7. NOMENCLATURE

This section of the chapter will introduce the different terminologies used in traditional Korean architecture and its joinery system. The nomenclature will define traditional Korean architectural terms in English.

Korean text	Image	English
포집/Po-Jip		Wooden structure with bracket system
민도리집/Min-Do-Ri-Jip		Wooden structure without bracket system
주심포계/Ju-Sim-Po type		Bracket systems over columns
다포계/Da-Po Type		Bracket systems over columns and between columns

익공계/Ik-Gong Type		Simplified version of Ju-Sim-Po
기둥/Gi-doong		Column
창방/Chang-bang 평방/Pyung-bang		Crossbeam
주두/Ju-doo		Main bracket
첨차/Cheom-cha		Cantilever arm
익공/Ik-gong		Cantilever arm
소로/So-ro		Sub-bracket
보/Bo		Girder
도리/Do-Ri		Purlin
이음/Ee-Eum		Overlapping joineries

맞춤/Mat-Cheom		Interlocking joineries
사괘맞춤/Sagwae-matcheom		Top plate joint (crosscut)
반턱이음/Ban-tuk-Eeum		Lap joint
빗 이음/ Bit-Eeum		Simple Scarf joint
장부 이음/ Jang-Bu-Eeum		Stud-Tenon joint
상투 촉 이음/Sang-Tu-Chok-Eeum		Blind-Square-Stud joint
장부 맞춤/Jang-Bu-Matcheom		Stud-Tenon joint
장부 맞춤 2/Jang-Bu-Matcheom 2		True-Mortise & Tenon joint
통장부 맞춤/Tong-Jang-Bu-Matcheom		Boxed Mortise & Tenon joint
주먹장 맞춤/Ju-Muk-Jang-Matcheom		Dovetail joint
주먹장 맞춤 2/Ju-Muk-Jang-Macheom 2		Housed Dovetail joint
메뚜기 장 맞춤/Mae-Ttu-Ii-Jang-Matcheom		Gooseneck Mortise & Tenon joint
쌍 장부 맞춤/Ssang-Jang-Bu-Macheom		Double-Tenon joint

8. REVIEW ON THE SELECTED TRADITIONAL KOREAN BUILDINGS

This section will explain the various time periods in traditional Korean wooden structures and their construction types. The three main types of bracket systems, the *Ju-Sim-Po, Ik-Gong, and Da-Po* structures; will be the primary research topic to further analyze the detail joineries of each type.

8.1 Buddhist Architecture

Chinese architecture influenced Korean Buddhist architecture after the arrival of Buddhism in Korea around 372 C.E. Although early Korean Buddhist architecture was similar to Chinese Buddhist temples in many ways, Korea developed its own Buddhist architectural styles to adapt to local conditions. Traditional Korean Buddhist temples followed a simple design that featured a square inner area, the sacrificial arena, which is often surrounded by an ambulatory route that is separated by lines of columns, with a conical or rectangular sloping roof, behind a porch or entrance area, generally framed by freestanding columns or a colonnade. Complexity of bracket system differs by each time periods and will be covered in a later chapter.

8.2 Buildings of the Go-Ryo Dynasty (918~1392)

Buddhist buildings and their structures during the Go-Ryo Dynasty used complex bracket systems over only column structures (Ju-Sim-Po Style). Although many various types of bracket systems were developed in traditional Buddhist architecture buildings, the most commonly used system was the Ju-Sim-Po system during the Go-Ryo Dynasty (when Buddhism spread throughout the Korea as a strong religious practice). The most well-known structures of the time are as follows: Guk-Rak-Jeon, Hall of Bong-Jeong-Sa temple, Moo-Ryang-Su-Jeon, Hall of Boo-Suk-Sa Temple, Dae-Woong-Jeon, and Hall of Soo-Duk-Sa Temple. Later chapters will provide more details on bracket systems.

8.3 Teachings of Confucius

The Confucian style of architecture is based on the principal teachings of Chinese philosopher Confucius (551-479 B.C.). Confucian Architecture emphasized the concept of order as a basis concept more than any other styles of Korean architecture.[20] Following this concept of order, Confucian Architecture is set up in a very strict, systematic order: most layouts of Confucian architecture buildings were planned in a very orderly manner. Confucianism greatly influenced a traditional Korean house's design, especially "han-ok", during the Jo-Seon Dynasty. Neo-Confucianism, with its emphasis on moral duties, became the dominant philosophy, in which the reverence of ancestors became the core practice of people's spiritual life. Under Confucian principles, social hierarchy was maintained within the extended family, as within the broader community. Several generations of an extended family lived together under the charge of the family patriarch. The separation of men from women and superior from inferior and the need for an ancestral shrine became fundamental elements in creating the traditional Korean residence.[21] The government guided the construction of houses. Confucian Architecture is divided into separate types based on its occupancy groups such as Hyang-Gyo Architecture (temple), Seo-Won Architecture (school), Jae-Sil Architecture (house) and Chong-Ryo Architecture (ancestral shrine).[22] Confucian Architecture greatly influenced Korean Architecture during the Jo-Seon Dynasty, when the emperor and royal families accepted the teachings of Confucius as a national belief over Buddhism. Whenever a new kingdom or dynasty was formed, its new belief or religion replaced the previous one, affecting the styles of living as well as Korean architecture (such as form, function and philosophy).

8.4 Buildings of the Jo-Seon Dynasty (1392~1910)

Although Korean architecture during the beginning of the Jo-Seon Dynasty followed architectural styles of Go-Ryo, the acceptance of Confucianism as the national belief eventually led to the change in styles of living and development of a new style of architecture. The style of architecture changed from the Bracket systems over columns structures (Ju-Sim-Po) to Bracket systems over columns and between column structures (Da-Po-Gae style). Influenced by the Confucian philosophy conveying strong orders of nature, buildings of the Jo-Seon Dynasty chose to have a set of ordering even in building forms and decorations within the bracket structures. The bracket structures acted as not only structural members but also as an aesthetical feature. A few of the buildings built during Jo-Seon Dynasty are as follow: Woon-Jin-Jeon, Hall of Suk-

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[20] Joo, Nam-Chul. *Traditional Korean Min-Ga.* Seoul, Korea: Daewoo Press, 1999. Pg.48

[21] Choi, Jaesoon. *Han-oak: Traditional Korean homes.* Elizabeth, NJ: Hollym 1999. Pg. 49

[22] Kim, Ji-Min. *Confucius Architecture in Korea*. Seoul, Korea: Bal-Un Press, 1993.

Wang Temple, Nam-Dae-Moon, West Gate, Myung-Jeong-Jeon, a residence in Chang-Kyung Palace and Dae-Woong-Jeon, and Hall of Gae-Sim temple. Most Jo-Seon Dynasty buildings are constructed under the Da-Po system with influences from Confucianism.

9. INVESTIGATION ON TRADITIONAL KOREAN JOINERY SYSTEM

The traditional Korean wooden structure was made through interlocking and overlapping members. The typical types of traditional wooden structures that are based on different bracket systems can be divided into two large categories: Min-Do-Ri (no bracket systems) and Po-Jip (with bracket systems) type. The Min-Do-Ri types are where the vertical load from roof structure transferred directly from purlin to beam to column in a building. These types were used for relatively small buildings such as a single residence. Po-Jip is a type of structure that uses bracket systems as means of main structural system in a building. The Po-Jip types can be subcategorized into three different styles based on their bracket systems: Ju-Sim-Po (bracket systems over columns), Da-Po (bracket systems over and between columns) and Ik-Gong (a simplified version of Ju-Sim-Po, in which the simple supporting member Ik-Gong is under the purlin and roof instead of the bracket system).

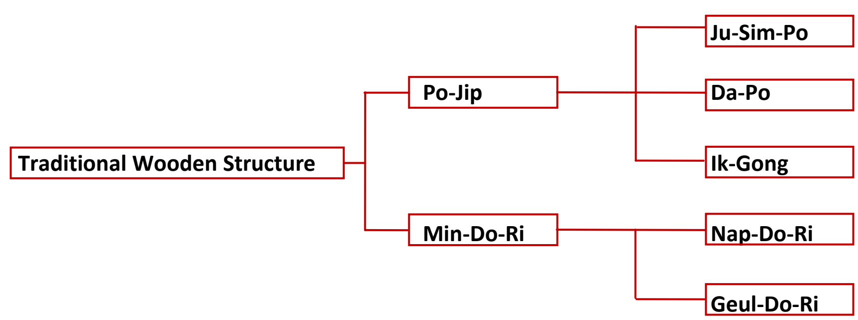

Figure 2. 4 Tree diagram of traditional Korean bracket system

Columns, beams and brackets are put together through a complex joinery method, known as the **bracket system** in western terminology. The bracket system is a unique method of supporting a structural vertical load that can be found only in traditional East-Asian architecture (especially those of Chinese, Japanese and Korean architecture). In the Po-Jip structures, the bracket system can be found between columns and under the roof structure, distributing and transferring the pressure of the roof's weight down to the foundation. Composing of individual structural members, the bracket system is carefully assembled together through various joinery methods. Individual joineries were measured and carefully calculated to prevent any failures that may occur in the connection between members, which can lead to a structural failure of entire building The building depends on not only overall structural ability of a bracket system but also an individual joinery connection of each member. Although bracket systems were designed for structural purposes, they became used more for aesthetic and ornamental purposes throughout different dynasties. The type of bracket system in a building is an important evidence of the history of the traditional wooden structure.[23]

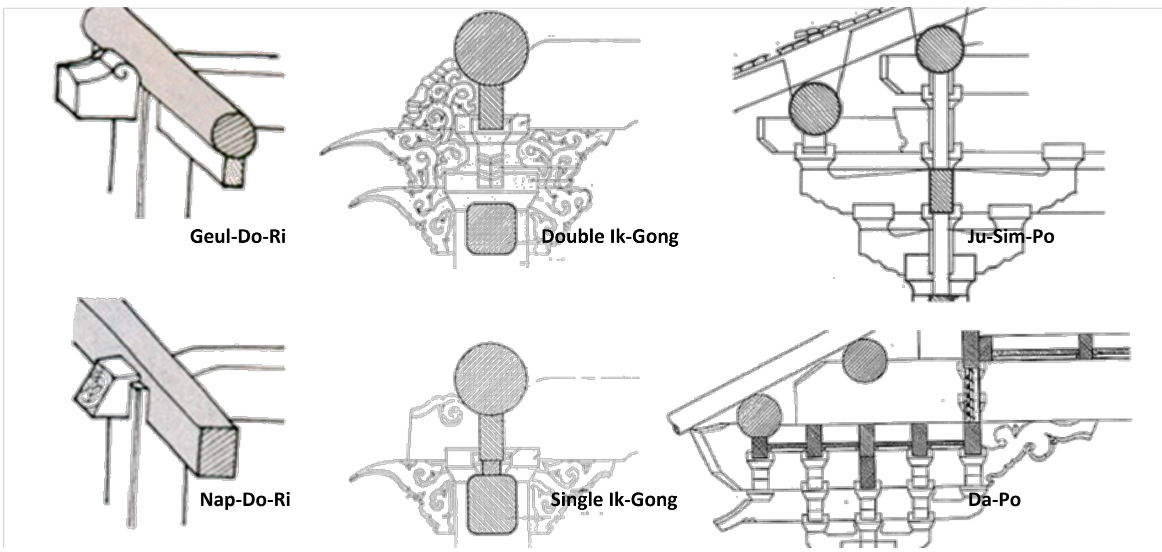

Figure 2. 5 Various types of bracket system

9.1 Bracket System of Korean Architecture

The bracket system is a structural system composite of column, main bracket, various beams (crossbeams and girders), sub-brackets, cantilever arms and purlin. The composition of different members can create a greater depth in roof structure or ceiling height, which indicates the societal status or power of an individual. The composite order of each member is listed in the following:

- Foundation stone
- Column
- Crossbeam
- Main bracket

[23] Kim, Dong-Hyun. *Korean Wooden-Architecture Methodology.* Seoul, Korea: Bal-Un Press, 1993. Pg. 3

- Cantilever arm
- Sub-bracket
- Crossbeam/cantilever arm
- Sub-bracket
- Cantilever arm
- Girder
- Sub-bracket
- Purlin

The order shown above may vary, depending on the different styles of the bracket system, but they generally remained similar to one another. The bracket systems had developed due to not only its natural use of material and structural ability but also the promotion of the natural flow of heat, wind, sunlight and protection from rain.[24] Due to the natural disadvantage of wooden material under moisture, the traditional Korean wooden structure needed long eaves to protect its walls and rest of the structures from the rain (especially with annual rainfall of 600 – 1,500 mm, Korea has a relatively higher density of moisture compared to China and Japan[25]). However, such long cantilever eaves were limited in distance and structural ability; therefore, purlin was placed further out pass the column to provide essential support for the heavy eaves. By bringing the purlin further out to pass the exterior walls and columns, the building structure is connected through brackets pinning the roof structure and columns together. The bracket systems not only increased the distance of cantilever eaves but also decreased the bending moment of a beam through connecting the columns together.

Among the many types of traditional bracket system, I will focus on the Ju-Sim-Po and Da-Po styles. It is because two styles are most known as Korean-influenced rather than Chinese influenced due to the modifications made during Go-Ryo and Jo-Seon Dynasty. Hence, the Ju-Sim-Po and Da-Po styles of bracket system have a unique composition of members compared to those of Chinese and early Korean (such as Three-Kingdom-Period and Silla Dynasty). **However, I do not intend to disregard the earlier stages of development of bracket system in Korea.**

MEMBERS OF WOODEN STRUCTURE AND JOINERY METHODS

Traditional Korean wooden structures used the bracket system as the main structural element in a building. The bracket system in which different members are assembled through various joineries needs the support of not only each member but also those of joining connections.

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[24] Joo, Nam-Chul. *Traditional Korean Wooden Structure.* Seoul, Korea: Seoul University Press, 1999. Pg.25

[25] Joo, Nam-Chul. *Traditional Korean Wooden Structure.* Seoul, Korea: Seoul University Press, 1999. Pg.3

Traditional Korean joineries can be divided into two large categories: overlapping (Ee-Eum) and interlocking (Mat-Cheom). Ee-Eum overlays on top of each other in same direction and Mat-Cheom interlock various elements.[26] Examples of Ee-Eum joints are lap joints, and examples of Mat-Cheom joints are Mortise and Tenon joint, Dado joints and Rabbet joints. From creating the building's foundation to finishing the building, tens of Ee-Eum and Mat-Cheom joineries are used in a traditional Korean structure. Multiples of simple joineries put together create a strong structural member in traditional Korean building. The next section will explain the two important structural elements, the column and brackets, and their respective joineries.

COLUMN (Gi-Doong)

The column is one of the most important members in a wooden structure, especially in a traditional Korean wooden structure. Its structural system used the Post and Beam structure, in which the columns behave as main supporting member when transferring vertical loads. Columns used in traditional Korean wooden structures are round or rectangular. Round columns are used in important buildings as well as governmental buildings, temples, palace, gates and residences of high officials. Rectangular columns are used mostly in residential buildings. Entasis was usually included in the design for the appearance.
There are no special connection methods between columns and foundation stones.

The most common method used for a traditional Korean structure was the simple free standing column on top of a foundation stone. By using simple frictional force, a column stands on top of a foundation stone relatively strong in compression force. Gu-Rang-Ii-Jil is often used to create a greater frictional force between the column and foundation stone. Gu-Rang-Ii-Jil is carving parts of top of a foundation stone in a form of column to create more friction between the two members. Although the joints may be weak in horizontal force, the strong and heavy roof structures protect the seismic movements of a building. Also due to the typical rectangular plan, most structural members are distributing equal amount of vertical load down to the ground, hence preventing rocking and movement of the building. Through compression, the connection between columns and foundation stones became relatively strong and firm with using only the concept of frictional force.

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[26] Yoon,Won-Tae. *Traditional Earth House Structure and its practice.* Kyung-Gi, Korea: Cultureline Press, 2004. Pg.119

The column head is carved to create the joinery between the column and crossbeams. The crossbeams are jointed in perpendicular direction to each other; hence the column head will have a cross cut slots for crossbeams. This connection is called top-plate joinery, or Sa-Gwae-Mat-Cheom.

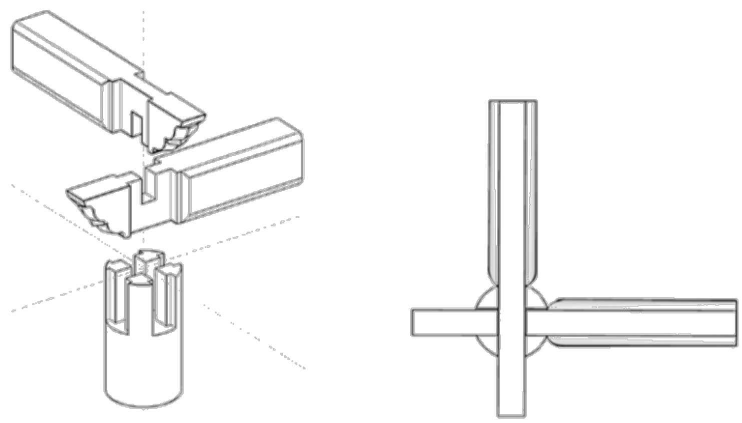


Figure 2. 6 Column head condition and joining method (*Sa-Gwae-Mat-Cheom*)

THE BRACKET SYSTEM (Gong-Po system)

The bracket system is a very unique method of supporting a structural vertical load, which can be found only in traditional East-Asian architecture. Bracket systems can be categorized in three different types: Ju-Sim-Po, Da-Po and Ik-Gong. Typical members of the bracket systems are the main bracket, cantilever arms, sub-brackets, secondary cantilever arms, sub-brackets, girder and purlin.

MAIN BRACKET (Ju-du)

The main bracket is typically a rectangular form where the cross nudges creates the joinery for the cantilever arms. Although few variations in form of the main bracket developed in various buildings, they will not be explained in this paper. The main bracket is usually placed on top of the column or crossbeam called Pyung-Bang and connected through blind-square-stud-joint to column. Based on the different types of bracket systems, the main bracket may be referred to in multiple terms such as **Ju-Du, Jae-Ju-Du** and **Dae-Jup-Bat-Chim**. To prevent the sliding of a cantilever arms and crossbeams, typical brackets have a cross-shaped cut-out.

SUB-BRACKET (So-Ro)

The sub-bracket is often considered a miniature version of a main bracket. Depending on the necessary assembly and its location, the sub-bracket can be made into different shapes. The sub-bracket in which the cantilever arms and crossbeams are joined together will have a cross cut-outs similar to those of the main bracket. However, the sub-bracket that is located at the end of each cantilever arms will support only the other cantilever arm in one coordinate and hence will have only one cut-out in the parallel direction to prevent the slide of that specific cantilever arm.

CANTILEVER ARM (Cheom-Cha)

The cantilever arm is a member in a bracket system. Depending on its location on a structure, it is called main cantilever arm, secondary cantilever arm and third cantilever arm. Also based on the dimensions and its size, the cantilever arm is divided into small and large cantilever arm.

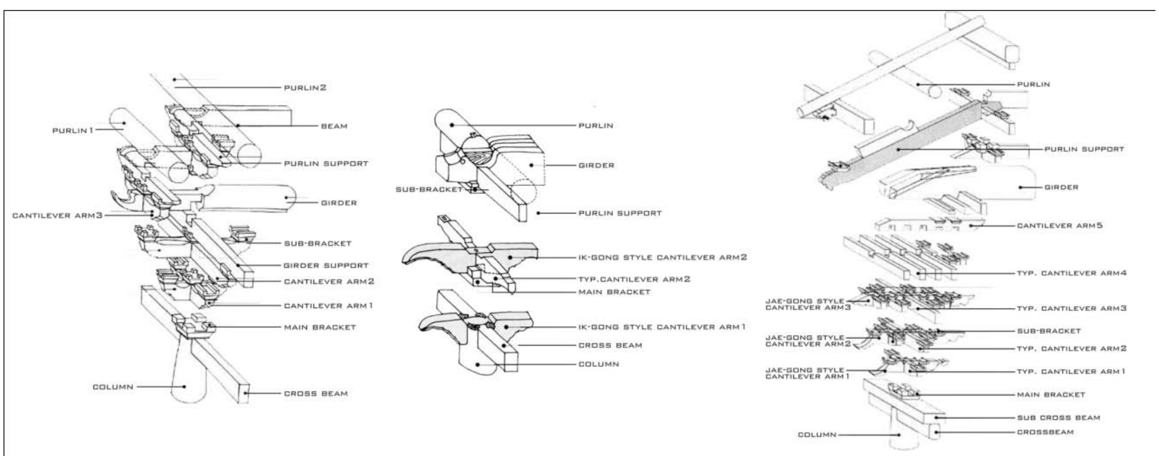


Figure 2. 7 Three main types of traditional Korean bracket system: *Ik-Gong* (left), *Ju-Sim-Po* (middle) and *Da-Po* (right)

9.2 JU-SIM-PO Bracket System

The first known evidence of the Ju-Sim-Po structure was found on wall paintings from the Go-Gu-Ryo Kingdom, during the Three-Kingdom-Period (57 B.C. - 668 B.C.). Although the exact year of first usage in Korea is not known, scholars estimate it to be around the fourth century. In the An-ak ancient tomb of Go-Gu-Ryo, wall paintings show the usages of stone columns and bracket systems. With this evidence, Ju-Sim-Po structures were already assumed to be practiced widely in mainland China. The Baek-Jae Kingdom used its first wooden bracket systems (Ju-Sim-Po) after the Kingdom of Go-Gu-Ryo. Much historic documentation proved that the Korean peninsula, especially the Kingdom of Baek-Jae, influenced the Asuka Era in Japan. Similarity in the Ju-Sim-Po bracket system can be found when comparing Dong-Tap of Baek-Jae and Geum-Dang of Nara Asuka. During the excavation of the Asuka temple, unlike other traditional Japanese temples, shapes of its purlin and layout followed those of Baek-Jae temples. The purlin's shape was circular rather than rectangular, which is the typical Japanese purlin shape. This finding is important evidence that proved that Baek-Jae heavily influenced the development of Japanese wooden structure. The Kingdom of Shilla conducted direct cultural exchanges with China, which was ruled by the Tang dynasty; therefore, it influenced Shilla architecture. An example of the Tang dynasty's influence is seen in the Shilla An-Ap-Ji wall painting, which showed a building structure that is very similar to the Tang's Dae-An Temple. For the Ju-Sim-Po type, the situating bracket systems over the columns support the purlin and transfer the vertical load from the roof to columns and foundations. Ju-Sim-Po is an early stage of bracket system. After creating the Min-Do-Ri types of structure, the ancient Koreans created a system where the ceiling height can be increased with relatively strong support. Some of the buildings that used the Ju-Sim-Po structures are Guk-rak-Jeon, Hall of Bong-Jeong-Sa Temple, Moo-Ryang-Su-Jeon, Hall of Boo-Suk-Sa Temple, and Dae-Woong-Jeon, Hall of Soo-Duk-Sa Temple

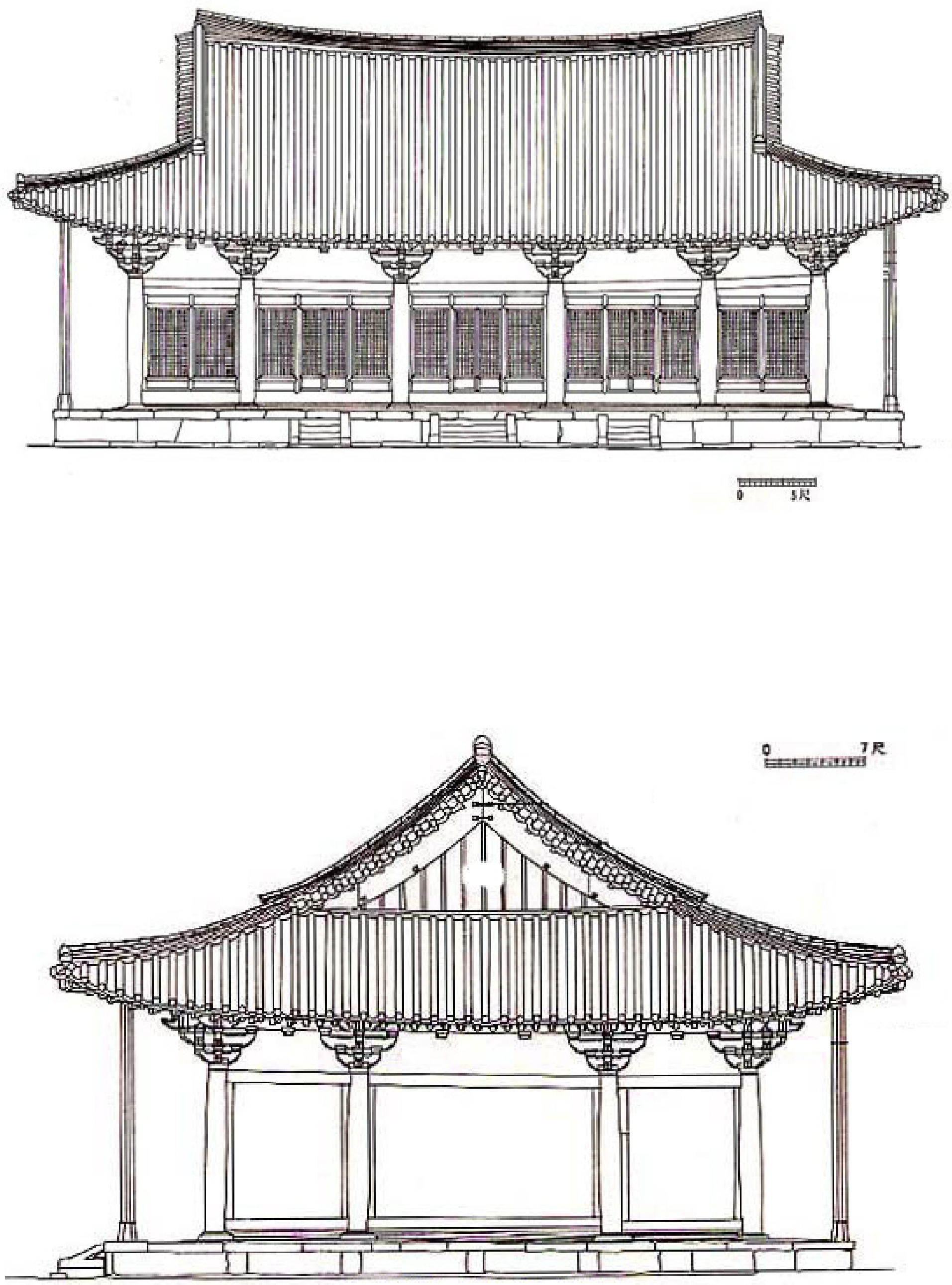


Figure 2. 8 Moo-Ryang-Su-Jeon, Hall of Boo-Suk-Sa Temple (*Ju-Sim-Po* bracket system)

9.3 IK-GONG Bracket System

The *Ik-gong* style is known as a simplified version of the *Ju-Sim-Po* style.[27] What makes the *Ik-Gong* style unique from Ju-*Sim-Po* and *Da-Po* is that the overall structure of the *Ik-Gong* style is relatively low and small due to the vertical members being less used. The *Ik-Gong* style follows the same construction styles of *Ju-Sim-Po,* yet *Ik-Gong* member (typically the maximum use of *Ik-Gong* members are double) are substituted for numbers of vertical crossbeams and cantilever arms found in *Ju-Sim-Po.* Therefore, *Ik-Gong* types were mostly used in the small additional structures next to the main building or small residential buildings. *Ik-Gong* styles consist of one purlin to support the roof instead of exterior and interior purlin shown in the *Ju-Sim-Po* style.

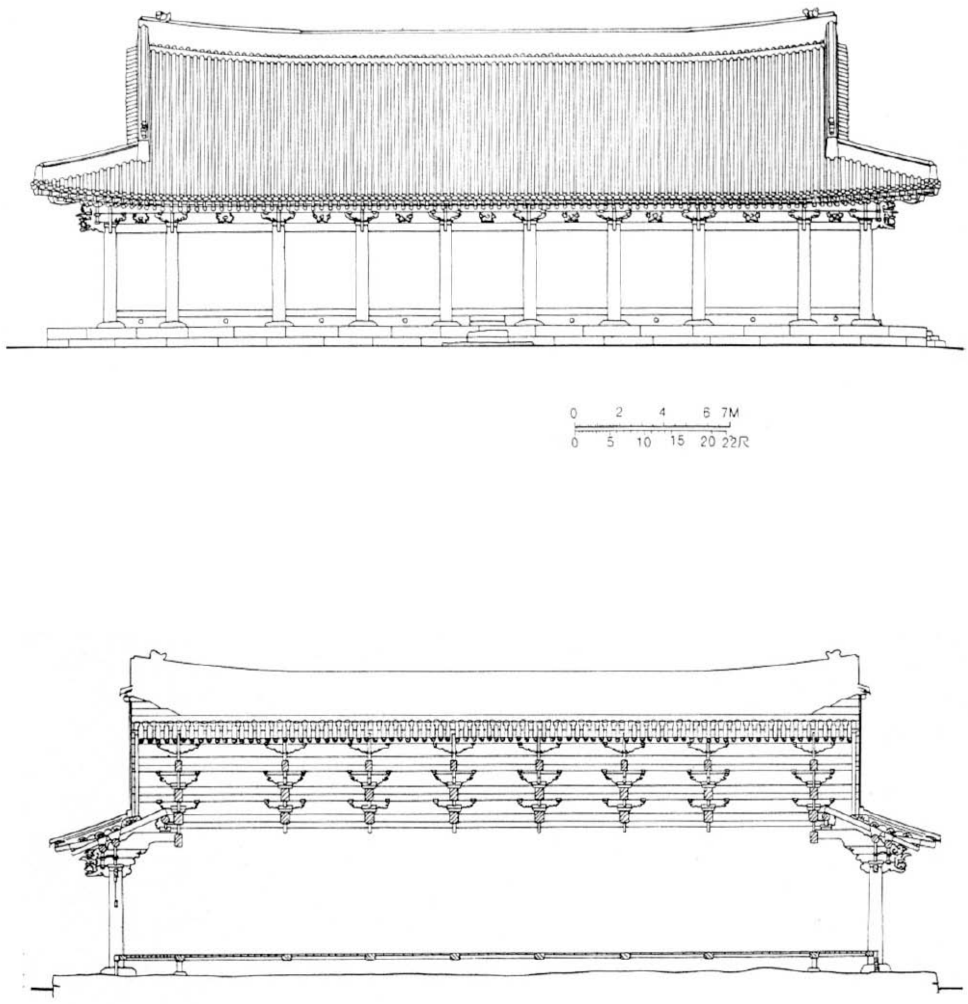


Figure 2. 9 Sae-Byung-Gwan (*Ik-Gong* bracket system)

[27] Choi, Jang-Soon. *Traditional Korean Architecture.* Gi-Moon-Dang, 2006, P.30

9.4 DA-PO Bracket System

Unlike the Ju-Sim-Po types, the Da-Po bracket systems have an extra member called Pyung-Bang between the column and main bracket. In the Ju-Sim-Po type, the main bracket is situated directly on top of the column. However, in the Da-Po type, a crossbeam called Pyung-bang is placed directly above the column instead. Pyung-bang is a crossbeam member supporting the bracket systems between the column and main bracket. Because the Da-Po types have a constant row of bracket system above column and between columns, Pyung-bangs act as a resting member for each bracket system placed in between columns. Also the increase in the number of cantilever arms increased the span between columns and the depth of ceiling height as well as relatively long eaves compared to the Ju-Sim-Po type. Overall, buildings with the Da-Po types are quite large in scale. The Da-Po type of buildings was widely constructed during the Jo-Seon Dynasty due to the size and majestic image of a Da-Po type building. Compared to the Ju-Sim-Po, the Da-Po types are more advanced in aesthetics, orders and building sizes. Examples of buildings that used Da-Po structures are Dae-Woong-Jeon, Hall of Bong-Jeong-Sa Temple, Bo-Gwang-Jeon, Hall of Sim-Won-Sa Temple, Eung-Jin-Jeon, Hall of Seok-Wang-Sa Temple, Myung-Jeon-Jeon, a residence in Chang-Kyung Palace and Nam-Dae-Moon Gate in Seoul.

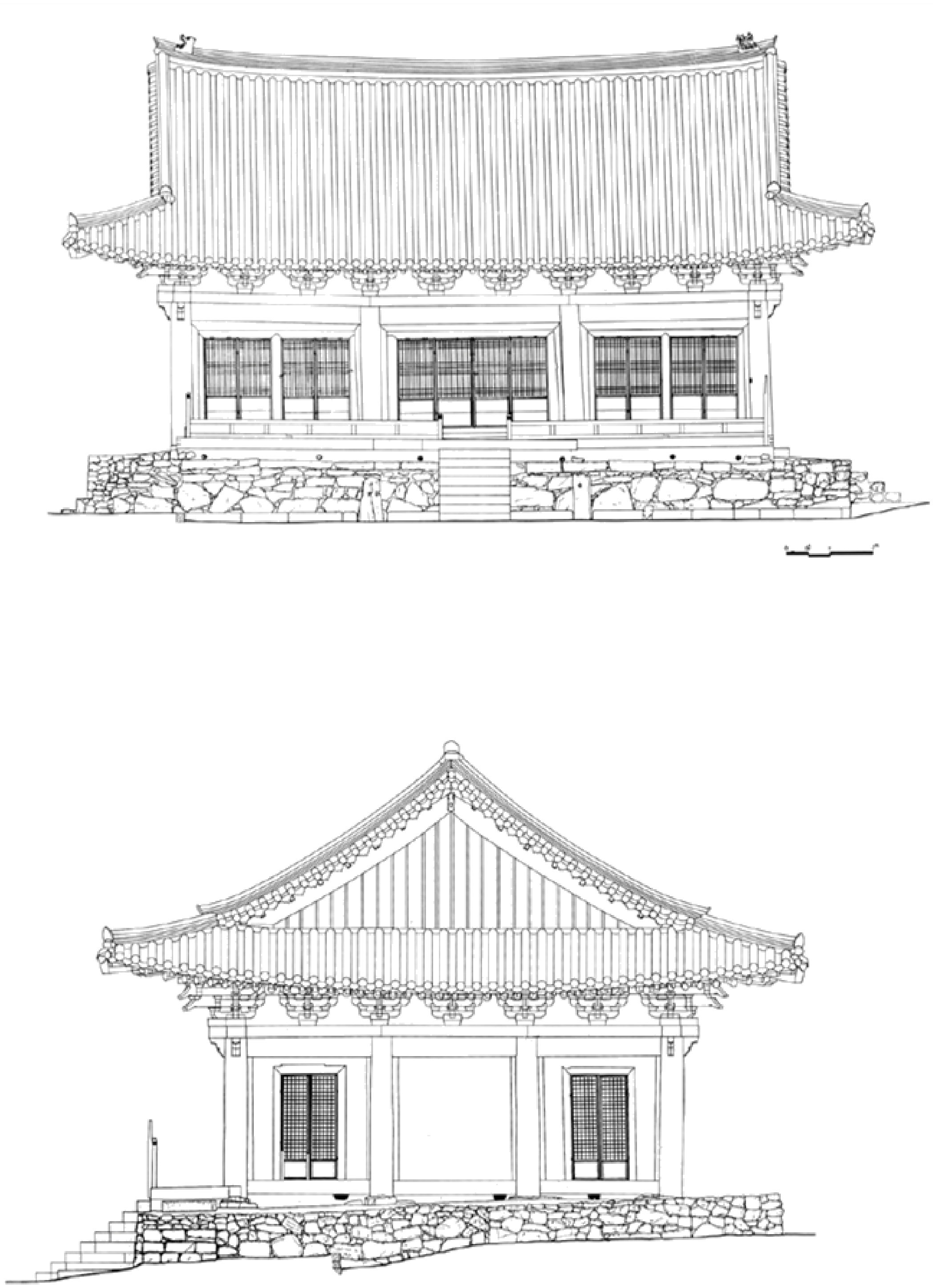


Figure 2. 10 Dae-Woong-Jeon, Hall of Bong-Jeong-Sa Temple (*Da-Po* bracket system*)*

9.5 Reusability in Traditional Korean Joinery

One of the most important guidelines written in the various documents of repairing works done in the past restoration works in traditional Korean wooden structure is the emphasis in minimizing the usage of new materials and conserving the original materials. Not a lot of information about the processes of restoring the traditional Korean structures in the past is known, due to the destruction of the past wars in Korea, However, through the remaining documentations and research conducted on the age of building material, the time of a building's construction and restoration can be predicted. The historic building of Hye-In-Sa displayed its repairing years, and the original and replacing components are still on the building.

Hye-In-Sa

The Hye-In-Sa temple was constructed in 802 B.C. during the Silla dynasty and was very well known as a scholarly library during the Go-Ryo dynasty. One of the treasure which is a first written script engraved in wooden strips are in store at Hye-In-Sa. The Japanese army damaged Hye-In-Sa in 1399, and reconstruction work occurred from 1488 to1491. Scholars recorded some of the detailed descriptions of Hye-In-Sa's restoring process in their personal texts.

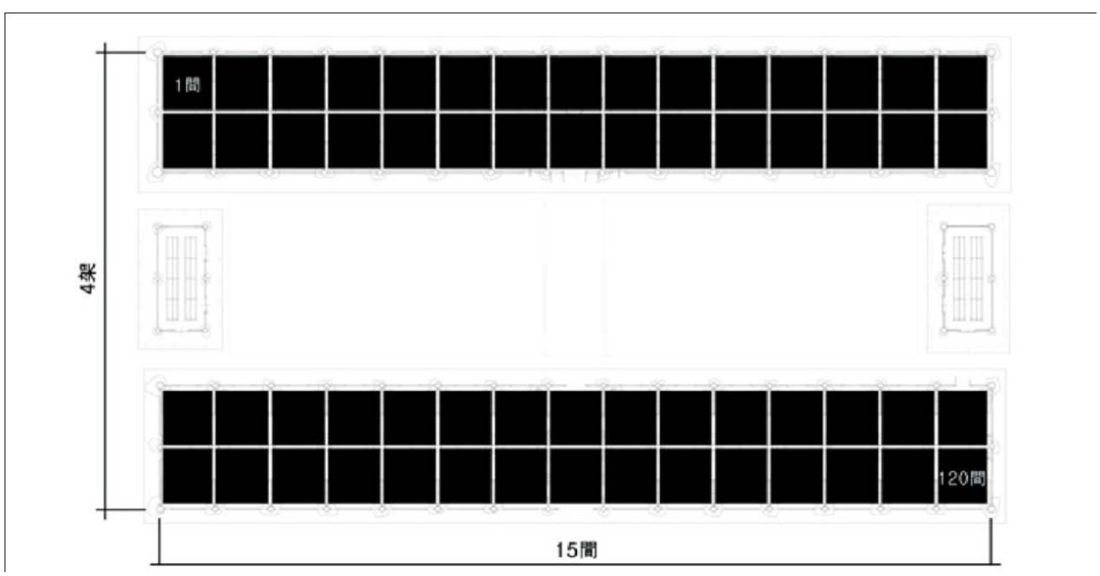


Figure 2. 11 Plan of Hye-In-Sa

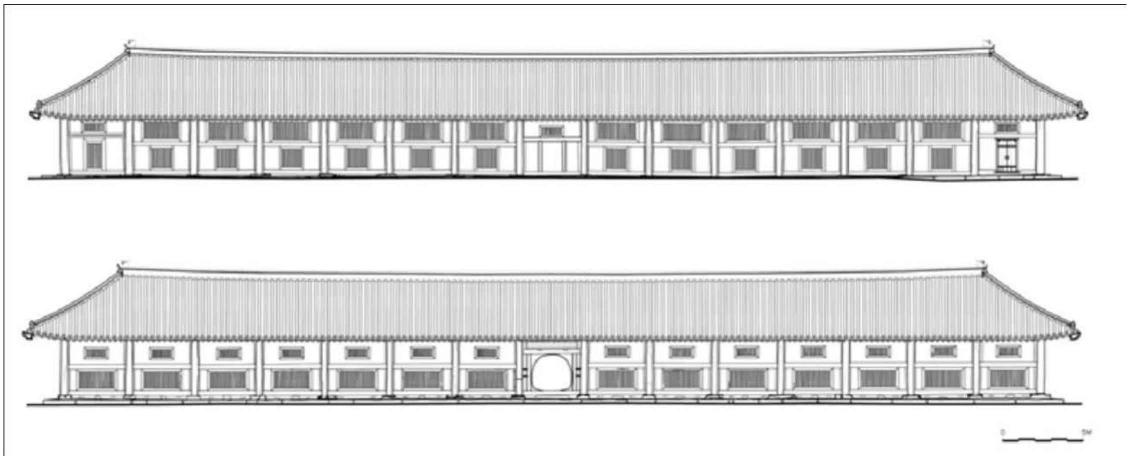


Figure 2. 12 Elevation of Hye-In-Sa

constructed with different types of wood species. For the first structure, 47 out of its 48 columns were made of zelkova tree, and 1 column was made of pine tree. However, the second structure had 21 out of its 50 columns made of zelkova, and 7 out of 50 columns were made of a combination of pine and fir. The hypothesis is that Zelkova was the main wood species used during the building's construction, and rest of the species was used as the replacing parts during the building's repair work.

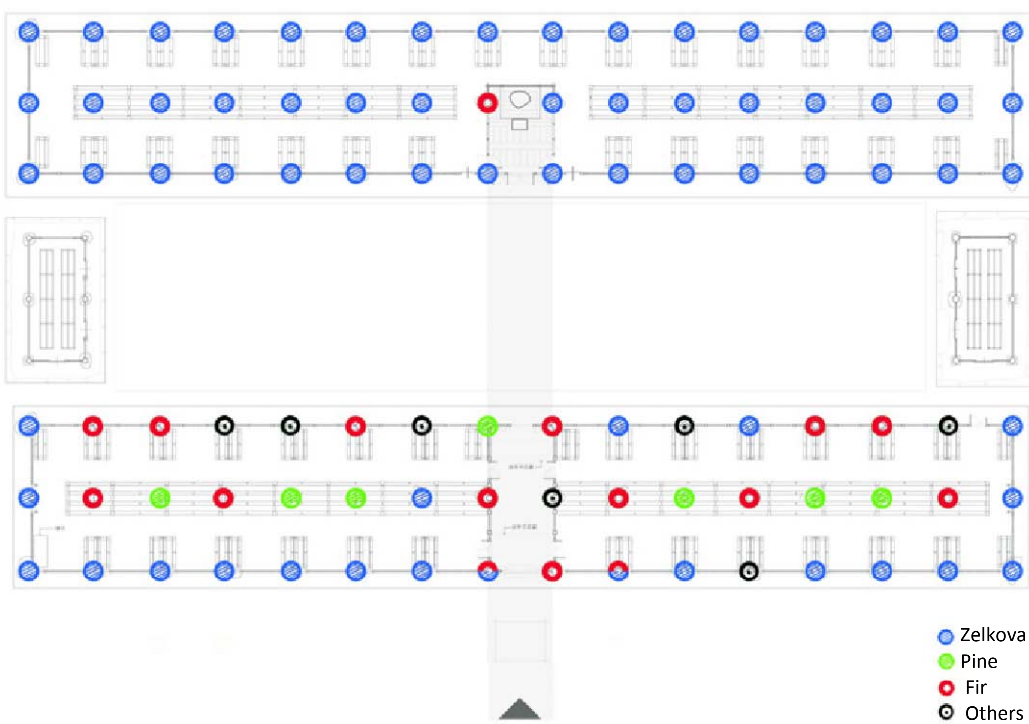


Figure 2. 13 Tree species used for column members in Hye-In-Sa

9.6 Categorization of Traditional Korean Joineries

First, a literature review on topics such as the definition, features and types of joinery was performed to categorize them according to the name and structure of joinery and to make the parametric database for the traditional joinery system. In addition, the utilization of joinery was analyzed by categorizing it by its use, location and whether it passed through other components. Using such systematic data to produce and experience various iterations, which were designed by the user through simulation, a user-customized 3-D model design program was developed. It could be used for popularizing or training traditional techniques based on the structural understanding and experience of joinery techniques.

Definition

Traditional joinery is when two pieces of important material and lumber that act as the skeleton of a structure are fitted by framing in a right angle or at a slant, and the term also refers to the methods used for it. The fitting can be divided between inlay and fitting. The inlay technique of the traditional Korean joinery system is when another lumber is inserted and fixed into the end of the tenon at the side of the main material, or also represents the connecting area. In the fitting technique, the lumber and severed part is fitted in a right angle or at a slant in the mid section, or also represents the connecting area.

Type of joinery

The types of joinery that use the inlay (interlocking) method are described in the following:

1. Fully inlay: The simplest and sturdiest inlay method, the fully inlay is a perforation in which the entire end pieces of a lumber can be put into the side of another lumber. Usually, the width of the lumber with the perforation is the same size or wider, with the end piece of the inlay lumber for the full inlay, while the depth of the perforation is no more than half the width of the lumber.
2. Projection (Teok) inlay: It is similar to the projection connection. A perforation is made in one piece, and another projection is carved into the inlay lumber to the connection. Depending on the type, the projection inlay is categorized as half-inlay or full-inlay.
3. Tenon (Jang-Bu) inlay: It is similar to the tenon connection, but has more connection methods than the simple tenon. Tenon inlay methods using the ssangpilbu are called gareumjang fitting, and this method is normally used when inlaying the lintel on a pillar.

Types of joinery that use setting-up (overlapping) method

1. Projection (Teok) setting-up: a Teok is made on both connection pieces to fit in at right angles or at a slant. There are also banteok setting-up, cross setting-up and sambunteok seeting-up. In banteok setting up, half of the height of the two materials' corner area is removed, the lower part is the receiving, and the upper part is the covering. Cross setting up is almost the same as banteok setting up, except that the teok is not formed at the severed part for connection. Cross setting up is usually used for connecting the ancon in the direction of the girder that makes up the purlin, where the lumber protrudes, as well as the crossbeams and main bracket
2. Sagwe setting-up: When four chocks (points) are made on the pillar head. Sagwe setting-up is used to cross the ancon in the direction of the purlin, crossbeam, girder head or girder. Sagwe setting-up is a fitting technique used in the pillar head of all traditional buildings.
3. Yeongwi setting-up: It is normally used for doors, window frames, ceiling frames and cheonpan (desk and box surfaces and the board place on the ceiling). Yeongwi setting-up is a fitting technique of cutting in a slight angle of the slant that touches the 45-degree angle, so that the end piece of the lumber that crosses in right angle or at a slant in is hidden.

Categories according to the types of reinforcement of other materials

There are categories according to the reinforcement methods of wooden materials such as sswegi, sanji (wood point or wood nail) and chock or iron materials such as ddiswe and nails. In the case of the reinforcement lumber, it normally uses the same material as the connecting materials or tough and strong materials such as oak wood.

1. Methods using sswegi include the side wedging where a slant-cut triangular piece of wood is hammered in or the beollim-sswegi, which makes and uses a wedging area, is made in advance at the connecting area, aside from the gap formed during setting-up, and the hidden sswegi.
2. In sanji reinforcement, a hole is made in the connecting part. A strong but thin piece of wood (sanji) is placed in it, so that it does not fall out or get pushed away. Depending on the reinforcement method, sanji can be categorized as either hairpin sanji or locust

sanji. The hairpin sanji is when two pieces of lumber are pierced and placed in, so that they do not fall out. The locust sanji is put into the head end of the protruding jangbu.

Constructing the Database through the setting-up analysis

Currently, the traditional Korean setting-up categories include jang-bu setting-up, teok setting-up, mat setting-up, yeongwi setting-up and panjae setting-up. Yeongwi setting-up and teok setting-up are the largest in number, followed by jang-bu setting-up, panjae setting-up and mat setting-up, in that order. Focusing on the above five setting-ups, the various names of setting-up was conjoined into those that are most frequently used. They were categorized to help illustrate the setting-up through contents according to the structure of setting-up**.** In addition, they were categorized by their use, location and whether or not they passed the jangbu to make identifying the features of each setting-up easier.

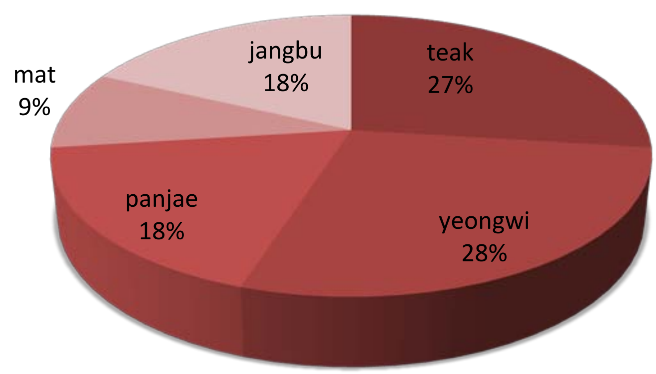


Figure 2. 14 Distributions of Major Traditional Joints

Categorization according to the name and structure of setting-up

Figures 7.11 to 7.18 show the categories of the following: 13 jangbu setting-up, 19 teok setting-up, 6 mat setting-up, 20 yeongwi setting-up and 13 panjae setting-up. They are categorized according to the or number, name and structure.

Categorization according to the use and location of setting-up

Depending on its use, setting-up can be categorized as side + end of lumber, end of lumber + end of lumber, inner side of lumber + inner side of lumber depending on the location through rectangular lumber + rectangular lumber, rectangular lumber + board, board + board. In addition, depending on whether the jangbu pierces it, setting-up is categorized as naedaji (piercing) or bandaji (non-piercing).

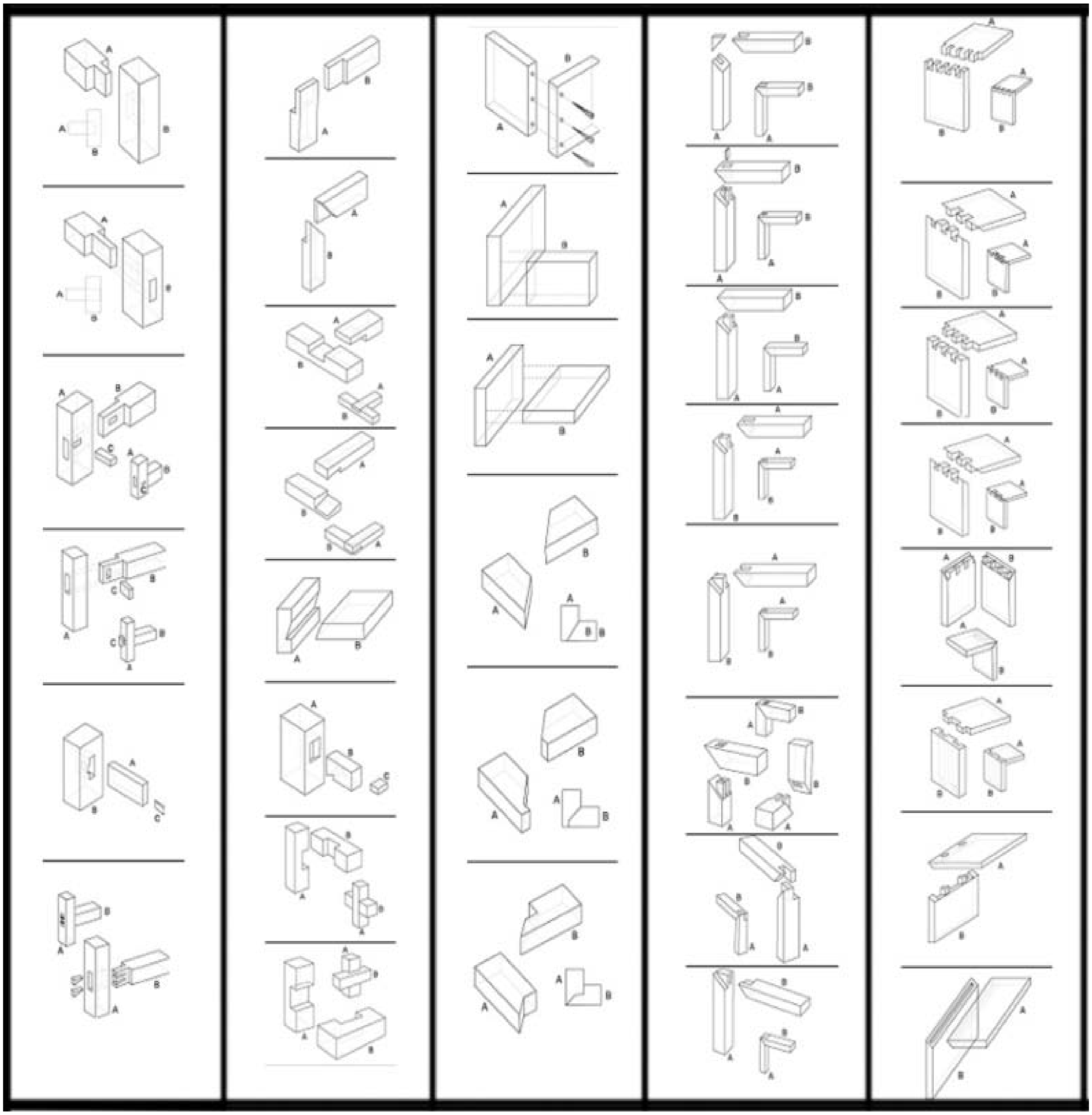


Figure 2. 15 Example of categorization according to the structure of the setting-up (Left to right- Jangbu, Teok, Mat, Yeongwi and Panjae setting up)

Jangbu Setting-Up

Jangbu setting-up is the most used setting-up for rectangular lumber. However, it can be used also in various ways by applying to the board and rectangular lumber, as well as board and board setting-up. Jangbu setting-up is usually located on the inner side of the lumber or at the end of the lumber, and both naedaji and bandaji are used for design and structural reasons.

NAME	Use of setting-up			Location of Setting Up			Jangbu piercing	
	Rectangular lumber + Rectangular lumber	Rentangular lumber + Board	Board + Board	Inside of lumber + End of lumber	End of lumber + End of lumber	Inside of lumber+ Inside of lumber	Naedaji	Bandaji
Hidden jangbu	O	O		O				O
Mak jangbu chock	O	O		O			O	
Mak ie san ji jangbu	O			O			O	
bang du san ji jangbu	O	O	O	O			O	
dae ril jangbu	O	O		O				O
beollim sswegi jangbu	O	O		O			O	
jiok jangbu	O	O		O				O
weo chock jangbu	O				O		O	
ju meok jangbu	O	O			O		O	
gin ju meok jangbu	O	O			O			
nae rim teok jangbu	O			O			O	
jangbu nae chock	O			O				O
sang jang bu	O			O			O	

Figure 2. 16 Categorization of Jangbu settings according to use, location and jangbu piercing

Teok Setting-Up

Teok setting-up is usually used for rectangular lumber and rectangular lumber, while the inlay method is also used for board and board. The inner sides of the lumber are crossed with banteok, or the ends of the lumber are crossed. The teok is made using inlay and setting-up.

NAME	Use of setting-up			Location of Setting Up			Jangbu piercing	
	Rectangular lumber + Rectangular lumber	Rentangular lumber + Board	Board + Board	Inside of lumber + End of lumber	End of lumber + End of lumber	Inside of lumber+ Inside of lumber	Naedaji	Bandaji
Ban teok	O		O		O			
Teongwi teok	O		O		O			
T-shape ban toek	O		O	O				
Slanted ban teok	O		O		O			
Bit teok	O		O	O				
Arae teok	O			O				
Cross ban teok	O					O		
Cross teok	O	O				O		
Cross geol chim teok	O	O				O		
Yeongwi ban teok	O		O			O		
Teok seol tangeotki	O		O	O				O
Sol teok	O		O	O				O
Gi dung sa gae	O		O	O		O		

Figure 2. 17 Categorization of Teok settings according to use, location and jangbu piercing

Mat Setting-Up

Mat setting-up is when the side and side is connected without jangbu or teok. It is used for rectangular lumber and rectangular lumber or board and board and is usually located at the end and end of the lumber.

NAME	Use of setting-up			Location of Setting Up			Jangbu piercing	
	Rectangular lumber + Rectangular lumber	Rentangular lumber + Board	Board + Board	Inside of lumber + End of lumber	End of lumber + End of lumber	Inside of lumber+ Inside of lumber	Naedaji	Bandaji
Mat setting up A	O		O		O			
Mat setting up B		O			O			
Heoritdam	O		O	O				
Mat yeong wi	O		O		O			
An yeong wi	O		O		O			
Bak yeong wi	O		O		O			

Figure 2. 18 Categorization of Mat settings according to use, location and jangbu piercing

Yeongwi Setting-Up

Yeongwi setting-up is used mainly for rectangular lumber and rectangular lumber. Though it is also used for the interior of the lumber, most of the time the Yeongwi setting-up is located at the end of the lumber. Both naedaji and bandaji pierces are used.

NAME	Use of setting-up			Location of Setting Up			Jangbu piercing	
	Rectangular lumber + Rectangular lumber	Rentangular lumber + Board	Board + Board	Inside of lumber + End of lumber	End of lumber + End of lumber	Inside of lumber+ Inside of lumber	Naedaji	Bandaji
San ji Yeongwi	O				O			O
Nae chok beoliim sswegi	O				O		O	
Hidden jangbu-yeongwi	O				O			O
Mak jangbu-yeongwi	O				O		O	
Weo chok jangbu-yeongwi	O				O		O	
Ssang jangbu-yeongwi	O				O		O	
Gae shim-yeongwi	O				O			
Yeonwi-jangbu A	O				O			O
Yeongwi-ju meok jang	O				O		O	
Ban yeongwi-hidden jangbu	O			O				O
Jae bi chok-jangbu	O			O			O	O
Yeongwi-soe mok teok	O			O				O
Sambang-yeongwi jangbu	O				O			O

Figure 2. 19 Categorization of Yeon-Gwi settings according to use, location and jangbu piercing

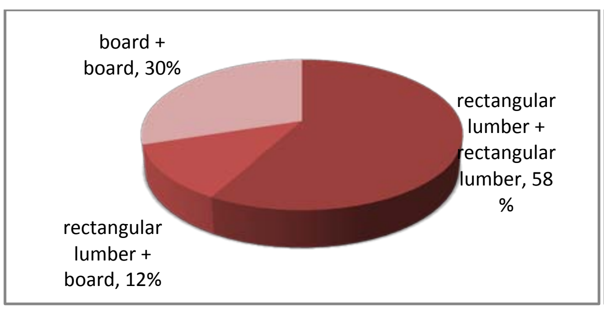
Panjae Setting-Up

Panjae setting-up is usually used for board and board. Thus, panjae setting-up is categorized as a setting-up. The location of the setting-up is where it is placed in the middle and the setting-up that connects the ends of the board and board.

NAME	Use of setting-up			Location of Setting Up			Jangbu piercing	
	Rectangular lumber + Rectangular lumber	Rentangular lumber + Board	Board + Board	Inside of lumber + End of lumber	End of lumber + End of lumber	Inside of lumber+ Inside of lumber	Naedaji	Bandaji
Sagae			O		O			
Yeongwi sagage			O		O			
Ju meok sagage			O		O			
Yeongwi ju meok jang sagae			O		O			
Hidden ju meok jang sagae			O		O			
Ban ju meok sagae			O		O			O
Tong pan yeongwi jangbu			O		O			O
Tong pan-Yeongwi			O		O		O	
Ssang jangbu			O		O			
Ban yeongwi-hidden jangbu			O	O				O
Yeongwi jangbu			O	O			O	O
Tong jangbu			O	O			O	
Beollim sswegi-tong jangbu			O	O			O	

Figure 2. 20 Categorization of Pan-Jae settings according to use, location and jangbu piercing

Results of the analysis of the categories according to the use and location of setting will now be discussed. It is evident from the analysis of the uses of setting-up that excluding the panjae setting-up, mostly used in rectangular lumber + rectangular lumber. Jangbu setting-up, yeongwi setting-up and teok setting-up took up a large part in rectangular lumber + rectangular lumber. In the case of the Panjae setting-up, it is a form made up through the application of jangbu setting and yeongwi setting-ups.



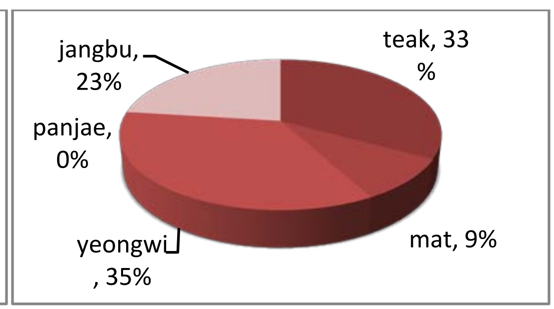


Figure 2. 21 Pie diagram of main uses of setting-up (left)
Figure 2. 22 Pie diagram of main uses of rectangular lumber and rectangular lumber (right)

As evident in the panjae setting-up and yeongwi setting-up, the use of setting-up is limited according to its characteristics. However, in the case of jangbu setting-up and teok setting-up, setting-up can be applied in various ways in rectangular lumber and board.

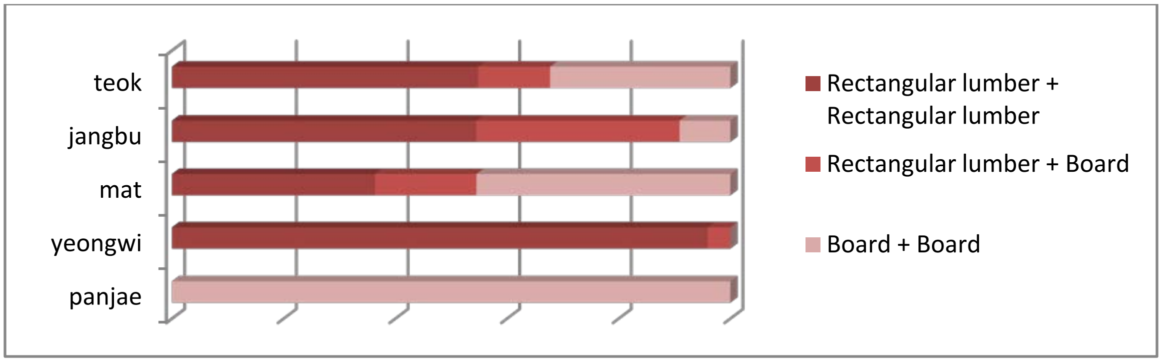
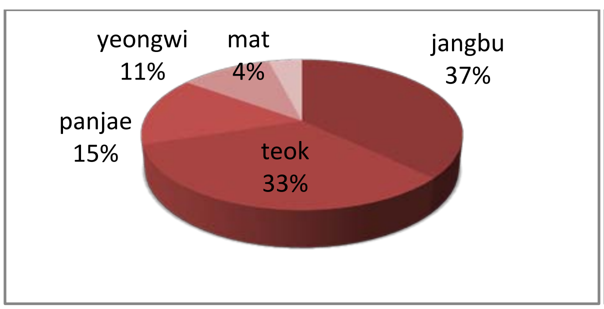


Figure 2. 23 Distribution of uses by setting-up

The following results of the analysis on the location of setting-up enable the identification of the use frequency at each location. Jangbu setting-up is used mostly for the inner side of the lumber and end of the lumber, because jangbu setting-up has a hold on one side of the jangbu, and the other side is made to insert the jangbu. In addition, to make the yeongwi setting-up's end to be at 45 degree, there are many instances when the end and end of the lumber are interlocked.



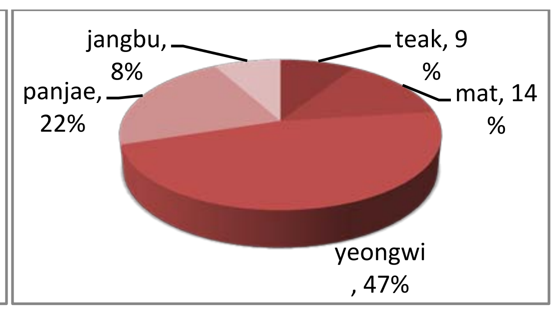


Figure 2. 24 Setting-up distribution for inner side of the lumber and end of lumber (left)
Figure 2. 25 Setting-up distribution for end of lumber and end of lumber (right)

10. EXPERIMENTATION

This section of the chapter explains the experimentation on the possible modification of the existing components found in one of the main types of the *Ju-Sim-Po* style bracket system. The case study building was chosen for of its unique characteristics as a traditional Korean wooden structure that was formed in *Ju-Sim-Po* style. Buildings made in the *Ju-Sim-Po* style are known to be the oldest wooden structures in Korea, and examples of those include Guk-Rak-Jeon, The Hall of Bong-Jeong-Sa Temple. Experimentation was the first phase of designing the catalog. Through the construction of an existing bracket system based on the case study building, the understanding of the joinery and composition of each member were studied. Finite Element Method (FEM) stress test was done in the Algor Design Check environment. The overall objective in the experimentation was to determine the method of changing the components. During this study, only the corner conditions of bracket systems from Guk-Rak-Jeon structure were built and tested.

10.1 Prototype Building Analysis: Guk-Rak-Jeon, Hall of Bong-Jeong-Sa Temple

Guk-Rak-Jeon, Hall of Bong-Jeong-Sa Temple is currently the oldest wooden structure in Korea . Guk-Rak-Jeon has nominated as a national treasure in December 20, 1962. During its repairing work in 1972, a form of documentation found stated even earlier repairing work took place in 1363, suggesting that the actual completion of the building may have happened 100 to 150 years earlier than the originally estimated completion year of 1363. The bracket systems in Guk-Rak-Jeon and Hall of Bong-Jeong-Sa Temple were designed with the Shilla types of Ju-Sim-Po style. Although Guk-Rak-Jeon was built during the end of the Go-Ryo Dynasty, its unique style of bracket system was similar to Dae-Jeon with a Chinese structure design. The bracket system is comprised of the main bracket on top of the column, first cantilever arms, sub-brackets on top of first cantilever arms, then second cantilever arms, and another set of sub-brackets and girders supporting purlin and roof structure.

Figure 2. 26 Guk-Rak-Jeon, Hall of Bong-Jeong-Sa Temple

Figure 2. 27 *Ju-Sim-Po* bracket systems of Guk-Rak-Jeon

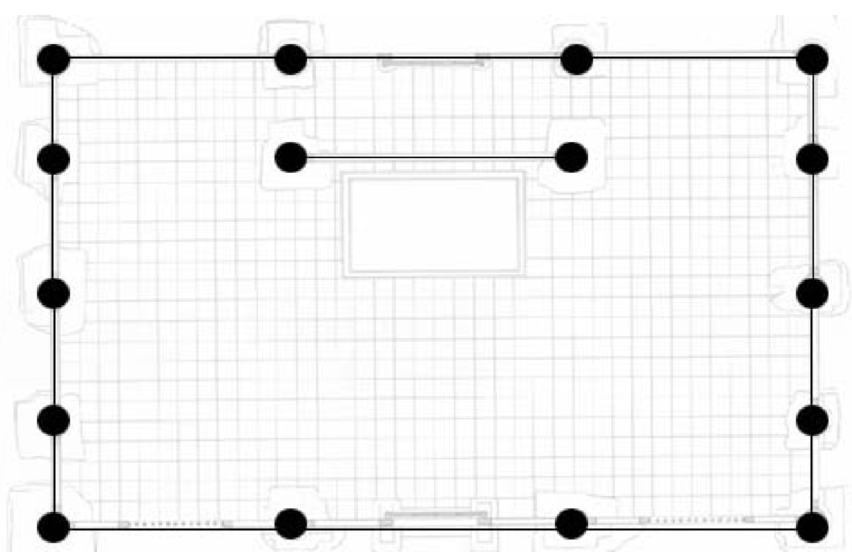


Figure 2. 28 Plan of Guk-Rak-Jeon, column placements with *Kan* dimension

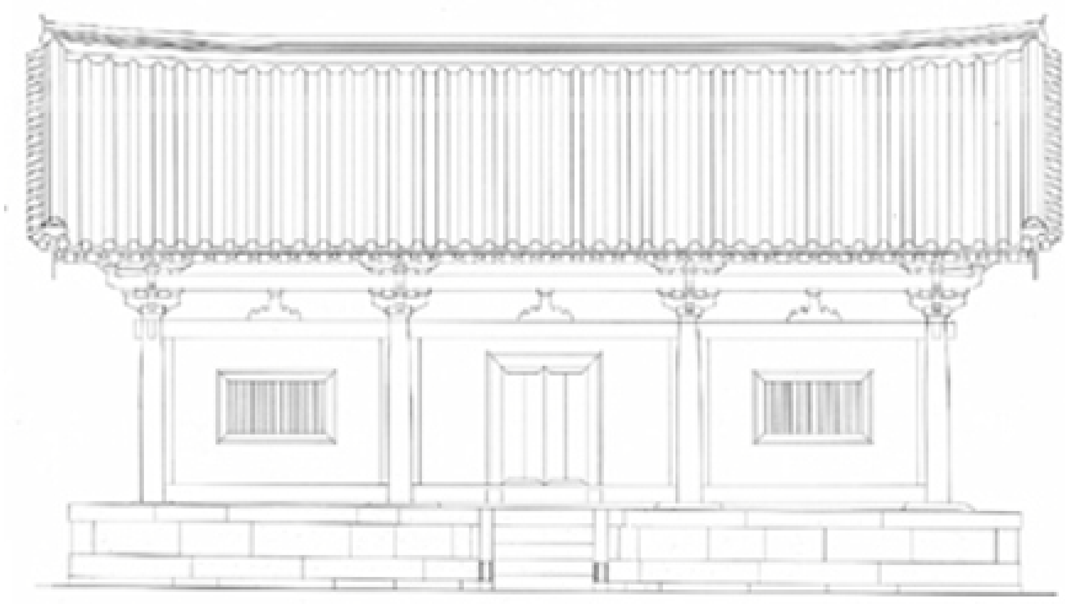


Figure 2. 29 Elevation of Guk-Rak-Jeon

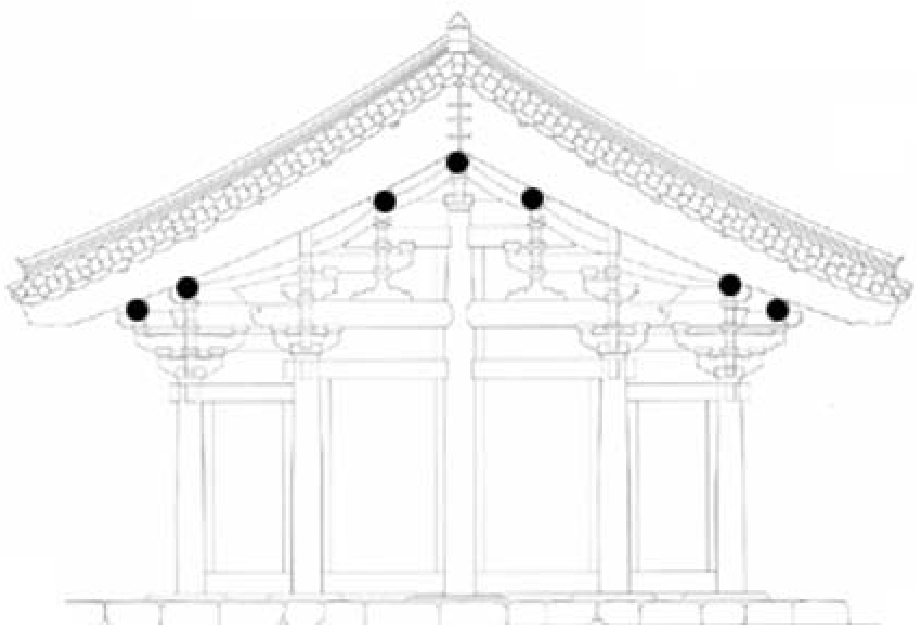


Figure 2. 30 Section of Guk-Rak-Jeon

The experimentations will be made on the Guk-Rak-Jeon structure as described below:

PLAN VARIATION

From the existing plan condition, experimentation will involve change in the plan type to further analyze the composite of the bracket system and its joinery. The modified conditions will be analyzed and recorded into a catalog design. During this case study, a simple structural analysis will be made using 3-D Rhinoceros and Autodesk Algor Designcheck. I have picked several plan types: Equilibrium Triangle, Circle, Octagon, Trapezoid and Parallelogram. The existing plan of a structure is a rectangular plan with five columns in depth and four columns in length distance. I chose the Guk-Rak-Jeon as my primarily source of research, because Guk-Rak-Jeon is currently the oldest wooden structures in Korea. Also many information about the past repair works were available. Guk-Rak-Jeon is very unique in a way that bracket system followed those of Shilla Dynasty, although the building itself was built in the late Go-Ryo Dynasty.

ANALYSIS

Prior to the experiment with various different conditions, an in-depth analysis on the current state of the existing conditions was necessary. To follow up on my experimentation, the following fields will be studied:

- Composition of an existing bracket system and its assembly and disassembly methods
- Geometric diagram of each member and joinery
- Mechanisms of each member

The study of an existing condition is the most important segment of the research in my D.Arch project. The modified individuals will be based on the rules created during this phase of research. A system- or rule-based logic will be followed by the form, function, mechanism and structural ability of an existing condition. However, I am not considering using an identical material as the existing structure, as forms, functions and mechanisms may have more varieties based on the materiality chosen for individuals. I may sound contradictory, but the main reason for this analysis is to further execute my experimentation in a guided rules (for example, the load distribution stays the same as the existing bracket system). Also this analysis will show the different and new condition of each individual member. From the existing Guk-Rak-Jeon structure, I have looked at three main parts:

1. Plan and corner conditions of bracket system (I have disregarded the bracket systems in-between columns, because when I broke down into individual joineries of members, corner conditions have slightly more varieties compared to inner columns).
2. Bracket structures
3. Kinetic connections found in existing building structure.

10.2 Existing plan analysis

Programs

- Sketchup
- 3-D Rhinoceros
- Autodesk Algor Designcheck V.23
- Autodesk Cad Architecture 2010
- Autodesk Revit Architecture 2010

I used the 3-D Rhinoceros Nurbs Modeling Tool to build the existing model and its modifications. Dimensions are correctly measured according to the existing drawings. However, the 3-D model may look slightly different from the existing structure, due to the heavy emphasis on the corner condition columns and bracket systems. The constructed model then interfaced with Algor Designcheck Version 23 for the static stress analysis, which has been made to a 3-D Rhino model. Images will display how the load is being distributed throughout the bracket system,, but I intend to analyze the load distribution. The **focus of the structural analysis is not in the structural ability of a bracket system,** as in how much load the bracket system can successfully support. Hence, the equal vertical load was applied, though the load is not the exact value to existing building.

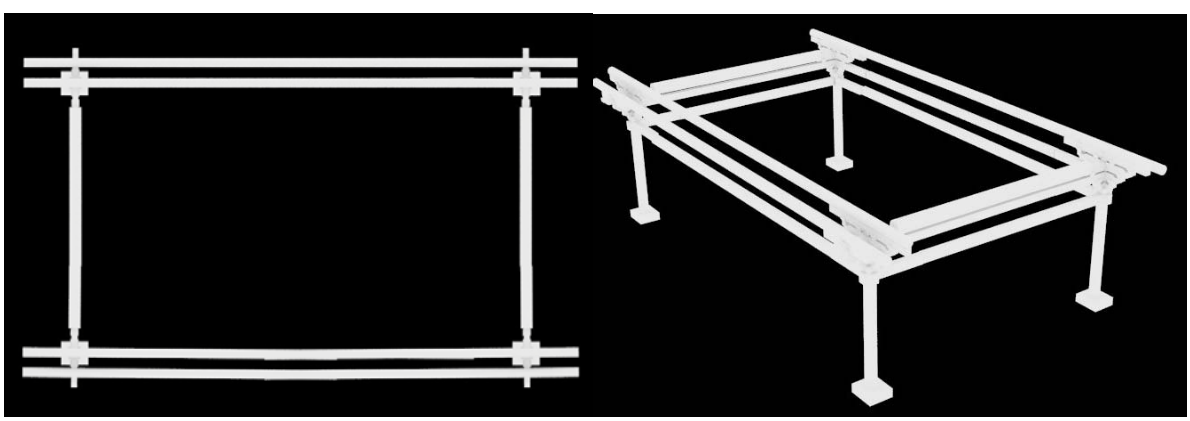


Figure 2. 31 3-D model constructed in Rhinoceros 3-D

The existing plan of Guk-Rak-Jeon is a simple rectangular plan. The girder runs through the width of a building, and the main and secondary purlins run in the length of a building. As previously stated, only the corner four columns and their bracket systems were being modeled.

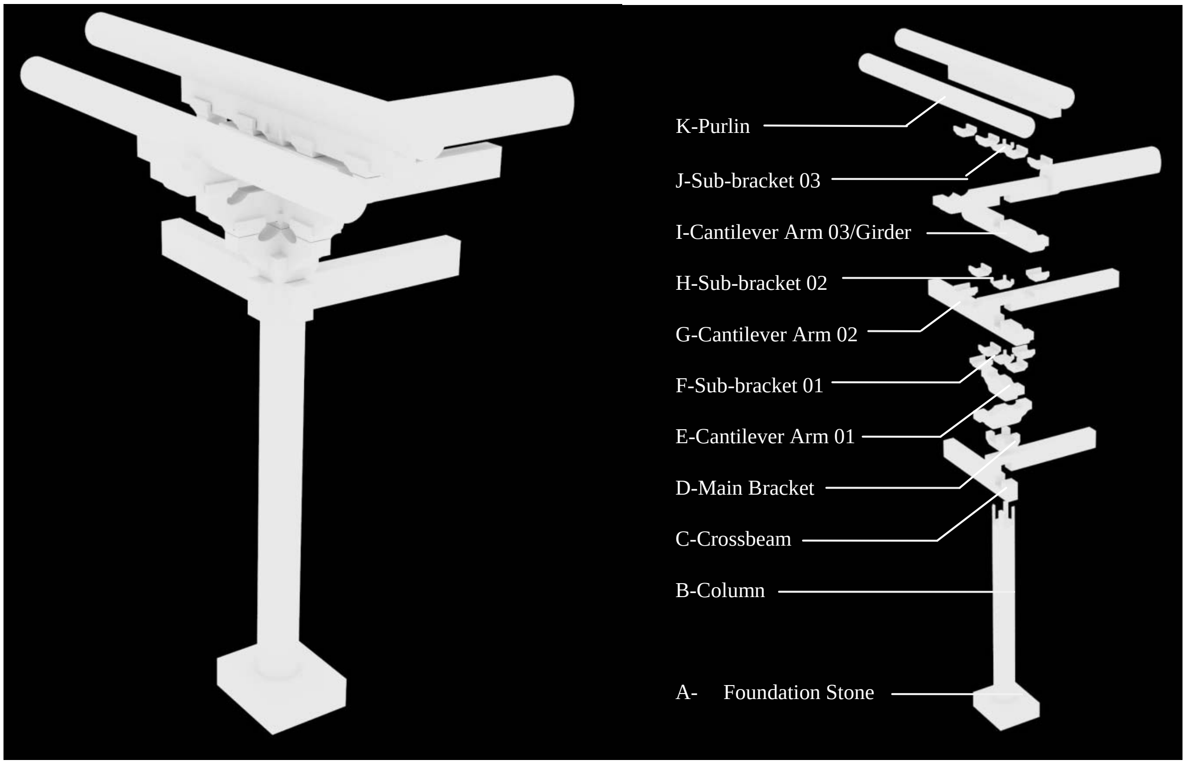


Figure 2. 32 Existing condition of *Ju-Sim-Po* and its composition

The composition of the existing bracket system can be written as the following:

A + [B + (C + C)] + [D + (E + E)] + [F + (G + G)] + [H + (I + I) + K] + J + K

The generated formula represents the joining of each member. The formula aims to show the simpler form of an overall composition of a bracket system. At this point, I have formulated only the order of each connecting members and its relations. Details showing individual joining methods will be discussed in later text.

Letters of the alphabet represent the members in forming a bracket system (e.g. A: Foundation Stone, B: Column, C: Crossbeam ~ K: Purlin). The individual joineries of each member will be discussed in detail in this section. A + B is a connected through frictional force (Gu-Rang-Ii-Jil), B + C is top-plate joint (Sa-Gwae-Mat-Cheom), C + C is cross-lap joint ~ J + K is blind-mortise & tenon joint. Rewriting the formula with the types of joinery will result in the following:

A + <Gu-Rang-Ii-Jil > [B + <top-plate-joint> (C + <cross-lap-joint> C)] + <blind-square-stud-joint> [D + < lap-joint> (E + <cross-lap-joint> E)] + <blind-square-stud-joint> [F + <lap-joint> (G + <cross-lap-joint> G)] + <blind-square-stud-joint> [H + <lap-joint> (I + <cross-lap-joint> I) + <blind-mortise-and-tenon-joint> K] + <blind-square-stud-joint> J + <blind-mortise-and-tenon-joint> K

Joineries are number coded as follow:

1	Gu-Rang-Ii-Jil
2	Top-Plate-Joint
3	Cross-Lap-Joint
4	Blind-Square-Stud-Tenon
5	Lap-Joint
6	Blind-Mortise-and-Tenon

Include the types of joinery in number coded, and formula becomes the following:

A + (1) [B + (2) (C + (3) C)] + (4) [D + (5) (E + (3) E)] + (4) [F + (5) (G + (3) G)] + (4) [H + (5) (I + (3) I) + (4) K] + (4) J + (6) K

10.3 Plan Variation: Equilibrium Triangle

The equilibrium triangle was the very first geometry I have decided to analyze for a simple reason: from an existing four-sided geometry, a three-sided triangle may generate different conditions in a bracket system. Also, due to the angle of difference, the joining condition needs to be modified. I wanted to test from an existing condition (where width and length are clearly displayed) to a three-sided triangular plan (where the concept of width and length does no longer exist). However, disregarding the concept of width and length also created confusion during the construction of the composite bracket system, where the girder runs in width distance and purlin runs in length of geometry at an existing plan type, now the clear definition of length and width had disappeared. Modifications were made from the rectangular plan to the equilibrium triangular plan. By switching the plan shape, I was able to observe the changes made on the existing elements. From the existing 90- degree angle of four faces in existing structure, angles changed to 60 degrees in three sides. Because there are onlythree corner conditions now, makes each cross elements to become a duplicated. Such as purlin and girder and crossbeams are no longer act as a separate entity but have common characteristics from each another. Also, the connections and angle of the joinery changed from 90 degrees to 60 degrees.

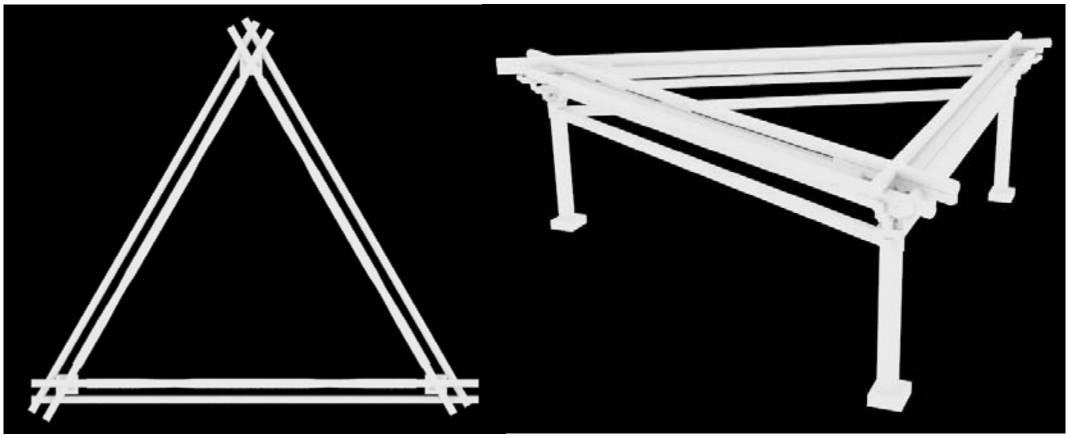


Figure 2. 33 3-D model of plan variation: Equilibrium Triangle

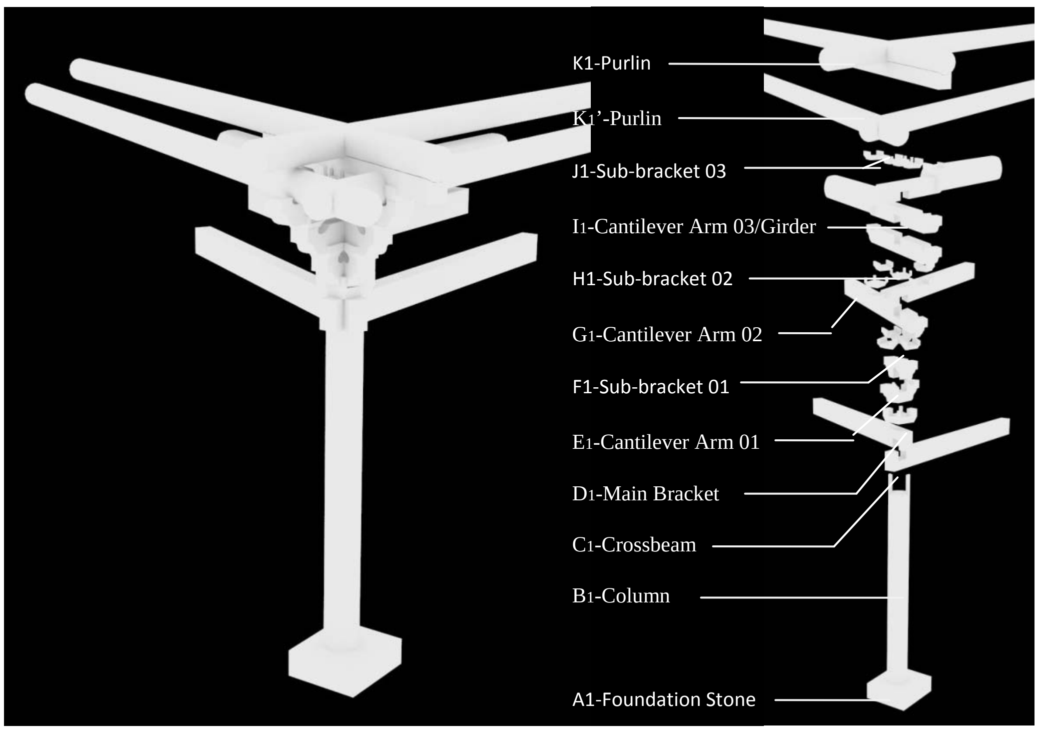


Figure 2. 34 Modified condition of *Ju-Sim-Po* and its composition

Modified composition of bracket system can be written as the following:

$$\mathbf{A_1 + [B_1 + (C_1 + C_1)] + [D_1 + (E_1 + E_1)] + [F_1 + (G_1 + G_1)] + [H_1 + (I_1 + I_1) + K'_1 + K'_1] + J_1 + K_1 + K_1}$$

Plan changes affected the composition of the bracket system. From the previous rectangular plan, one can the members are duplicated in new modification such as girder and purlin [I don't understand this sentence]. This is due to the changes in the number of sides from the existing four faces to the modified three faces. Because there is no such term as width and length in a triangle, purlin from one corner runs to one direction and the other purlin come from the other corner bracket system. Therefore, no difference in the purlin and girder exists in this case. Both the girder and purlin are running in the same direction. Also, due to the equal distance of three sides, I can predict that the vertical load is equally distributed. Before the static stress analysis has been done, I can predict that bracket structure is much strong in supporting equal amount of force applied in existing structure. Although difference in composition is bit hard to see from axonometric view, it clearly shows change of angle in plan. From a 90 degree angle, the equilibrium triangle has 60 degrees of an angle meaning that all of the joinery needs to consider the angle change.

Now, let's look at individual joineries and its changes made although we can predict that most joinery will remain relatively similar to existing condition except its changes in angle. Also some members are doubled in number compared to existing condition. Therefore, extra joineries may require in equilibrium triangle plan condition.

A_1 + **<Gu-Rang-Ii-Jil >** [B_1 + **<top-plate-joint>** (C_1 + **<cross-lap-joint>** C_1)] + **<blind-square-stud-joint>** [D_1 + **< lap-joint>** (E_1 + **<cross-lap-joint>** E_1)] + **<blind-square-stud-joint>** [F_1 + **<lap-joint>** (G_1 + **<cross-lap-joint>** G_1)] + **<blind-square-stud-joint>** [H_1 + **<lap-joint>** (I_1 + **<cross-lap-joint>** I_1) + **<blind-mortise-and-tenon-joint>** K'_1 + **<Wang-Jji-Jja-Im>**K'_1] + **<blind-square-stud-joint>** J_1 + **<blind-mortise-and-tenon-joint>** K_1 + **<Wang-Jji-Jja-Im>**K

1	Gu-Rang-Ii-Jil
2	Top-Plate-Joint
3	Cross-Lap-Joint
4	Blind-Square-Stud-Tenon
5	Lap-Joint
6	Blind-Mortise-and-Tenon
7	Wang-Jji-Jja-Im

Include the type of joinery in number coded, and the formula becomes the following:

A_1 + (1) [B_1 + (2) (C_1 + (3) C_1)] + (4) [D_1 + (5) (E_1 + (3) E_1)] + (4) [F_1 + (5) (G_1 + (3) G_1)] + (4) [H_1 + (5) (I_1 + (3) I_1) + (4) K'_1 + (7) K'_1] + (4) J_1 + (6) K_1 + (7) K_1

9.4 Plan Variation: Circle

The circle is a geometric shape defined by an area of space is enclosed by a curved line and where every point on which is the same distance from the center.[28] A circular plan does not have any straight lines or surface at all. Therefore, the circle itself has totally different characteristics from geometries with straight sides, such as the rectangle and triangle.

[28] Oxford Advanced Learner's Dictionary of Current English

Experimentation with the circular plan was very interesting in a way that some of the members do not intersect with one another like in previous experimentation, and good examples of these members are girder and purlin. From the existing x and y coordinates in the existing plan condition (where x is the length and y is the width), the y coordinate had diminished. This condition results in the interlocking of individual element that may not be required for certain members. Similar to the equilibrium triangular plan, the vertical load is being equally distributed, which means that no differentiation occurs between the cross members. However, to support the sub-purlin (which is offset from purlin), the cantilever arms remained interlocked to one another. In a way, the circular plan is a simpler version of equilibrium triangle. However, when a member is in a curved form, there is a tendency of breakage in a midpoint of this curved element.

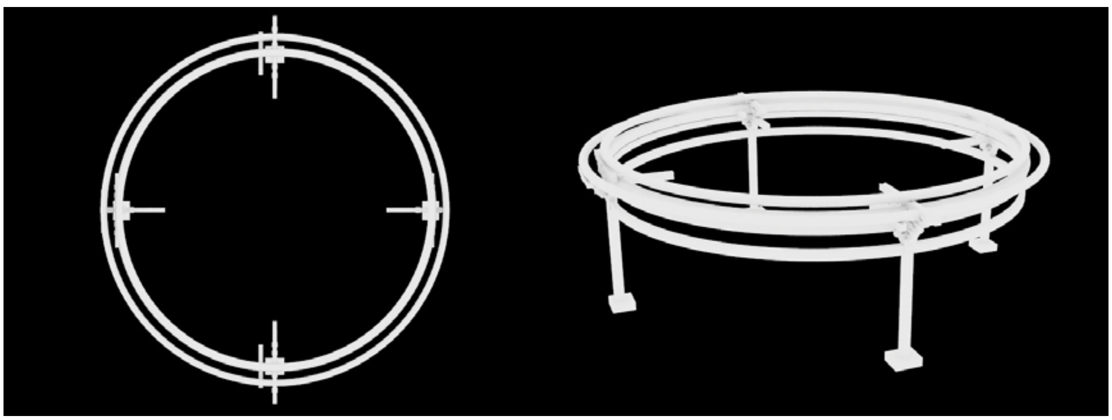


Figure 2. 35 3-D model of plan variation: Circle

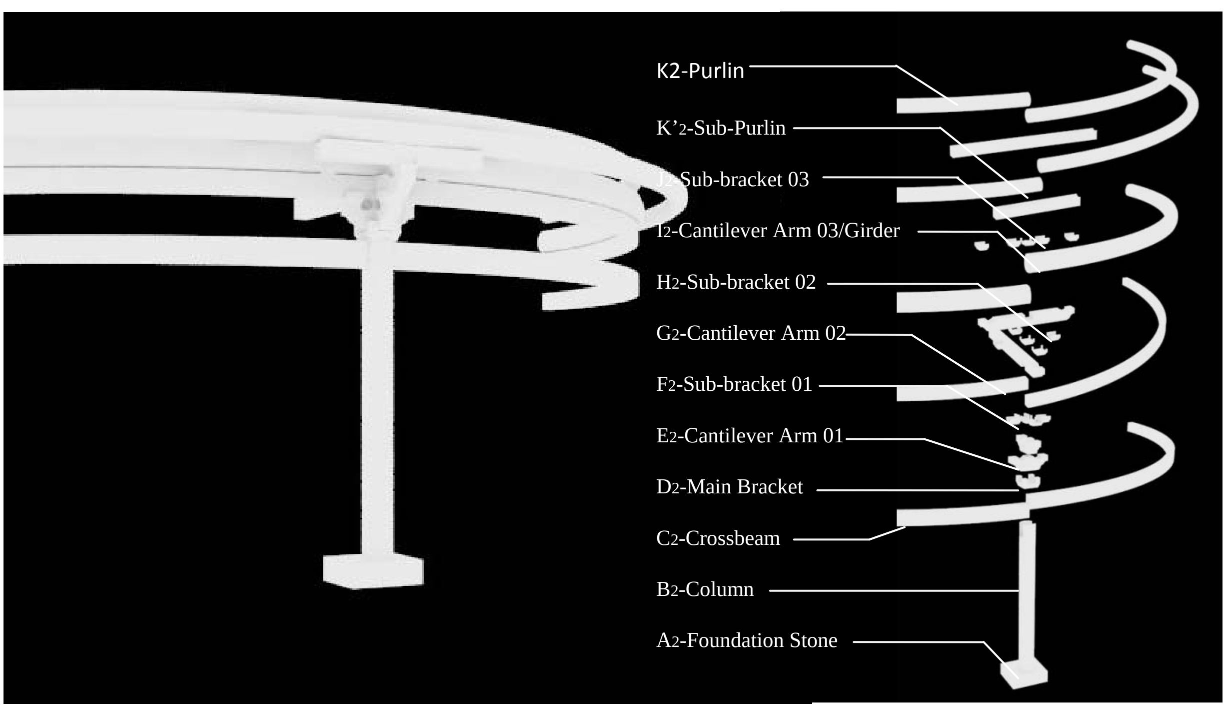


Figure 2. 36 Modified condition of *Ju-Sim-Po* and its composition

Modified composition of bracket system can be written as followed:

$A_2 + [B_2 + (C_2 + C_2)] + [D_2 + (E_2 + E_2)] + [F_2 + (G_2 + G_2 + G_2)] + [H_2 + (I_2 + I_2 + I_2) + K'_2 + K'_2] + J_2 + K_2 + K_2$

Plan changes have affected the composition of the bracket system. The overall composition of modified bracket system is relatively the same in terms of how each member is situated after another. However, the circular plan displayed very different aspects compared to the earlier two experimentations. The most noticeable difference in a circular plan is that there are no corner conditions. Since the sides transformed to a curved form, there is neither a starting point nor an end point in the circular geometry, meaning that the previously interlocking members have changed. Such as crossbeam, girder and purlin members are no longer interlocking with each other, and hence the different joinery method had to be introduced. From the existing cross-lap-joint system, now members face each other. In a way, the circular plan required more modifications than the equilibrium triangular plan. Due to the diminishing of the corner condition, each member in x-direction needs to be connected through the separated joining system (in which these members are considered as one member in the previous plan conditions), and at the same time another crossing member requires either an existing or changed joinery system.

This result was quite promising due to the several conditions listed below:

1. Cross members (girder, purlin and crossbeam) run continuously until meet the second/third column appears.
2. Due to their continuous run, cross members need to be created with more than one member. (From one existing purlin running from the x to the y coordinate, one purlin runs to x, and other purlin runs to x' from the same column head point.)
3. Two members are sharing one column head condition (due to condition 2).

Therefore, due to the changes made in the members of the bracket system, new types of joineries were required. Suggested joineries between these members were the stud-tenon-joint and lap-joint with dowels. Because the two members (crossbeam, girder or purlin) are meeting end to end, joineries needed to connect this end condition.

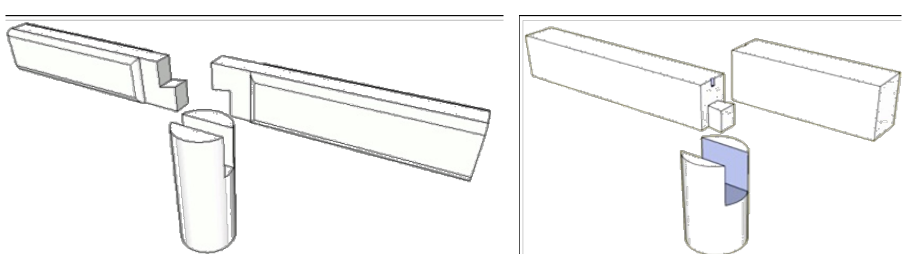


Figure 2. 37 Stud-tenon-joint and Lap-joint

Fig.2.37 exemplifies the modified joineries based on the plan changes made. The structural ability of these connections is not a problem, since these two examples of joineries are already used for the column and bracket system in between the corner conditions on an existing building structure.

$A_2 + [B_2 + (C_2 + C_2)] + [D_2 + (E_2 + E_2)] + [F_2 + (G_2 + G_2 + G_2)] + [H_2 + (I_2 + I_2 + I_2) + K'_2 + K'_2] + J_2 + K_2 + K_2$

With changes made in joinery system, the original formula may be written as the following:

A_2 + **<Gu-Rang-Ii-Jil >** $[B_2$ + **<top-plate-joint>** $(C_2$ + **<stud-tenon-joint/lap-joint>** $C_2)]$ + **<blind-square-stud-joint>** $[D_2$ + **< lap-joint>** $(E_2$ + **<cross-lap-joint>** $E_2)]$ + **<blind-square-stud-joint>** $[F_2$ + **<lap-joint>** $(G_2$ + **<stud-tenon-joint/lap-joint>** G_2 + **<stud-tenon-joint/lap-joint>** $G_2)]$ + **<blind-square-stud-joint>** $[H_2$ + **<lap-joint>** $(I_2$ + **<stud-tenon-joint>** I_2 + **<stud-tenon-joint/lap-joint>** $I_2)$ + **<blind-mortise-and-tenon-joint>** K'_2 + **<Wang-Jji-Jja-Im>** $K'_2]$ + **<blind-square-stud-joint>** J_2 + **<blind-mortise-and-tenon-joint>** K_2 + **<Wang-Jji-Jja-Im>** K_2

1	Gu-Rang-Ii-Jil
2	Top-Plate-Joint
3	Cross-Lap-Joint
4	Blind-Square-Stud-Tenon
5	Lap-Joint
6	Blind-Mortise-and-Tenon
7	Wang-Jji-Jja-Im
8	Stud-Tenon-Joint
9	Lap-Joint

Include the type of joinery in number coded, and the formula becomes the following:

$A_2 + (1)\ [B_2 + (2)\ (C_2 + (8/9)\ C_2)] + (4)\ [D_2 + (5)\ (E_2 + (3)\ E_2)] + (4)\ [F_2 + (5)\ (G_2 + (8/9)\ G_2) + (8/9)\ G_2] + (4)\ [H_2 + (5)\ (I_2 + (8/9)\ I_2 + (8/9)\ I_2) + (4)\ K'_2 + (7)\ K'_2] + (4)\ J_2 + (6)\ K_2 + (7)\ K_2$

The numbers of joineries in the circular plan have increased compared to those in the existing equilibrium triangular plan type. The increase in joinery indicates that the number of bracket members had also increased. These increased numbers of members are due to the diminishing of corner conditions as well as use of existing members in a bracket system. From both plan type analysis, we could conclude that with an experiment with identical members of bracket system, the number of members may increase or decrease. However, due to the increased numbers of members, the structure may become safer in vertical force. If that is the case, when the same amount of force is applied, some of the members in new plan type do not necessarily For example, the girder is no longer called a girder, but rather a purlin instead, because of the function of the girder has shifted from supporting the width to supporting the roof structure. Therefore, a cautious prediction can be made that an increase in the number of joineries can decrease the number of members.

The plan experimentation and analysis in static stress aim to capture the essence of the bracket system and its possible form change through the different geometric constraint. Purely in a geometric modeling sense, each component changes according to how the form changes. The test shows the change of angle in joinery change the plan of the building and vice versa. The following figure illustrates the 3-D model of each component and its changes made through plan variation:

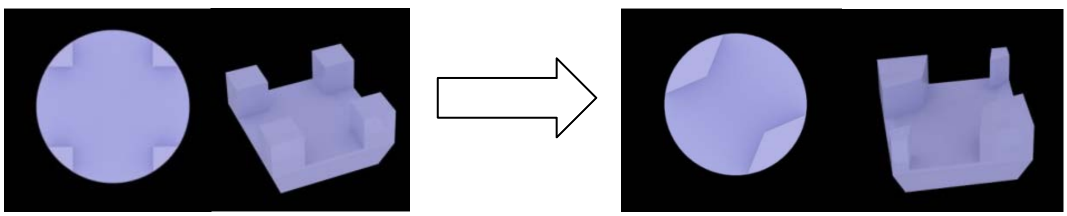


Figure 2. 38 Example: The change in components through the plan variation from rectangular plan to the equilibrium triangular plan

The plan variation experimentation is one of the options in generating changes to the existing components. The initial phase of building a 3-D model was done in the Rhinoceros application. The experimentation well displayed the changes made in existing conditions. However, setting the parameter for much flexible modifications was difficult to achieve in the Rhinoceros application. Therefore, Rhinoceros was used for constructing and simulating different variations of existing structure, but is not focused in parametric changes. Yet, based on the geometric changes, the 3-D model of components could be created in Revit Architecture.

CHAPTER 3

APPLICATION OF DIGITAL CATALOG

11. MORPHOLOGICAL VARIATIONS

The following chapter explains the design process of a prototype structure using digital catalog. Early phase of the chapter will explain the process of constructing components and its modifications through parametric changes. Existing components will be modified based on the design factors of type joinery, use of joinery, location of joinery and assembly of joinery. Each modified components will be categorized into digital catalog. Assembly methods and constraints in each component will be explained to guide the construction process of a prototype structure. The end goal of the chapter is to create various morphological iteration of a prototype structure to display the use of components in its assembly and disassembly.

11.1 Components Generating

The total number of forty four existing components was created from the existing three types of bracket system such as *Ju-Sim-Po*, *Ik-Gong* and *Da-Po*. All the forty four components of the systems become a series of modules in the catalogue for the parametric changes and the rearrangements among the components within Autodesk Revit environment. Since the catalog contains the components created from various joinery conditions, any single module or the combinations of the multiple modules from the catalogue can be employed for easy fabrication, removing, reattaching and acting as a structural element as well as sub-structures after its usage.

Creating components using Revit Architecture

Components can be created in Revit Architecture under the family type (.rft) format. A Revit model is based on a compilation of items called families inside the Revit environment. A system family type and hosted family type files are a separated directory from the Revit (.rvt) file format. System families are inherent to the current model and are not inserted in the traditional sense. Hosted families are the components which can be created by the user of the Revit. One can only modify a system family through its element properties within the model. System families in Revit Architecture are as follows:

Walls
Floors
Roofs
Ceilings
Stairs
Ramps
Shaft
Rooms
Schedule/Quantity takeoffs
Annotation items
Views

Instance parameters are the items that can be immediately edited and shows in model, meaning that these parameters will change only the object being added to the model at the time. Unlike instance parameters, type parameters will alter every item that type in the entire model. The existing components will be divided into 3 groups: group J for *Ju-Sim-Po,* group I for *Ik-Gong* and group D for *Da-Po* styles. The constraints in the parametric modeling are the dimensional, geometric al and assembly constraints. Dimensional constraints are the constraints in distance, length, angle and radius/diameter. A constraint in distance is the parametric control in distance between the components (or members within the components such as lines). A constraint in Length is the parametric control in length of a component. A constraint in angle is the parametric control in an angle between the components. A constraint in Radius/Diameter is the parametric control in radius/diameter of a circle.

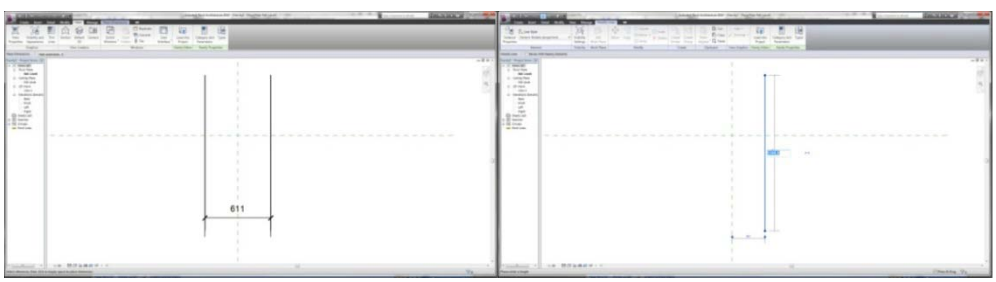


Figure 3. 1 Dimensional constraints in Revit environment
(Example of parametric control in distance (left) and length (right))

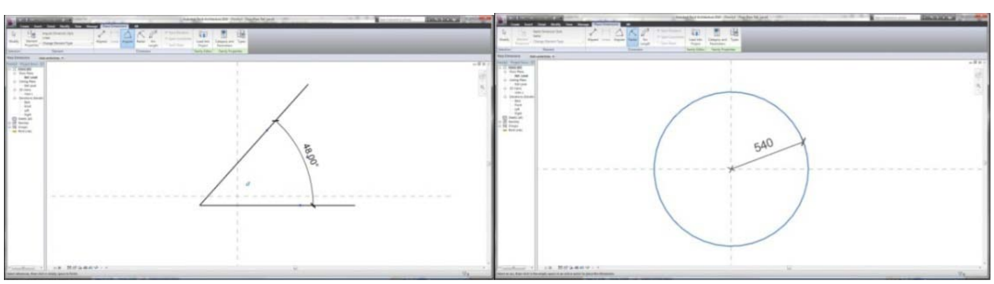


Figure 3. 2 Dimensional constraints in Revit environment
(Example of parametric control in angle (left) and radius/diameter (right))

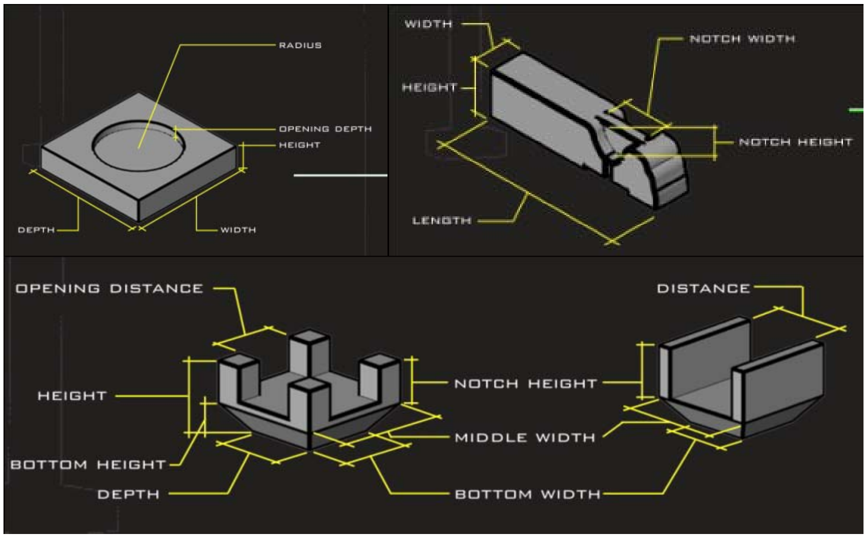


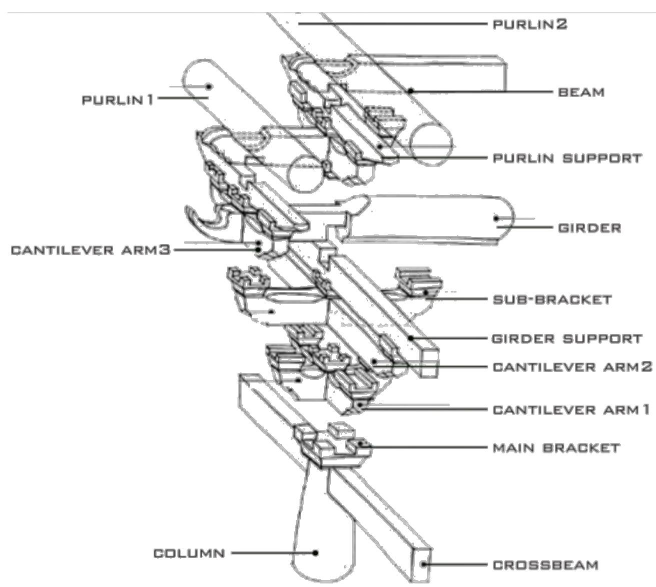
Figure 3. 3 Example: Dimensional constraints on existing components

Figure 3.3 shows the components in J group (*Ju-Sim-Po*) generated in Revit environment with the parametric constraints in dimensional, length, angle and radius/diameter. Most common type of joinery used in *Ju-Sim-Po* bracket system is lap joint (*Teok-Jja-Im*). Figure 3.4, a chart illustrates the component condition of each in *Ju-Sim-Po* bracket system according to type, use, location, and jangbu pierce.

GROUP-J: *Ju-Sim-Po* Style

Based on the constructed 3-D bracket system model of *Ju-Sim-Po* style, existing condition of the components and joinery types were generated in Revit Architecture. Total number of 15 components was created from the *Ju-Sim-Po* style bracket system. Each component was grouped under **J** (*Ju-Sim-Po*). Following is the list of components:

1. J_01 (Foundation stone circular)
2. J_02 (Foundation stone rectangular)
3. J_03 (Column circular)
4. J_04 (Column rectangular)
5. J_05 (Crossbeam)
6. J_06 (Main bracket)
7. J_07 (Cantilever arm)
8. J_08 (Sub bracket)
9. J_09 (Cantilever arm2)
10. J_10 (Sub bracket)
11. J_11 (Girder support)
12. J_12 (Girder)
13. J_13 (Cantilever arm3)
14. J_14 (Purlin support)
15. J_15 (Purlin)



Component name	Connecting member(s)	Type of joinery	Use of setting-up	Location of setting up	Jangbu pierce
J_01	J_03 & J_04	Simple scarf	Rectangular lumber + board	End of lumber + End of lumber	
J_02	J_03 & J_04	Simple scarf	Rectangular lumber + board	End of lumber + End of lumber	
J_03	J_05	Sagwe choke joinery	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	
J_04	J_05	Sagwe choke joinery	Rectangular lumber+ Rectangular lumber	End of lumber + Inside of lumber	
J_05	J_06	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
J_06	J_07 & J_08	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
J_07	J_08	Hidden jangbu (dowel)	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	O
J_08	J_09	T_shape half lap joint	Rectangular lumber + Rectangular lumber	inside of lumber + Inside of lumber	
J_09	J_10 & J_11	Hidden jangbu (dowel) & Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	O
J_10	J_11	T_shape half lap joint	Rectangular lumber + Rectangular lumber	End of lumber + End of lumber	
J_11	J_12	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	O
J_12	J_14	Half lap joint	Rectangular lumber + Rectangular lumber	End of lumber + End of lumber	
J_13	J_14	Half lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
J_14	J_15	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	O
J_15	J_14	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	Inside od lumber + Inside of lumber	O

Figure 3. 4 Categorization of joineries in *Ju-Sim-Po* bracket style according to use, location and jangbu pierce

Most of the components were joined between solid rectangular lumber to another solid rectangular lumber with the exception of component J_01 and J_02. Component J_01 is a board member typically for the foundation of the structure. Rectangular lumber to rectangular lumber are fairly commonly used in lap joints and tenon joints. Due to the structural composition of bracket system, most joinery is connected through lap joints, interlock each other. Special type of joinery you find in *Ju-Sim-Po* bracket system is in component J_03 & J_04. *Sagwe choke* joint shown in component J_03 and J_04 is where 4 points in a member creates a cross-cut space to connect the cross lap joint members.

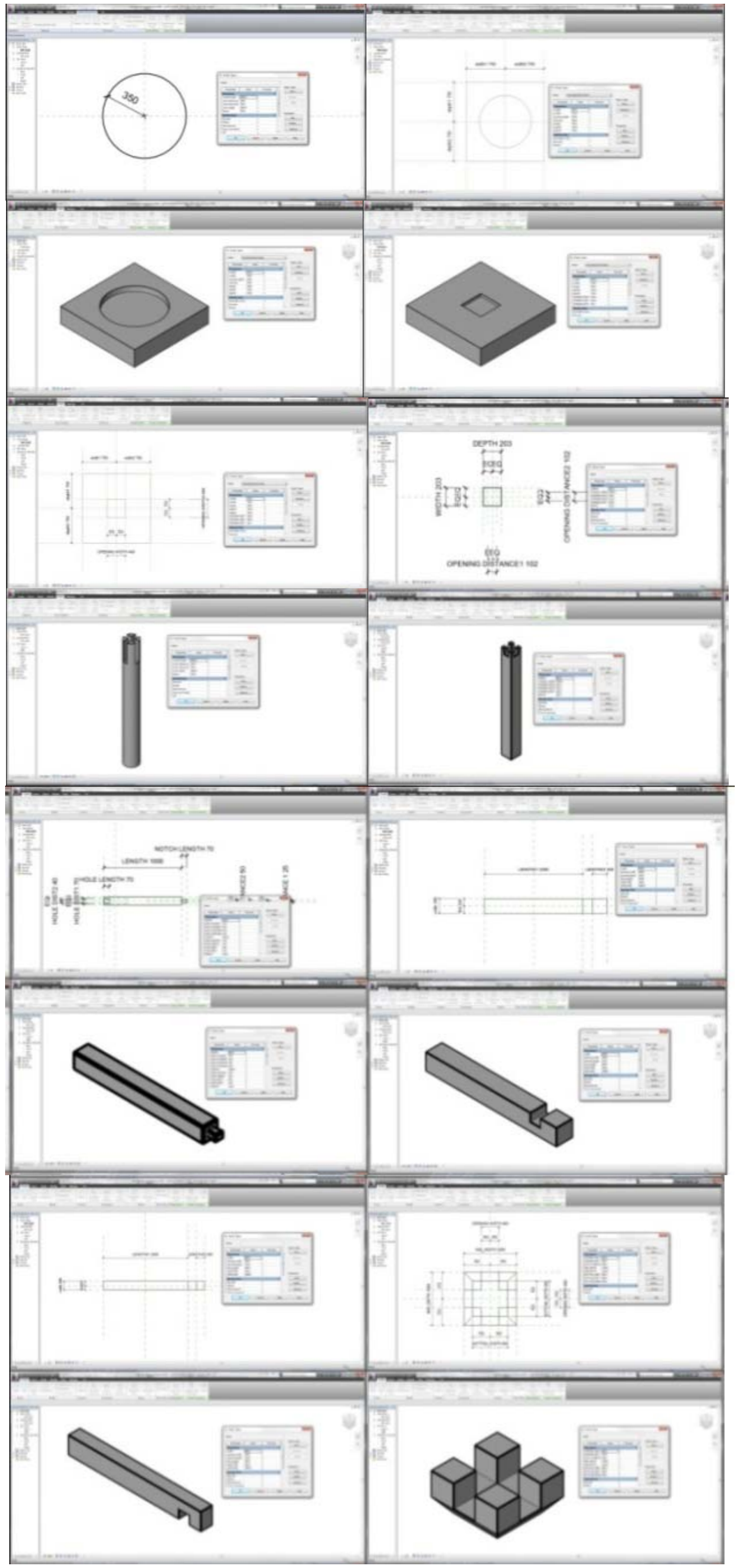


Figure 3. 5 Existing Component J (J_01 ~ J_06): Parametric constraints and 3-D modeling in Revit

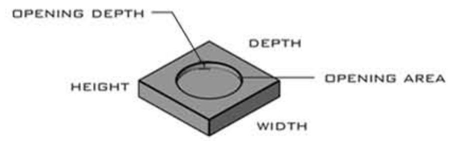
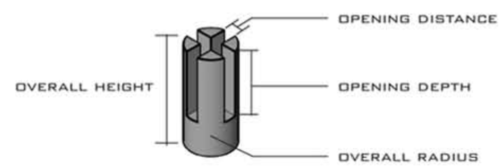
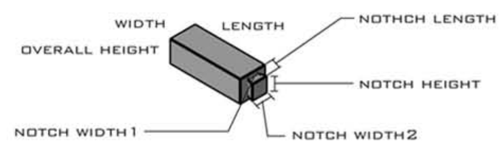
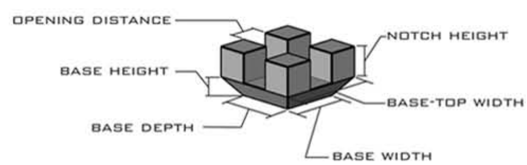
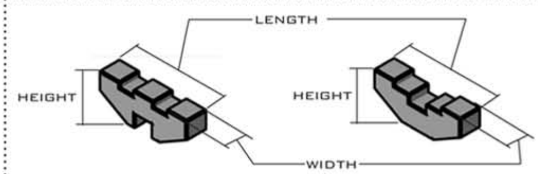
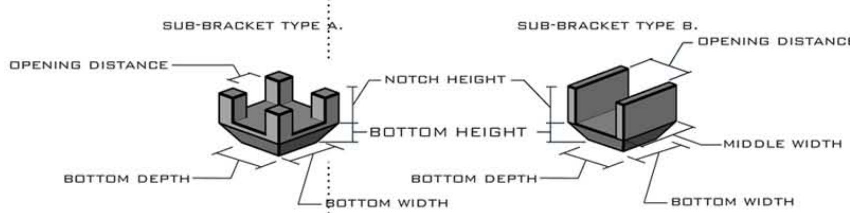
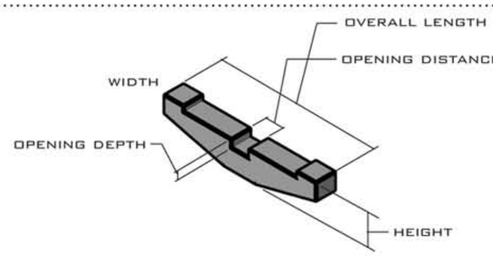
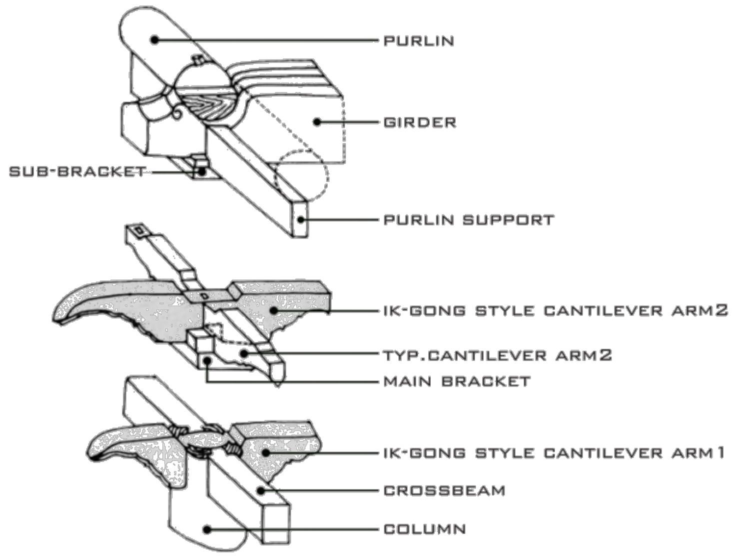
NAME	PARAMETERS	IMAGE
J-01	.WIDTH .DEPTH .HEIGHT .OPENING RADIUS FOR COLUMN .OPENING DEPTH	
J-02	.HEIGHT .RADIUS .OPENING DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2	
J-03	.WIDTH .LENGTH .HEIGHT .NOTCH WIDTH1 .NOTCH WIDTH2 .NOTCH HEIGHT .NOTCH LENGTH	
J-04	.BASE WIDTH .BASE DEPTH .BASE HEIGHT .BASE-TOP WIDTH .BASE-TOP DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2 .NOTCH HEIGHT (OPENING DEPTH)	
J-05	.WIDTH .LENGTH .HEIGHT .REST DISTANCE1 .REST DISTANCE2 .OPENING DEPTH .OPENING DISTANCE	
J-06	.WIDTH .DEPTH .HEIGHT .OPENING RADIUS FOR COLUMN .OPENING DEPTH	
J-07	.WIDTH .LENGTH .HEIGHT .OPENING DISTANCE .OPENING DEPTH	

Figure 3. 6 Existing Component J: Description of the parameters

GROUP-I: *IK-GONG* STYLE

Following is the list of existing components in *Ik-Gong* style bracket system under group I:

1. I_01 (Foundation stone circular)
2. I_02 (Foundation stone rectangular)
3. I_03 (Column circular)
4. I_04 (Column rectangular)
5. I_05 (Crossbeam)
6. I_06 (Ik-Gong1)
7. I_07 (Main bracket)
8. I_08 (Ik-Gong2)
9. I_09 (Cantilever arm)
10. I_10 (Sub bracket)
11. I_11 (Girder)
12. I_12 (Purlin support)
13. I_13 (Purlin)



By applying the same logic and parameters as group J (*Ju-Sim-Po)*, each component was generated in Revit Architecture (Fig. 3.9).

Ik-Gong style is the simplified version of *Ju-Sim-Po*, where the *Ik-Gong* members replaced the cantilever arms. Reducing the number of components resulted in less number of components with simple assembly. The most common type of joinery used in *Ik-Gong* bracket system is lap joint (*Teok-Jja-Im*). Figure 3.7 describes the condition of each component in *Ik-Gong* bracket system. The *Ik-Gong* members have a very unique form. However, the cultural meanings and metaphors in the form making of *Ik-Gong* members *were* not emphasized in this paper. Therefore, *Ik-Gong* components were simplified in the digital catalog. Also the *Ik-Gong* style shared identical members from the *Ju-Sim-Po* style. The only exception is the absence of cantilever arm with the replacement of *Ik-Gong* components.

Component name	Connecting member(s)	Type of joinery	Use of setting-up	Location of setting up	Jangbu pierce
I_01	I_03 & I_04	Simple scarf	Rectangular lumber + board	End of lumber +	
				End of lumber	
I_02	I_03 & I_04	Simple scarf	Rectangular lumber + board	End of lumber +	
				End of lumber	
I_03	I_05 & I_06	Sagwe choke joinery	Rectangular lumber +	End of lumber +	
			Rectangular lumber	Inside of lumber	
I_04	I_05 & I_06	Sagwe choke joinery	Rectangular lumber+	End of lumber +	
			Rectangular lumber	Inside of lumber	
I_05	I_03 & I_04	Cross lap joint	Rectangular lumber +	Inside of lumber +	
			Rectangular lumber	Inside of lumber	
I_06	J_07	Cross lap joint	Rectangular lumber +	Inside of lumber +	
			Rectangular lumber	Inside of lumber	
I_07	I_08 & I_09	Cross lap joint	Rectangular lumber +	Inside of lumber +	O
			Rectangular lumber	Inside of lumber	
I_08	I_09	Half lap joint	Rectangular lumber +	Inside of lumber +	
			Rectangular lumber	Inside of lumber	
I_09	I_10 & I_11	Half lap joint	Rectangular lumber +	Inside of lumber +	O
			Rectangular lumber	Inside of lumber	
I_10	I_09	Half lap joint	Rectangular lumber +	End of lumber +	
			Rectangular lumber	Inside of lumber	
I_11	I_09 & I_12	Cross lap joint & Half lap joint	Rectangular lumber +	End of lumber +	O
			Rectangular lumber	Inside of lumber	
I_12	I_11 & I_13	Half lap joint & True mortise and tenon	Rectangular lumber +	Inside of lumber +	
			Rectangular lumber	Inside of lumber	
I_13	I_12	True mortise and tenon	Rectangular lumber +	Inside of lumber +	
			Rectangular lumber	Inside of lumber	

Figure 3. 7 Categorization of joineries in *Ik-Gong* bracket style according to use, location and jangbu pierce

As Fig.3.7 shows, most of the members are rather solid rectangular lumber to solid rectangular lumber except component I_01 and I_02. Rectangular lumber to rectangular lumber uses are fairly common in lap joints and tenon joints. Due to the structure of bracket system, most joinery is lap joints interlock to each other. Special type of joinery you find in *Ik-Gong* bracket system is in component I_03 & I_04. Sagwe choke joint is where 4 points in a member creates a cross-cut space to connect the cross lap joint members.

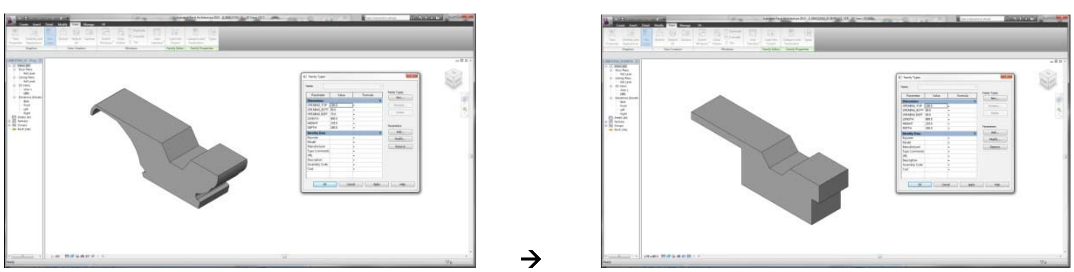


Figure 3. 8 Simplification of *Ik-Gong* member

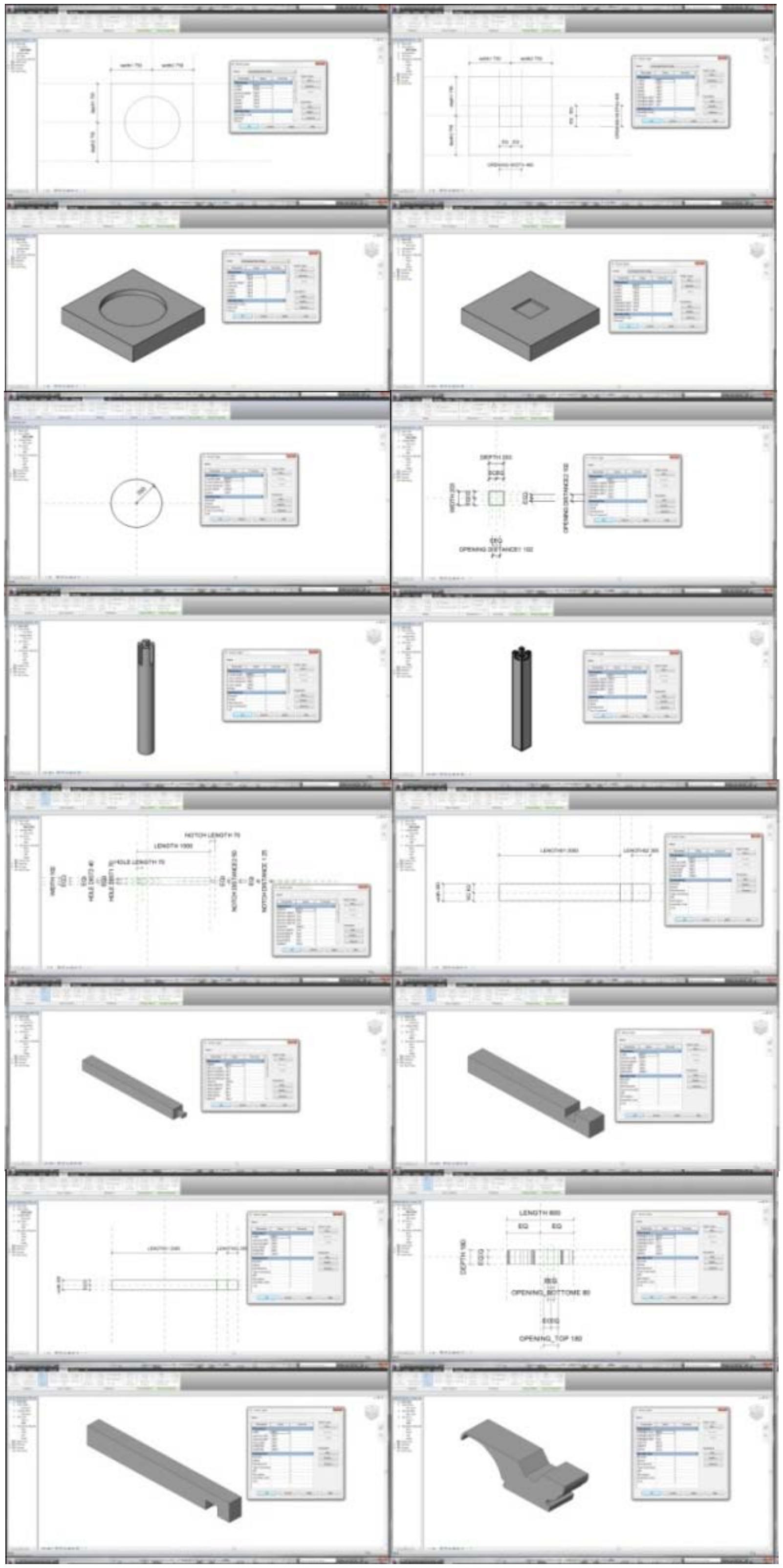


Figure 3. 9 Existing Component I (I_01 ~ I_8): Parametric construction and 3-D modeling

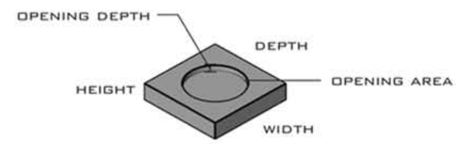
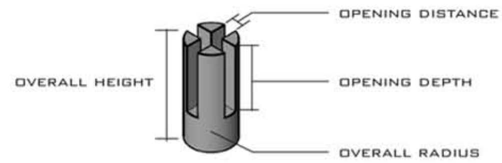
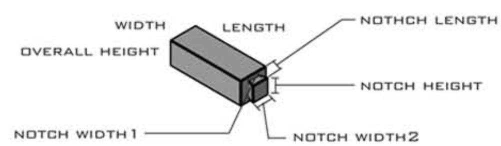
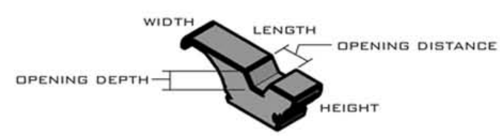
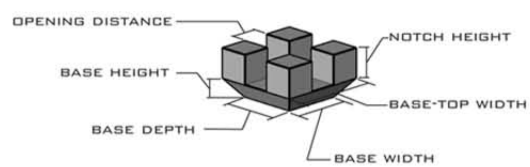
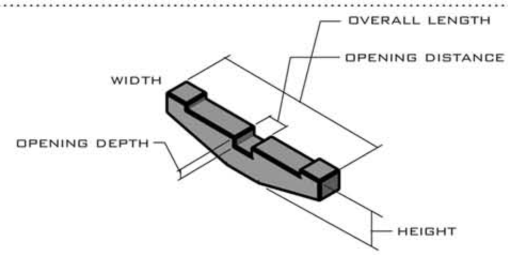
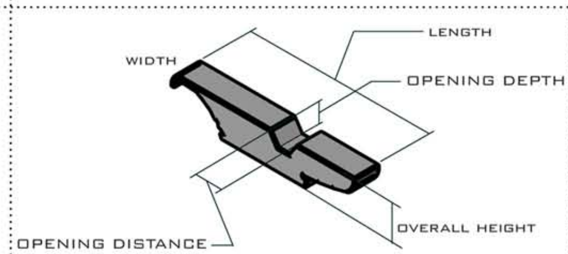
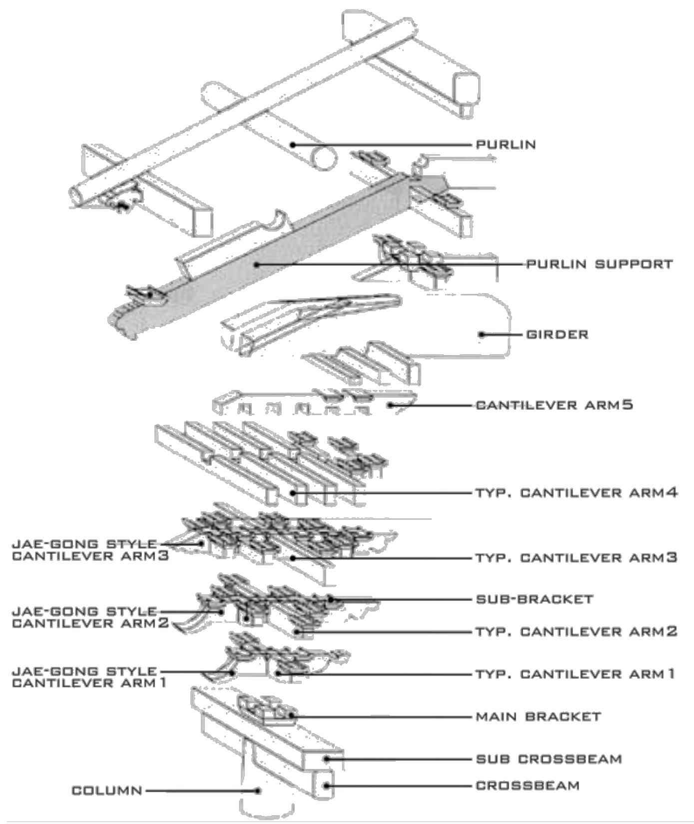
NAME	PARAMETERS	IMAGE
I-01	.WIDTH .DEPTH .HEIGHT .OPENING RADIUS FOR COLUMN .OPENING DEPTH	
I-02	.HEIGHT .RADIUS .OPENING DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2	
I-03	.WIDTH .LENGTH .HEIGHT .NOTCH WIDTH1 .NOTCH WIDTH2 .NOTCH HEIGHT .NOTCH LENGTH	
I-04	.WIDTH .LENGTH .HEIGHT .OPENING DISTANCE .OPENING DEPTH	
I-05	.BASE WIDTH .BASE DEPTH .BASE HEIGHT .BASE-TOP WIDTH .BASE-TOP DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2 .NOTCH HEIGHT (OPENING DEPTH)	
I-06	.WIDTH .LENGTH .HEIGHT .OPENING DISTANCE .OPENING DEPTH	
I-07	.WIDTH .LENGTH .HEIGHT .OPENING DISTANCE .OPENING DEPTH	

Figure 3. 10 Existing Component I: Component description

Group-D: *Da-Po* Style

The following is the list of components in the *Da-Po* style under group D:

1. D_01 (Foundation stone circular)
2. D_02 (Foundation stone rectangular)
3. D_03 (Column circular)
4. D_04 (Column rectangular)
5. D_05 (Crossbeam)
6. D_06 (Sub-crossbeam)
7. D_07 (Main bracket)
8. D_08 (Cantilever arm1)
9. D_09 (Jae-Gong1)
10. D_10 (Sub-bracket)
11. D_11 (Jae-Gong2)
12. D_12 (Cantilever arm2)
13. D_13 (Cantilever arm3)
14. D_14 (Cantilever arm4)
15. D_15 (Jae-Gong3)
16. D_16 (Cantilever arm5)
17. D_17 (Girder)
18. D_18 (Purlin support)
19. D_19 (Purlin)



By applying the same logic and parameters, each component was generated in Revit Architecture (Fig. 3.12). *Da-Po* style is unique in component assembly. The numbers of *Jae-Gong* components behave similar to previous cantilever arms. Through the joineries of *Jae-Gong* components, *Da-Po* system required extra number of components. Increased number of components resulted in high ceiling structure. The most common type of joinery used in *Da-Po* bracket system is lap joint (*Teok-Jja-Im*). Figure 3.11 describes the condition of each component in *Da-Po* bracket system.

Component name	Connecting member(s)	Type of joinery	Use of setting-up	Location of setting up	Jangbu pierce
D_01	D_03 & D_04	Simple scarf	Rectangular lumber + board	End of lumber + End of lumber	
D_02	D_03 & D_04	Simple scarf	Rectangular lumber + board	End of lumber + End of lumber	
D_03	D_05 & D_06	Sagwe choke joinery	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	
D_04	D_05 & D_06	Sagwe choke joinery	Rectangular lumber+ Rectangular lumber	End of lumber + Inside of lumber	
D_05	D_07	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
D_06	D_03 & D_04	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
D_07	D_08 & D_09	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
D_08	D_09 & D_10	T_shape half lap joint & Hidden jangbu	Rectangular lumber + Rectangular lumber	inside of lumber + Inside of lumber	O
D_09	D_08 & D_10	Hidden jangbu (dowel) & Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	O
D_10	D_11	T_shape half lap joint	Rectangular lumber + Rectangular lumber	End of lumber + End of lumber	
D_11	D_12, D_13 & D_14	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	O
D_12	D_11	Half lap joint	Rectangular lumber + Rectangular lumber	End of lumber + End of lumber	
D_13	D_11	Half lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
D_14	D_11 & D_15	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside of lumber + Inside of lumber	
D_15	D_14 & D_16	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside od lumber + Inside of lumber	
D_16	D_17	Cross lap joint	Rectangular lumber + Rectangular lumber	Inside od lumber + Inside of lumber	
D_17	D_18	Half lap joint	Rectangular lumber + Rectangular lumber	Inside od lumber + Inside of lumber	
D_18	D_19	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	O
D_19	D_18	Hidden jangbu (true mortise & tenon)	Rectangular lumber + Rectangular lumber	End of lumber + Inside of lumber	O

Figure 3. 11 Categorization of joineries in *Da-Po* bracket style according to use, location and jangbu pierce

As Fig.3.11 shows, most of the members are rather solid rectangular lumber to solid rectangular lumber except component D_01 and D_02. Rectangular lumber to rectangular lumber uses are fairly common in lap joints and tenon joints. Due to the structure of bracket system, most joinery is lap joints interlock to each other. Special type of joinery you find in Da-Po bracket system is in component D_03 & D_04. Sagwe choke joint is where 4 points in a member creates a cross-cut space to connect the cross lap joint members.

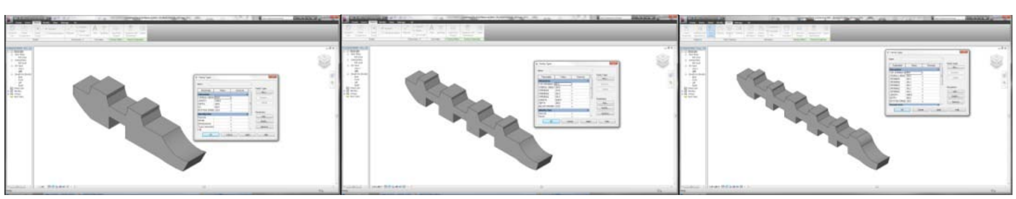


Figure 3. 12 *Jae-Gong* components in group D (*Da-Po*)

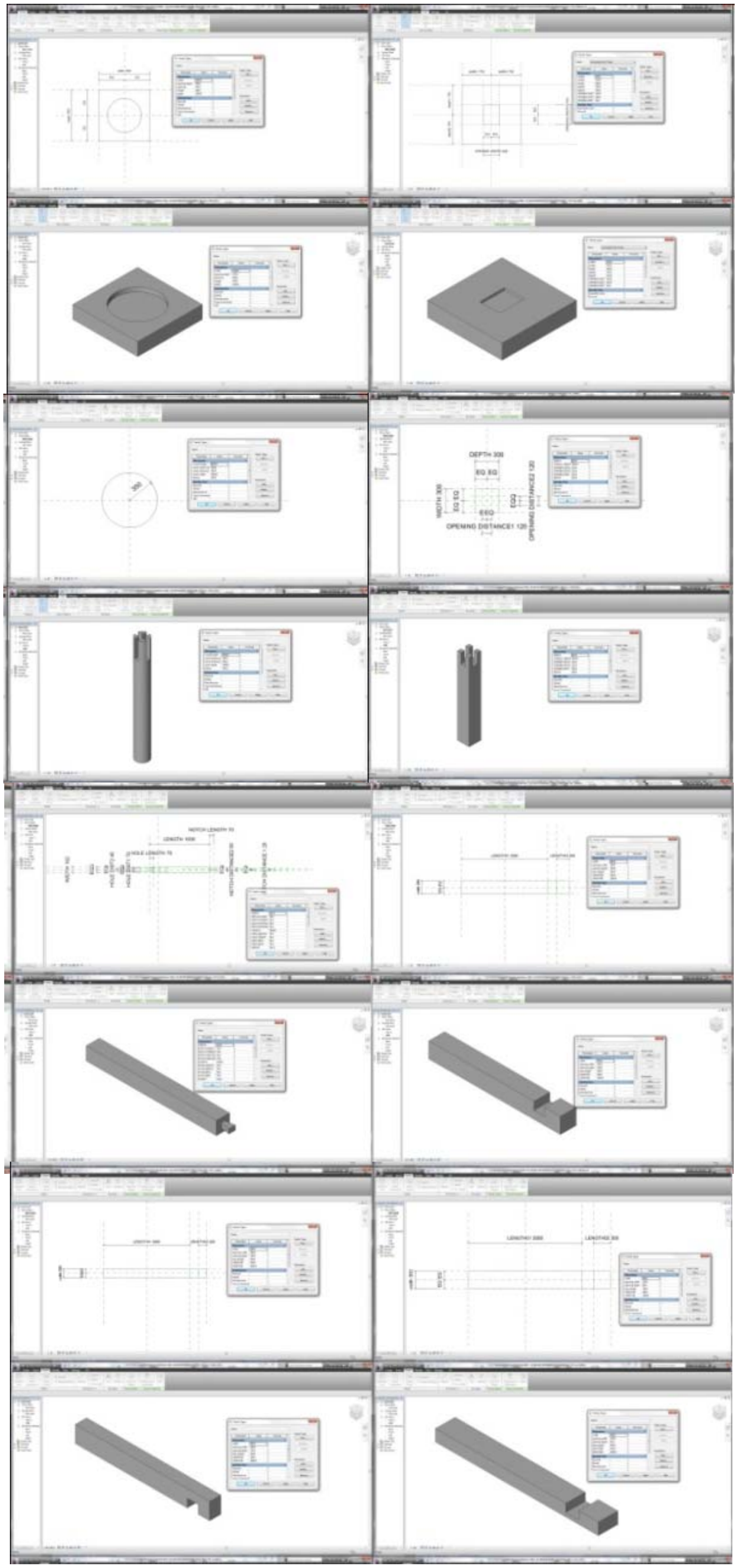


Figure 3. 13 Existing Component D (D_01 ~ D_08): Parametric construction and 3-D modeling

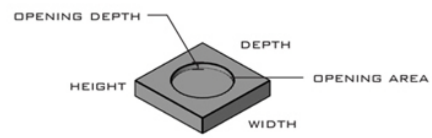
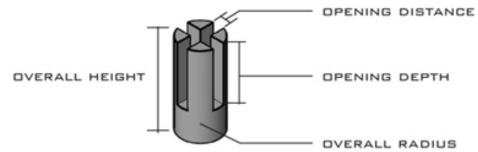
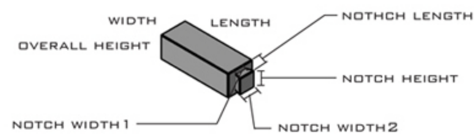
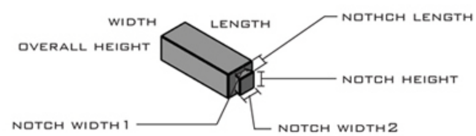
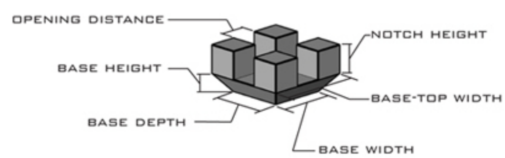
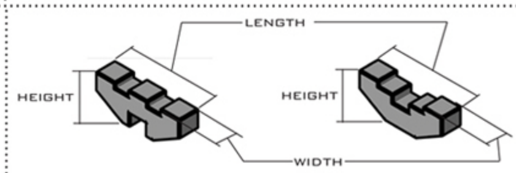
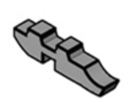
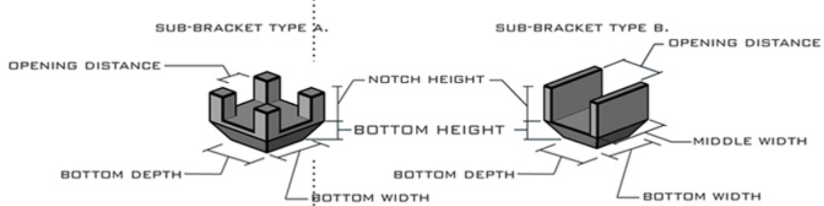
NAME	PARAMETERS	IMAGE
D-01	.WIDTH .DEPTH .HEIGHT .OPENING RADIUS FOR COLUMN .OPENING DEPTH	
D-02	.HEIGHT .RADIUS .OPENING DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2	
D-03	.WIDTH .LENGTH .HEIGHT .NOTCH WIDTH1 .NOTCH WIDTH2 .NOTCH HEIGHT .NOTCH LENGTH	
D-04	.WIDTH .LENGTH .HEIGHT .NOTCH WIDTH1 .NOTCH WIDTH2 .NOTCH HEIGHT .NOTCH LENGTH	
D-05	.BASE WIDTH .BASE DEPTH .BASE HEIGHT .BASE-TOP WIDTH .BASE-TOP DEPTH .OPENING DISTANCE1 .OPENING DISTANCE2 .NOTCH HEIGHT (OPENING DEPTH)	
D-06	.WIDTH .LENGTH .HEIGHT .REST DISTANCE1 .REST DISTANCE2 .OPENING DEPTH .OPENING DISTANCE	
D-07	.WIDTH .LENGTH .HEIGHT .REST DISTANCE1 .REST DISTANCE2 .OPENING DEPTH .OPENING DISTANCE	
D-08	.WIDTH .DEPTH .HEIGHT .OPENING RADIUS FOR COLUMN .OPENING DEPTH	

Figure 3. 14 Existing Component D (D_01 ~ D_08): Component description

11.2 Digitalization and Parametric Modifications

This section demonstrates the modification of the original components to new components using parametric changes and the cross referencing the 4 design factors (*joinery type, use of joinery,* and *location of joinery* and *jangbu piercing of components)*. Four design factors are as followed:

1. Joinery type
2. Use of joinery (rectangular lumber + rectangular lumber, rectangular lumber + board and board + board)
3. Location of joinery (inside of lumber + end of lumber, end of lumber + end of lumber and inside of lumber + inside of lumber)
4. Jangbu piercing

By adding the value of different joinery type, use, location of joinery and jangbu piercing, existing components will change its form and dimension through parametric modifications. Component I_01 and I_03 were used for testing the parametric changes to achieve various use and location of joinery.

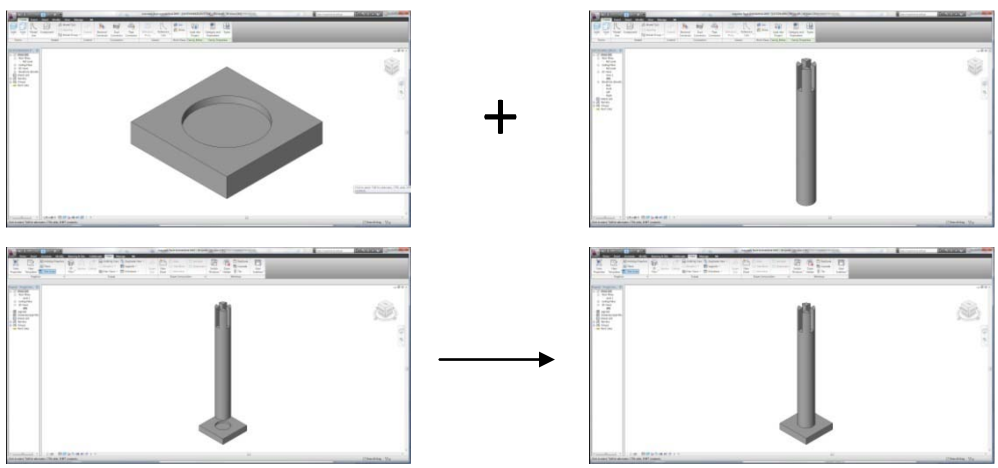
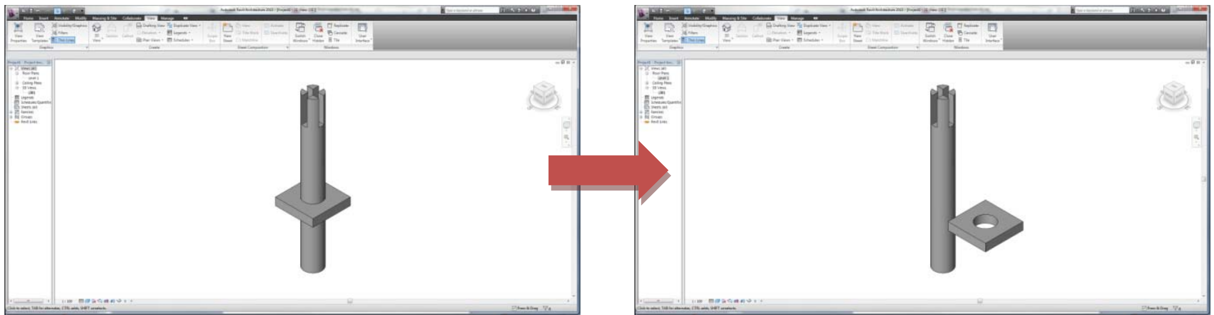


Figure 3. 15 Assembly of I_01 and I_03 through simple scarf joinery
(Use: rectangular lumber + board, Location: end of board + end of lumber, jangbu pierce: none)

The existing condition of component I_01 + I_03 depicted in traditional *Ik-Gong* bracket system uses simple scarf joint. The joinery is being used between Rectangular lumber + Board, Location of joinery is in the End of lumber + End of lumber and jangbu piercing is not present. However, by changing each factor, existing components can be modified its dimension and form. For example, the type of joinery can be change to mortise and tenon joint, where the use of joinery and location of joinery also changes due to the basic rule of mortise and tenon joint. Figure 3.16

shows the change in type joinery can be applied to change the use, location and jangbu pierce of the joinery that changes the form of the existing components.



Changes in type of joinery to mortise and tenon

Component I_01 require changes in its depth of the opening

Figure 3. 16 Component I_01: Demonstration in change of joinery type in Use, Location and Jangbu pierce lead to change in form

Changes made in existing components in figure 3.16 are as follow:

1. Type of joinery (simple scarf joint ⟶ mortise and tenon joint)
2. Use of joinery (rectangular lumber + board ⟶ rectangular lumber + rectangular lumber)
3. Location of joinery (end of lumber + end of lumber ⟶ inside of lumber + inside of lumber)
4. Jangbu pierce (none ⟶ present)

Therefore, by adding and subtracting the 4 design factors, each component is flexible in change in form and dimension.

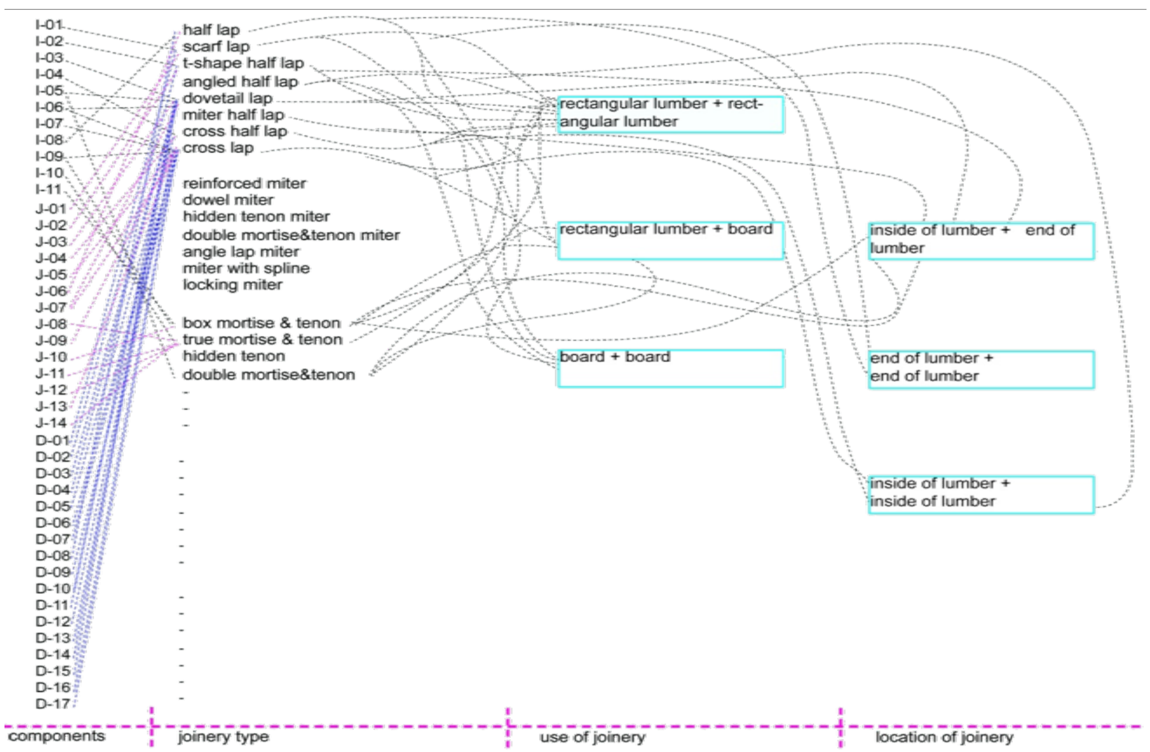


Figure 3. 17 Existing component analysis using four design factors: type of joinery, use, location and pierce

Figure 3.17 is the diagram showing the four design factors of the existing components. Each component showing on the left column is categorized according to its joinery type, use and location of the joinery.

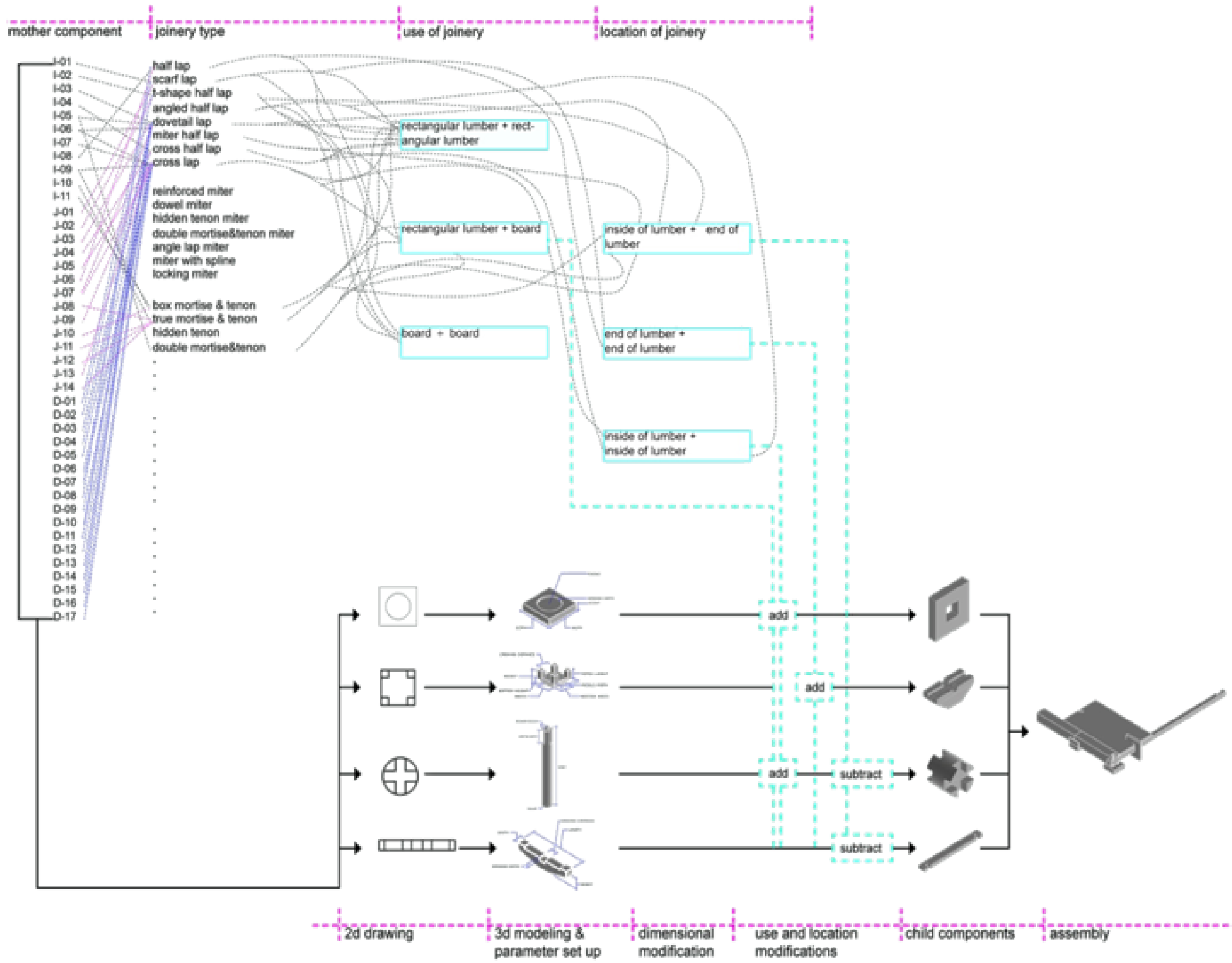


Figure 3. 18 Modification process through adding and subtracting four factors: Joinery type, use, location and pierce

By adding the value of different joinery type, use, location of joinery and piercing of the component, existing components change in form and dimension through parametric modifications. According to user's preference, the component parameter can be substituted to change the form and its relationship to the assembly units. Figure 3.18 is showing the change of four design factors according to the user preference. Each component can be changed according to users' desire through adding or subtracting the four design factors.

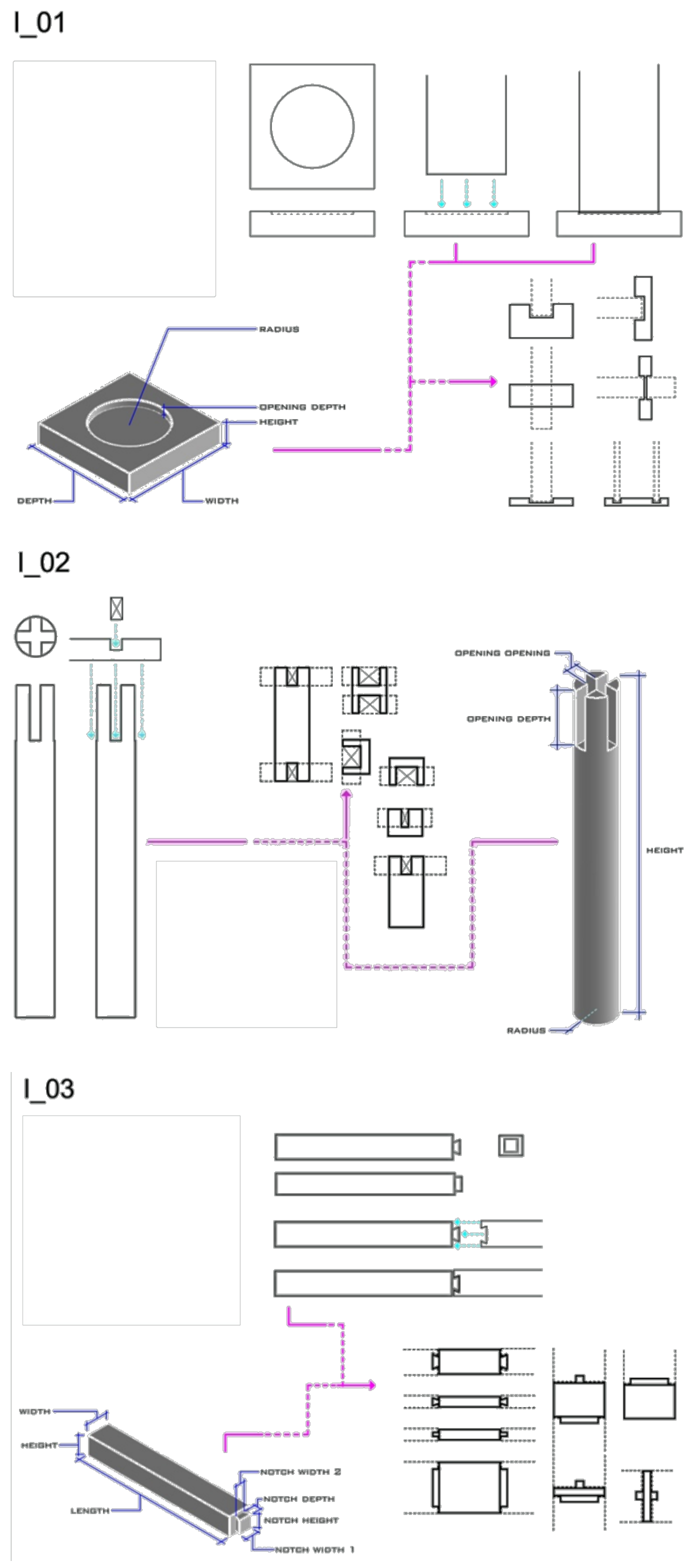
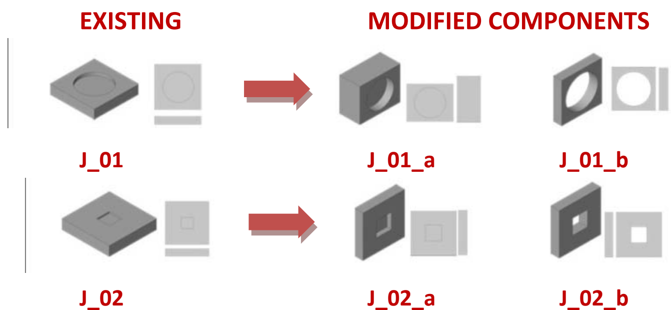


Figure 3. 19 Modification of existing component group I: Using parametric constraints

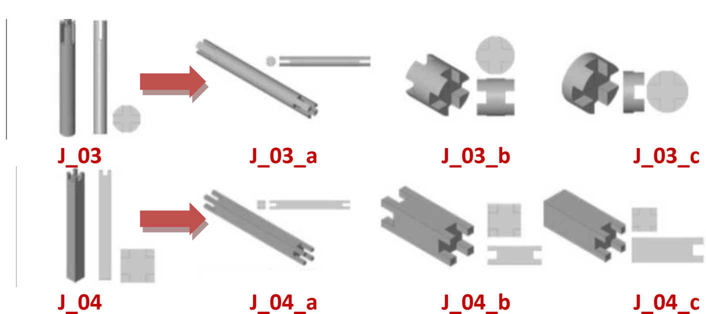
Group J

Followings are the modifications of the existing components in group J with the changes in four design factors. Components are grouped according to their function shown in existing condition of bracket system. There are total numbers of 15 existing and 45 modified components in group J.



1. Type of joinery: simple scarf joint → simple scarf (J_01_a & J_02_a) and mortise and tenon joint (J_01_b & J_02_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (J_01_a, J_01_b, J_02_a and J_02_b)
3. Location of joinery: end of lumber + end of lumber → end of lumber + end of lumber (J_01_a & J_02_a) and inside of lumber + inside of lumber (J_01_b & J_02_b)
4. Jangbu pierce: none → none (J_01_a & J_02_a) and present (J_01_b & J_02_b)

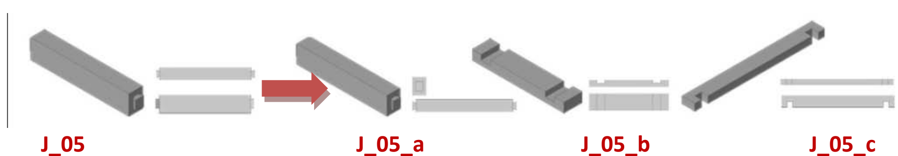
Original function of J_01 and J_02 is foundation stone using simple scarf joinery. J_01_a and J_02_a use same type of joinery, use, location and jangbu pierce in vertical direction. However, the function no longer supports compression force. J_01_b and J_02_b however became more of an inner member due to the change in jangbu pierce. Two modified components have mortise and tenon joints which required the joinery to occur at location of inner member to inner member although these two components do not have a structural ability to support the compression load as existing J_01 and J_02.



1. Type of joinery: Sagwe choke joint → Sagwe choke joint (all 6 modified components)

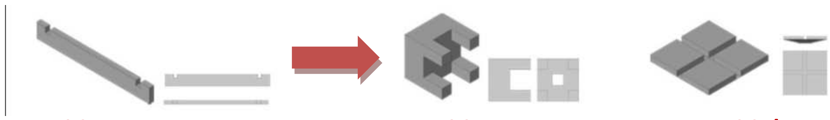
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (all 6 modified components
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none (all 6 modified components)

Original function of J_03 and J_04 is a structural column with Sagwe choke joinery (fig. 2.12). All 6 modified versions of J_03 and J_04 use same type of joinery, use, location and jangbu pierce in horizontal distance. Through the angular changes in parametric constraints, each component is now acts as horizontal member rather than vertical element. However, Sagwe choke joint is now located at each ends of the lumber makes two point connection. Members of J_03_a and J_04_a to J_03_c and J_04_c decreased in their length and width through changes in dimensional constraints. Also the function no longer supports compression force down to J_01 and J_02. Each individual are not connected to J_01 directly in modified components. Modified members are now become like a connector especially in case of last four components (J_03_b, J_03_c, J_04_b and J_04_c). Therefore, longer members J_03_a and J_04_a can now become a horizontal members (such as beams and girder) while J_03_b, J_03_c, J_04_b and J_04_c act as a connector between 2 other cross joint members.



1. Type of joinery: Mortise and tenon joint → Mortise and tenon (J_05_a), Half lap joint (J_05_b) and half mortise and tenon (J_05_c)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (J_05_a, J_05_b and J_05_c)
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none

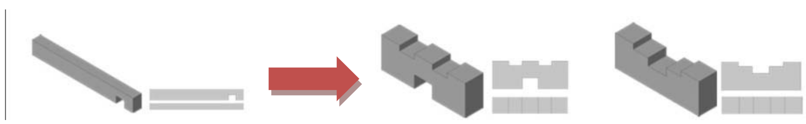
Original function of J_05 is a crossbeam member which connects free standing columns together. Typically J_05 component is connected edge to edge of rectangular lumbers. The modified components are through 1.dimensional and 2.assembly. J_05_a is simply change in dimension to become more micro components. J_05_b and J_05_c components are modified to become an interlocking member (or to become a connector rather than connecting member) to lock two members into a place.



J_06 J_06_a J_06_b

1. Type of joinery: Half lap joint → Sagwe choke joint (J_06_a) and Half Sagwe choke joint (J_06_b)
2. Use of joinery: board + board → rectangular lumber + rectangular lumber (J_06_a) and board + board (J_06_b)
3. Location of joinery: end of lumber + end of lumber → inner lumber + end of lumber (opt.) and end of lumber + end of lumber (opt.)
4. Jangbu pierce: none → none

Existing component J_06 is a crossbeam type B, which acts very similar to component J_05. The difference between J_05 is the type of joinery used and its location. This is due to the various types of column connections. Sagwe joint is most known joinery for column head condition; however those joints are mainly for the corner columns and for those in the middle columns will have different connections. Although the study only focused on corner conditions of the bracket system, various types of crossbeams were articulated. Component J_06 is one of those various conditions of crossbeam with half-lap joints.

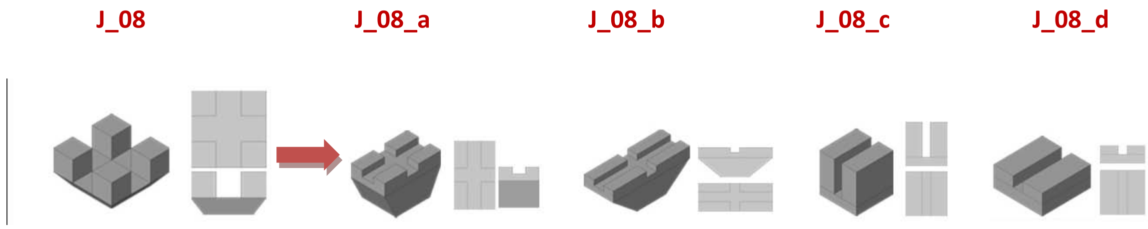


J_07 J_07_a J_07_b

1. Type of joinery: Half lap joint → three half lap joints (J_07_a) and Half lap joint (J_06_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (J_07_a and J_07_b)
3. Location of joinery: end of lumber + end of lumber → inner lumber + end of lumber (opt.) and end of lumber + end of lumber (opt.)
4. Jangbu pierce: none → none

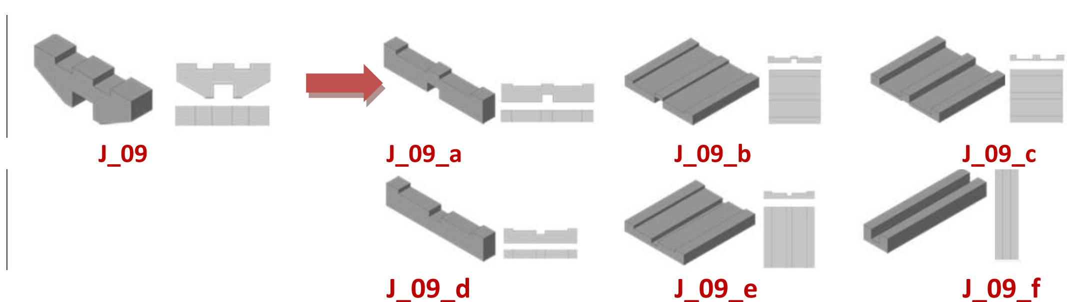
Existing component J_07 is a crossbeam type B, which acts very similar to component J_05. The difference between J_05 is the type of joinery used and its location. This is due to the various types of column connections. Sagwe joint is most known joinery for column head condition; however those joints are mainly for the corner columns and for those in the middle columns will have different connections. Although the study only focused on corner conditions of the bracket system, various types of crossbeams were articulated. Component J_07 is one of those various conditions of crossbeam using half-lap joinery. J_07_a is now used in inner lumber +

inner lumber, although the decrease in length minimizes its structural ability in moment, J_07_a and J_07_b now became a connector.



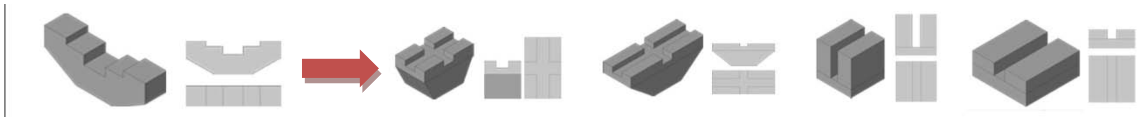
1. Type of joinery: Sagwe joint → Sagwe joint (J_08_a and J_08_b) and Half lap joint (J_08_c and J_08_d)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (J_08_a and J_08_b) and rectangular lumber + rectangular lumber (J_08_c and J_08_d)
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber
4. Jangbu pierce: none → none

Component J_08, main bracket is the very starting of bracket system. Situated on top of column, J_08 component provided cross-cut half-lap joints for the interlocking of two cross-beam members. The shape and type of joinery used is very similar to component J_01 and J_02, yet the purpose of J_08 is not to support massive load but interlock two cross joint members. Four possible modified components were made through dimensional changes. J_08_a and J_08_b use between lumber + board depends on the depth of opening cut-outs. If the opening cut-outs are much deeper, components can be used in rectangular lumber as well. Component J_08_c and J_08_d simplified its joints through provide one cut-outs for only one member to be placed through lap-joints.



1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (J_09_a, J_09_d and J_09_f) and rectangular lumber + board
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (J_09_a, J_09_d and J_09_f) and end of lumber + end of lumber (J_09_b, J_09_c and J_09_e)
4. Jangbu pierce: none → none

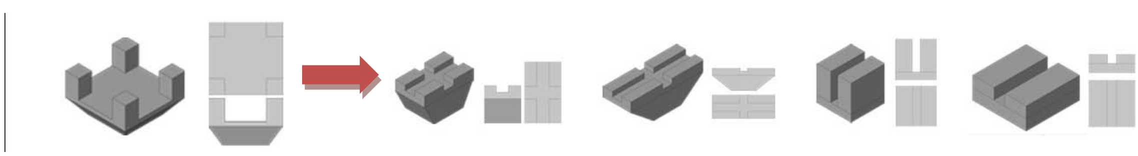
Component J_09 is a cantilever arm which is connected to the main bracket system. The joinery used is half lap joint connected to the other set of cantilever arm. J_09 is connected in the inner of lumber + inner of lumber using rectangular lumber + rectangular lumber. Modifications were made 1.to simplify the geometry from unique shape of cantilever arm to more of common rectangular form, and 2.width increased to joint to board components.



J_10 J_10_a J_10_b J_10_c J_10_d

1. Type of joinery: Half-lap joint → Sagwe joints (J_10_a and J_10_b) and half lap joint (J_10_c and J_10_d)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (J_10_a and J_10_b) and rectangular lumber + rectangular lumber (J_10_c and J_10_d)
3. Location of joinery: inner of lumber + inner of lumber → end of lumber +inner lumber (J_10_a and J_10_b) and inner lumber + inner of lumber (J_10_c and J_10_d)
4. Jangbu pierce: none → none

Component J_10 is the second component of cantilever arm which is connected to the main bracket system. The joinery used is half lap joint connected to the other previous set of cantilever arm, J_09. J_10 is connected in the inner of lumber + inner of lumber using rectangular lumber + rectangular lumber. Modifications were made 1.to simplify the geometry from unique shape of cantilever arm to more of common rectangular form, and 2.width increased to joint to board components. The existing component J_09 and J_10 are to create a strong base of bracket structure connected to the main bracket member J_08.



J_11 J_11_a J_11_b J_11_c J_11_d

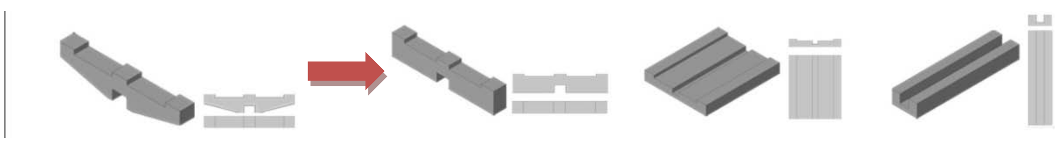
1. Type of joinery: Sagwe joint → Sagwe joints (J_11_a and J_11_b) and half lap joint (J_11_c and J_11_d)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (J_11_a and J_11_b) and rectangular lumber + rectangular lumber (J_11_c and J_11_d)
3. Location of joinery: inner of lumber + inner of lumber → end of lumber +inner lumber (J_11_a and J_11_b) and inner lumber + inner of lumber (J_11_c and J_11_d)
4. Jangbu pierce: none → none

Sub-bracket type a, which is component J_11 acts very similar to those of J_03 and J_08. The type of joinery used for J_11 is cross lap joints. J_11 situated in the middle of the members on top of main bracket. Cross shape cut outs makes the second cantilever arms to be located after J_11. Modifications were made to change the overall form into simpler rectangular form (J_11_c and J_11_d) and to be able to connect to boards (J_11_a and J_11_b).

J_12 J_12_a J_12_b J_12_c

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (J_09_a, J_09_d and J_09_f) and end of lumber + end of lumber (J_09_b, J_09_c and J_09_e)
4. Jangbu pierce: none → none

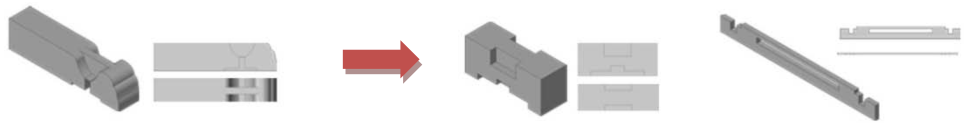
Component J_12 is sub-bracket type B. J_12 is situated towards the end of previous cantilever arm member. J_12 is typically connection for rectangular lumber + rectangular lumber, which second cantilever arm joint to J_12 using half lap joinery.



J_13 J_13_a J_13_b J_13_c

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (J_13_a and J_13_c) and rectangular lumber + board (J_13_b)
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (J_13_a and J_13_c) and end of lumber + end of lumber (J_13_b)
4. Jangbu pierce: none → none

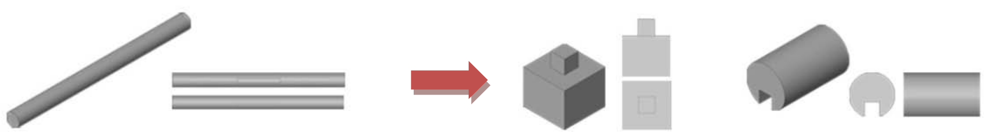
Component J_013 is a second cantilever arm which is connected to the sub- brackets. The joinery used is half lap joint connected to the other set of cantilever arm. J_13 is connected in the inner of lumber + inner of lumber using rectangular lumber + rectangular lumber. Modifications were made 1.to simplify the geometry from unique shape of cantilever arm to more of common rectangular form, and 2.width increased to joint to board components.



J_14 **J_14_a** **J_14_b**

1. Type of joinery: Half-lap joint ➞ half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber ➞ rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + inner of lumber ➞ inner lumber + inner of lumber (J_14_a) and end of lumber + end of lumber (J_14_b)
4. Jangbu pierce: none ➞ none

Existing component J_14 is a girder member to support the purlin and roof structure. Relatively large in size, girder uses several joineries instead of single joint method. J_14 component were simplified to create a common form in rectangular geometry. The joineries are remained very similar to the existing in case of J_14_a, yet J_14_b have totally different form according to its dimensional change and width changes and the location of joinery.



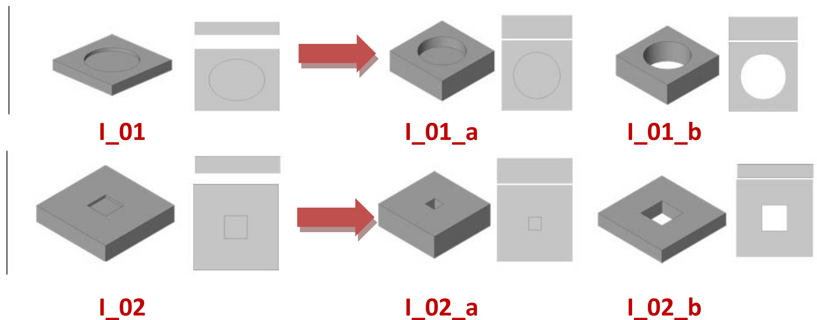
J_15 **J_15_a** **J_15_b**

1. Type of joinery: mortise and tenon joint ➞ true mortise and tenon joint (J_15_a) and mortise and tenon joint (J_15_b)
2. Use of joinery: rectangular lumber + rectangular lumber ➞ rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + end of lumber ➞ end of lumber + end of lumber
4. Jangbu pierce: none ➞ present (J_15_a) and none (J_15_b)

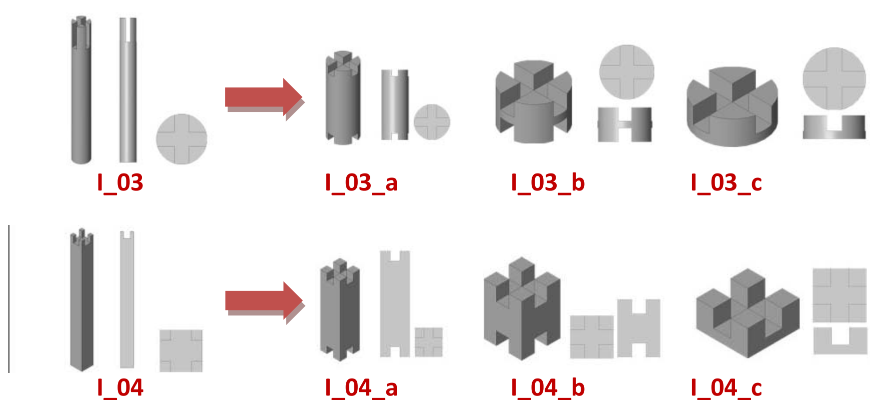
Group I

Component group I (*Ik-gong*) is simple version of *Ju-Sim-Po*. Therefore, many of the existing components are very identical to group J. Exception is the absence of cantilever arms and introduce of *Ik-Gong* members. Therefore, some of the descriptions on existing component will be *identical to component J.* There are total numbers of 13 existing and 39 modified components in group I.

EXISTING **MODIFIED COMPONENTS**



1. Type of joinery: simple scarf joint → simple scarf (I_01_a & I_02_a) and mortise and tenon joint (I_01_b & I_02_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (I_01_a, I_01_b, I_02_a and I_02_b)
3. Location of joinery: end of lumber + end of lumber → end of lumber + end of lumber (I_01_a & I_02_a) and inside of lumber + inside of lumber (I_01_b & I_02_b)
4. Jangbu pierce: none → none (I_01_a & I_02_a) and present (I_01_b & I_02_b)



1. Type of joinery: Sagwe choke joint → Sagwe choke joint (all 6 modified components)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (all 6 modified components
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none (all 6 modified components)

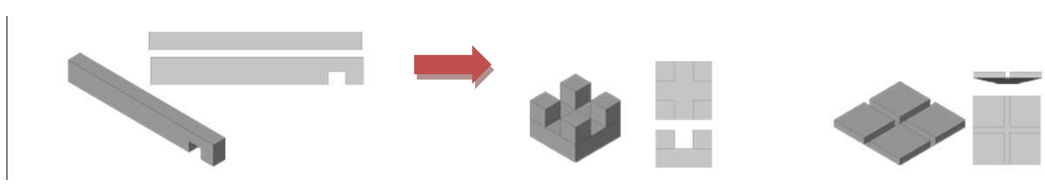
I_05 I_05_a I_05_b I_05_c I_05_d

I_05_e I_05_f I_05_g

1. Type of joinery: True mortise and tenon joint → Mortise and tenon (I_05_a, I_05_b, I_05_c), Half lap joint (I_05_d, I_05_e) and half mortise and tenon (I_05_f and I_05_g)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (I_05_a, I_05_d, I_05_f and I_05g) and board + rectangular lumber (I_05_b, I_05_c and I_05_e)
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none

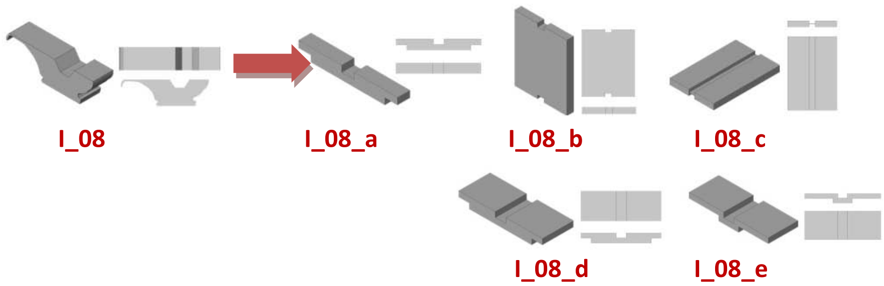
I_06 I_06_a I_06_b I_06_c I_06_d I_06_e

1. Type of joinery: Half lap joint → half lap joint
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (I_06_a), board + rectangular lumber (I_06_d and I_06_e) and board + board (I_06_b and I_06_c)
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none

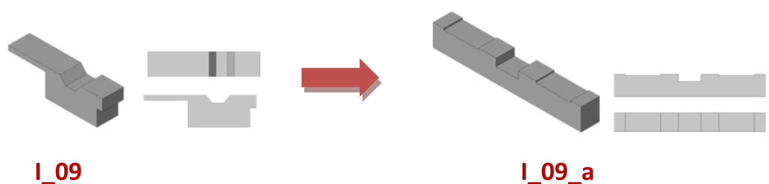


I_07 I_07_a I_07_b

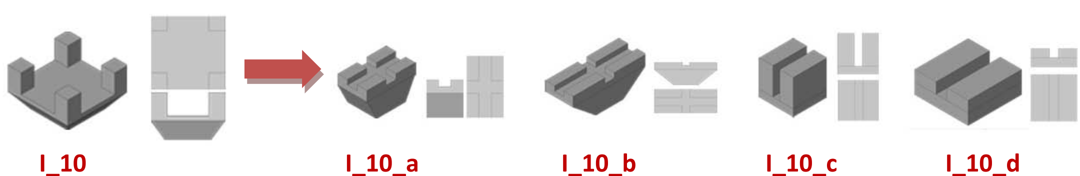
1. Type of joinery: Half lap joint → Sagwe choke joint (I_07_a) and Half Sagwe choke joint (I_07_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (I_07_a) and board + board (I_07_b)
3. Location of joinery: end of lumber + end of lumber → inner lumber + inner lumber (opt.) and end of lumber + end of lumber (opt.)
4. Jangbu pierce: none → none



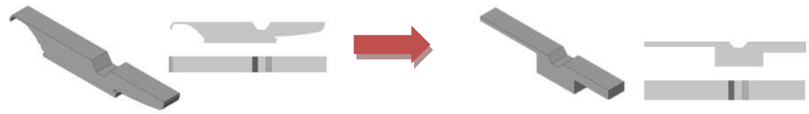
1. Type of joinery: Half lap joint → Half lap joint (I_08_a) and half mortise and tenon (I_08_b, I_08c, I_08_d and I_08_e)
2. Use of joinery: rectangular lumber +rectangular lumber → rectangular lumber + rectangular lumber (I_08_a) and board + board
3. Location of joinery: innerlumber + end of lumber → inner lumber + end of lumber (opt.) and end of lumber + end of lumber (opt.)
4. Jangbu pierce: none → none



1. Type of joinery: Half lap joint → Half lap joint
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner lumber + inner lumber → inner lumber + end of lumber (opt.) and inner lumber + inner lumber (opt.)
4. Jangbu pierce: none → none

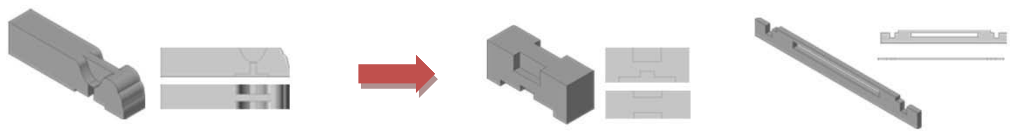


1. Type of joinery: Sagwe joint → Sagwe joints (I_10_a and I_1o_b) and half lap joint (I_10_c and I_10_d)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board I_10_a and I_10_b) and rectangular lumber + rectangular lumber (I_10_c and I_10_d)
3. Location of joinery: inner of lumber + inner of lumber → end of lumber +end of lumber (I_10_a and I_10_b) and inner lumber + inner of lumber (I_10_c and I_10_d)
4. Jangbu pierce: none → none



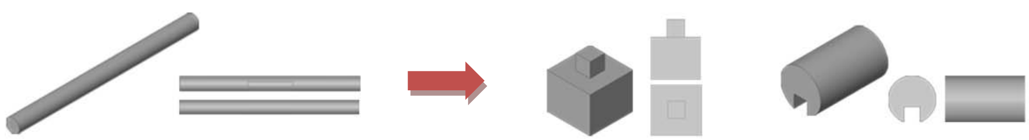
I_11 **I_11_a**

1. Type of joinery: Half lap joint → half lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber
4. Jangbu pierce: none → none



I_12 **I_12_a** **I_12_b**

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (I_12_a) and end of lumber + end of lumber (I_12_b)
4. Jangbu pierce: none → none

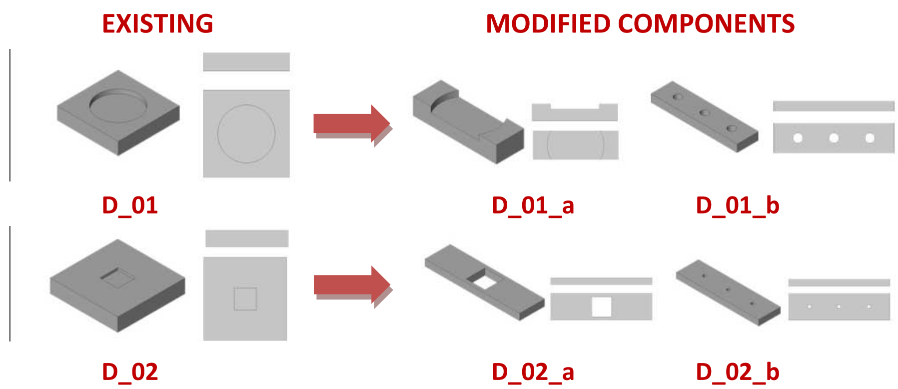


I_13 **I_13_a** **I_13_b**

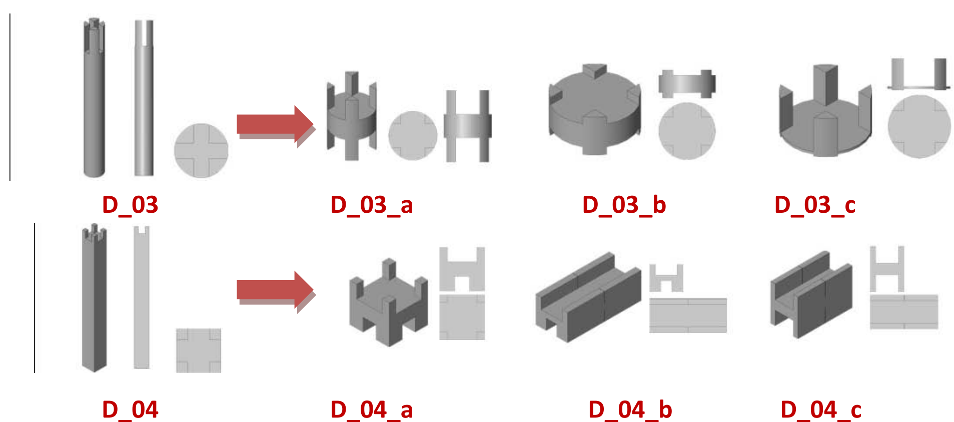
1. Type of joinery: mortise and tenon joint → true mortise and tenon joint (I_13_a) and mortise and tenon joint (I_13_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + end of lumber → end of lumber + end of lumber
4. Jangbu pierce: none → present (I_13_a) and none (I_13_b)

Group D

Component group D (*Da-Po*) consist the most number of components amongst three bracket types. The unique members called *Jae-Gong* behave as to what cantilever arms but provide multiple joineries for extra components. Therefore, instead of having two members to create a layer, group D have multiple members create one layer of bracket system. There are total numbers of 16 existing components and 52 modified components.

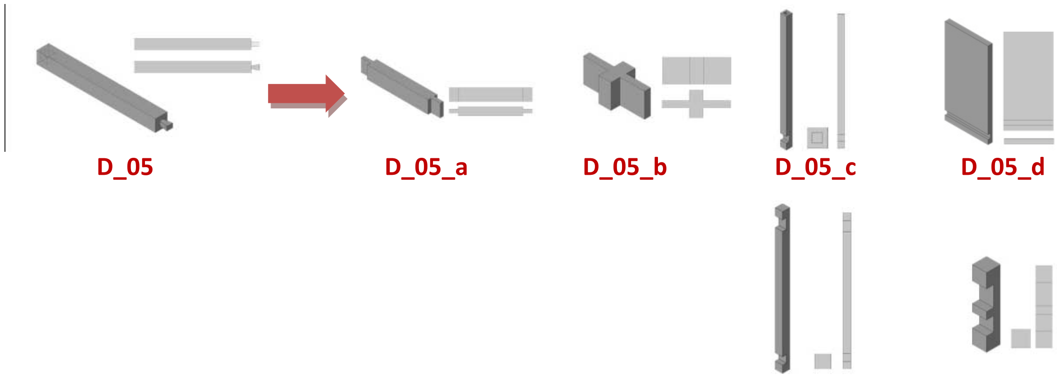


1. Type of joinery: simple scarf joint → lap joints (D_01_a) and mortise and tenon joint (D_01_b, D_02_a and D_02_b)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (D_01_a) and board + rectangular lumber (D_01_b, D_02_a and D_02_b)
3. Location of joinery: end of lumber + end of lumber → end of lumber + end of lumber (D_01_a) and inside of lumber + inside of lumber (D_01_b, D_02_a and D_02_b)
4. Jangbu pierce: none → none (D_01_a) and present (D_01_b, D_02_a and D_02_b)



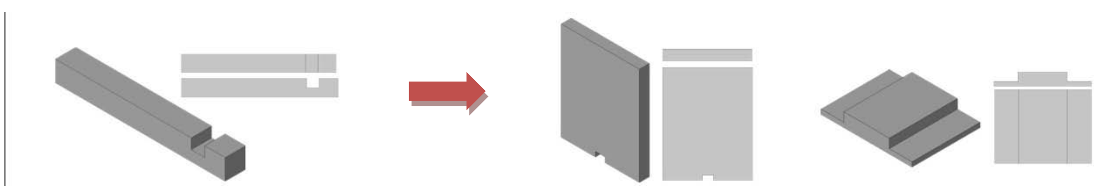
1. Type of joinery: Sagwe choke joint → Sagwe choke joint (D_03_a, D_03_b, D_03_c and D_04_a) and mortise and tenon joint (D_04_b and D_04_c)

2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (all 6 modified components)
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none (all 6 modified components)



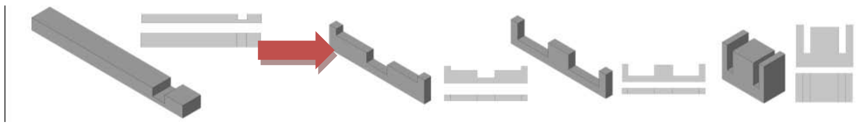
D_05 D_05_a D_05_b D_05_c D_05_d D_05_e D_05_f

1. Type of joinery: True mortise and tenon joint → Mortise and tenon (D_05_a and D_05_b) and Half lap joint (D_05_c, D_05_d, D_05_e and D_05_f)
2. Use of joinery: Rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber and board + board (D_05_d)
3. Location of joinery: end of lumber + end of lumber → end of lumber + end of lumber (opt.) and end of lumber + inner of lumber (opt.)
4. Jangbu pierce: none → none



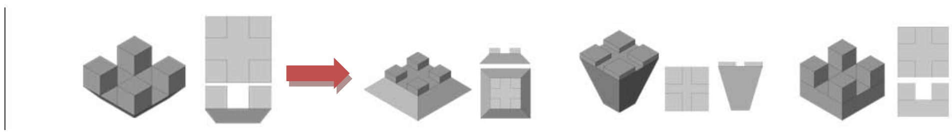
D_06 D_06_a D_06_b

1. Type of joinery: Half lap joint → half lap joint
2. Use of joinery: rectangular lumber + rectangular lumber → board + rectangular lumber (D_06_a) and board + board (D_06_b)
3. Location of joinery: end of lumber + inner lumber → end of lumber + end of lumber
4. Jangbu pierce: none → none



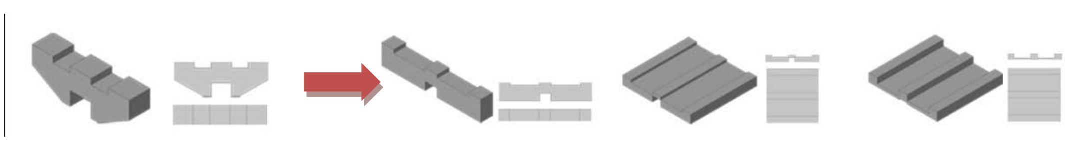
D_07 D_07_a D_07_b D_07_c

1. Type of joinery: Half lap joint → half lap joint
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (D_07_c) and board + rectangular lumber (D_07_a and D_07_b)
3. Location of joinery: end of lumber + inner lumber → end of lumber + inner lumber and end of lumber + end of lumber
4. Jangbu pierce: none → none

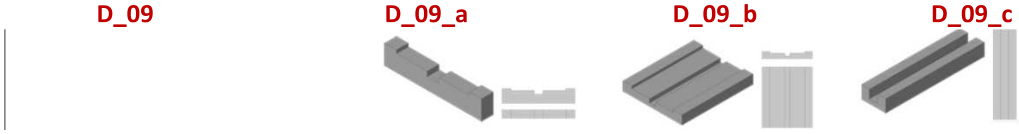


D_08 D_08_a D_08_b D_08_c

1. Type of joinery: Sagwe joint → Sagwe joint
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (D_08_a and D_08_b) and rectangular lumber + rectangular lumber (D_08_c)
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber
4. Jangbu pierce: none → none

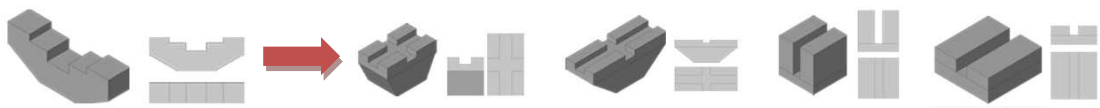


D_09 D_09_a D_09_b D_09_c



D_09_d D_09_e D_09_f

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (D_09_a, D_09_d and D_09_f) and rectangular lumber + board (D_09_b, D_09_c and D_09_e)
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (D_09_a, D_09_d and D_09_f) and end of lumber + end of lumber (D_09_b, D_09_c and D_09_e)
4. Jangbu pierce: none → none

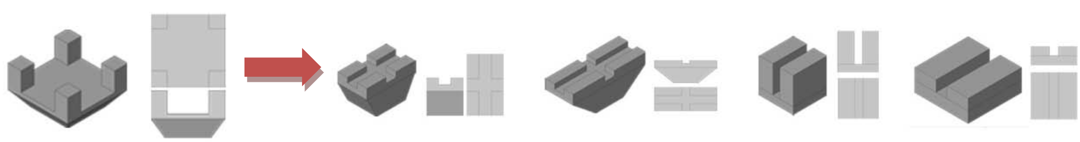


D_10 D_10_a D_10_b D_10_c D_10_d

1. Type of joinery: Half-lap joint → Sagwe joints (D_10_a and D_10_b) and half lap joint (D_10_c and D_10_d)
1. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (D_10_a and D_10_b) and rectangular lumber + rectangular lumber (D_10_c and D_10_d)
2. Location of joinery: inner of lumber + inner of lumber → end of lumber +inner lumber (D_10_a and D_10_b) and inner lumber + inner of lumber (D_10_c and D_10_d)
3. Jangbu pierce: none → none

D_11 D_11_a D_11_b D_11_c

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber (D_11_a and D_11_c) and rectangular lumber + board (D_11_b)
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner of lumber (D_11_a and D_11_c) and end of lumber + end of lumber (D_11_b)
4. Jangbu pierce: none → none

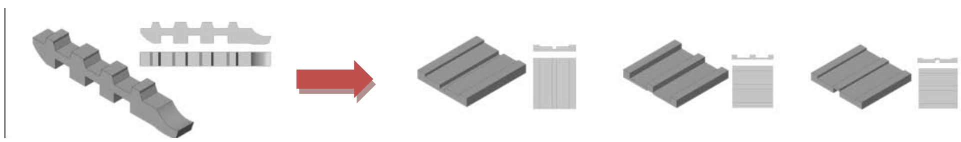


D_12 D_12_a D_12_b D_12_c D_12_d

1. Type of joinery: Sagwe joint → Sagwe joints (D_12_a and D_12_b) and half lap joint (D_12_c and D_12_d)
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board D_12_a and D_12_b) and rectangular lumber + rectangular lumber (D_12_c and D_12_d)
3. Location of joinery: inner of lumber + inner of lumber → end of lumber +end of lumber (D_12_a and D_12_b) and inner lumber + inner of lumber (D_12_c and D_12_d)
4. Jangbu pierce: none → none

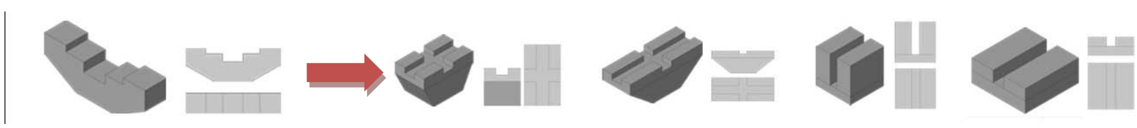
D_13 D_13_a D_13_b D_13_c

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: Rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: Inner lumber + inner lumber → inner lumber + inner of lumber (D_13_a and D_13_c) and end of lumber + end of lumber (D_13_a)
4. Jangbu pierce: none → none



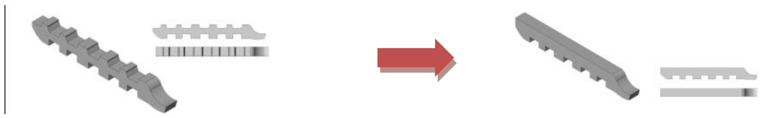
D_14 D_14_a D_14_b D_14_c

1. Type of joinery: Half-lap joint → half-lap joints
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board
3. Location of joinery: inner lumber + inner lumber → end of lumber + end of lumber
4. Jangbu pierce: none → none



D_15 D_15_a D_15_b D_15_c D_15_d

2. Type of joinery: Half-lap joint → Sagwe joints (D_15_a and D_15_b) and half lap joint (D_15_c and D_15_d)
4. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + board (D_15_a and D_15_b) and rectangular lumber + rectangular lumber (D_15_c and D_15_d)
5. Location of joinery: inner lumber + inner lumber → end of lumber +inner lumber (D_15_a and D_15_b) and inner lumber + inner of lumber (D_15_c and D_1d_d)
6. Jangbu pierce: none → none



D_16 D_16_a

1. Type of joinery: Half-lap → half lap joint
2. Use of joinery: rectangular lumber + rectangular lumber → rectangular lumber + rectangular lumber
3. Location of joinery: inner of lumber + inner of lumber → inner lumber + inner lumber
4. Jangbu pierce: none → none

Total number of existing and modified components from group J, I and D are 180. However, many of the components are similar or even identical. The reason of having these identical components (instead of getting rid of them) is for the possible chances of re-modification.

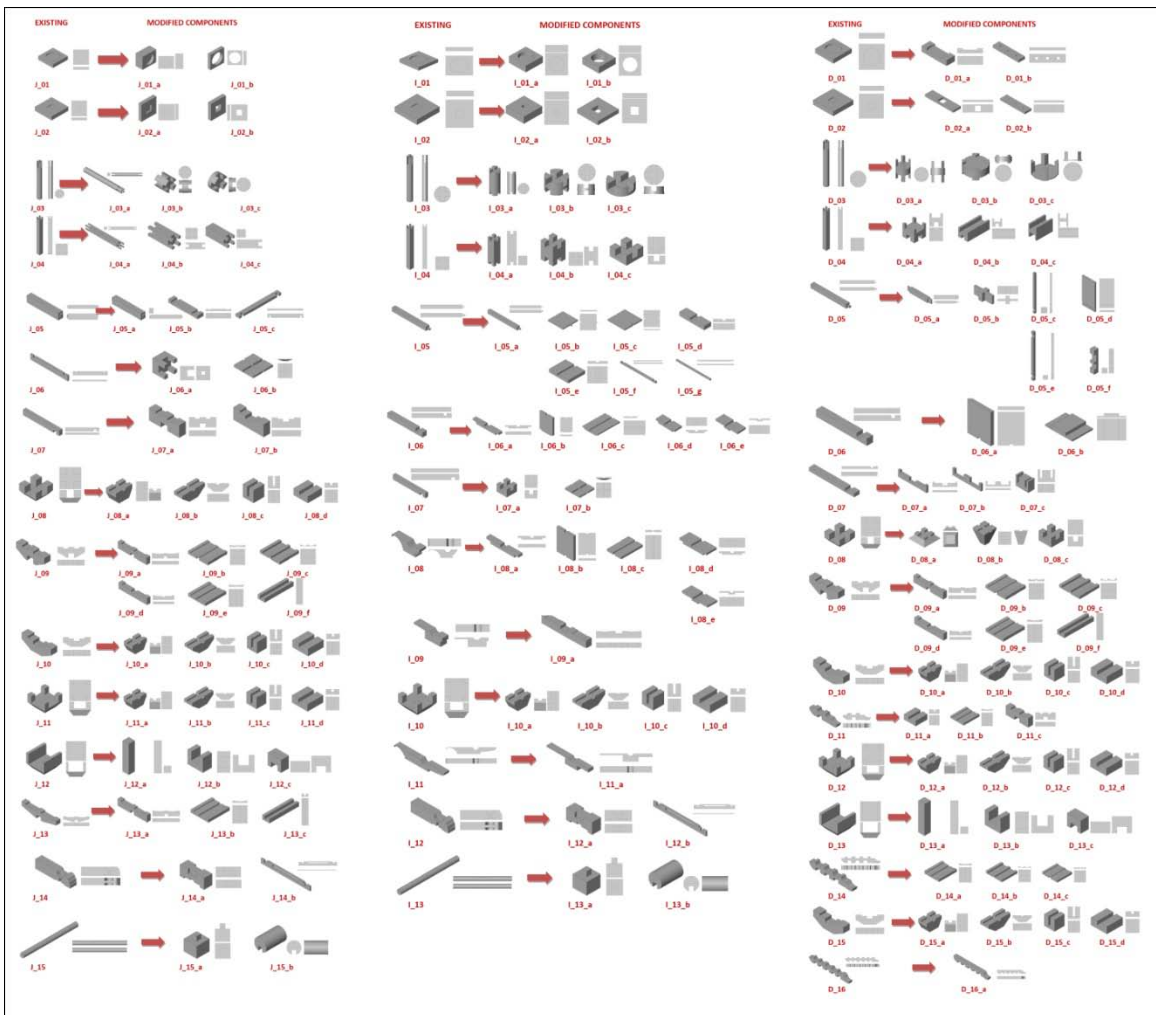


Figure 3. 20 Total number of components in digital catalog

10.3 Digital Catalog

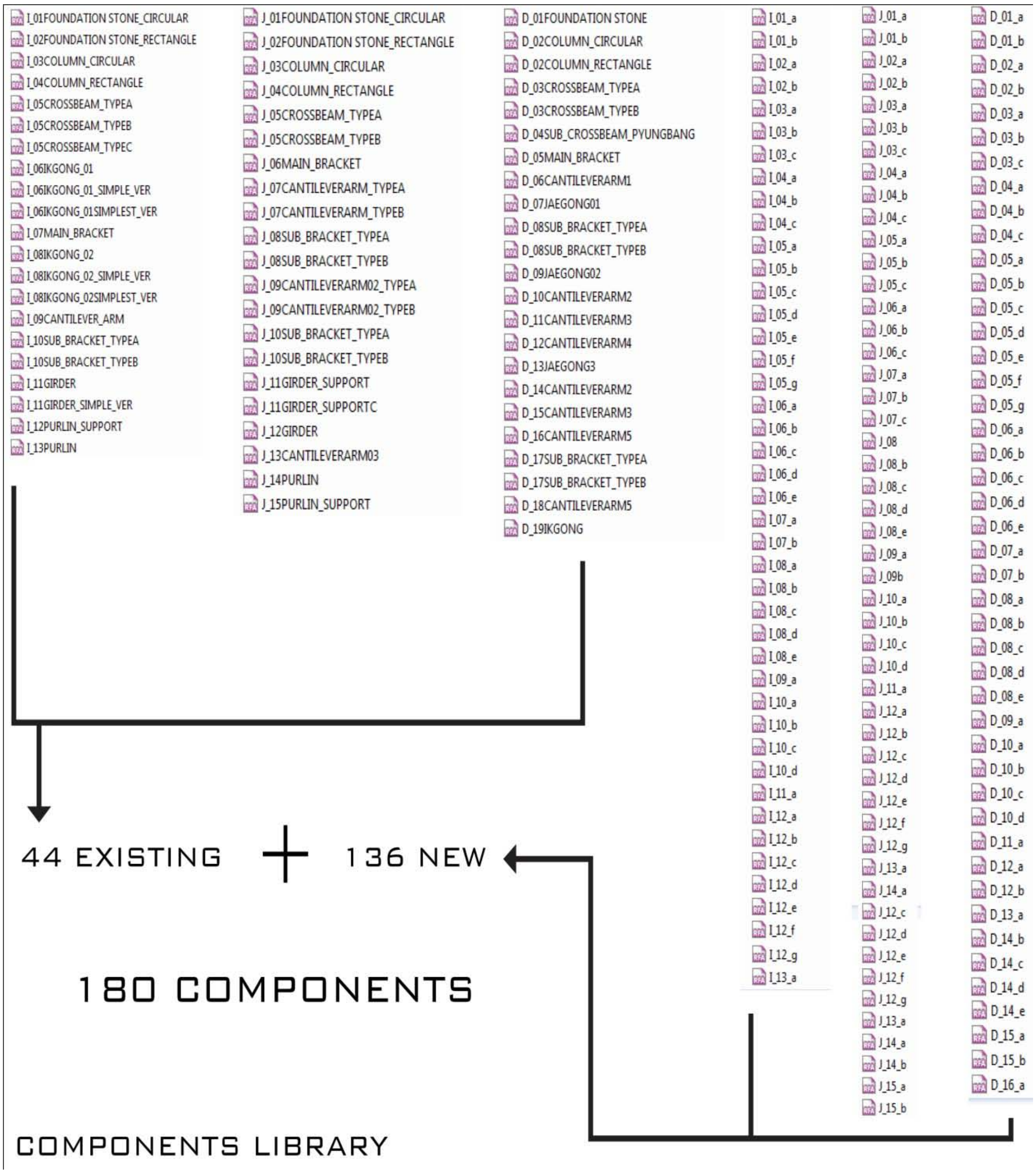


Figure 3. 21 Components library

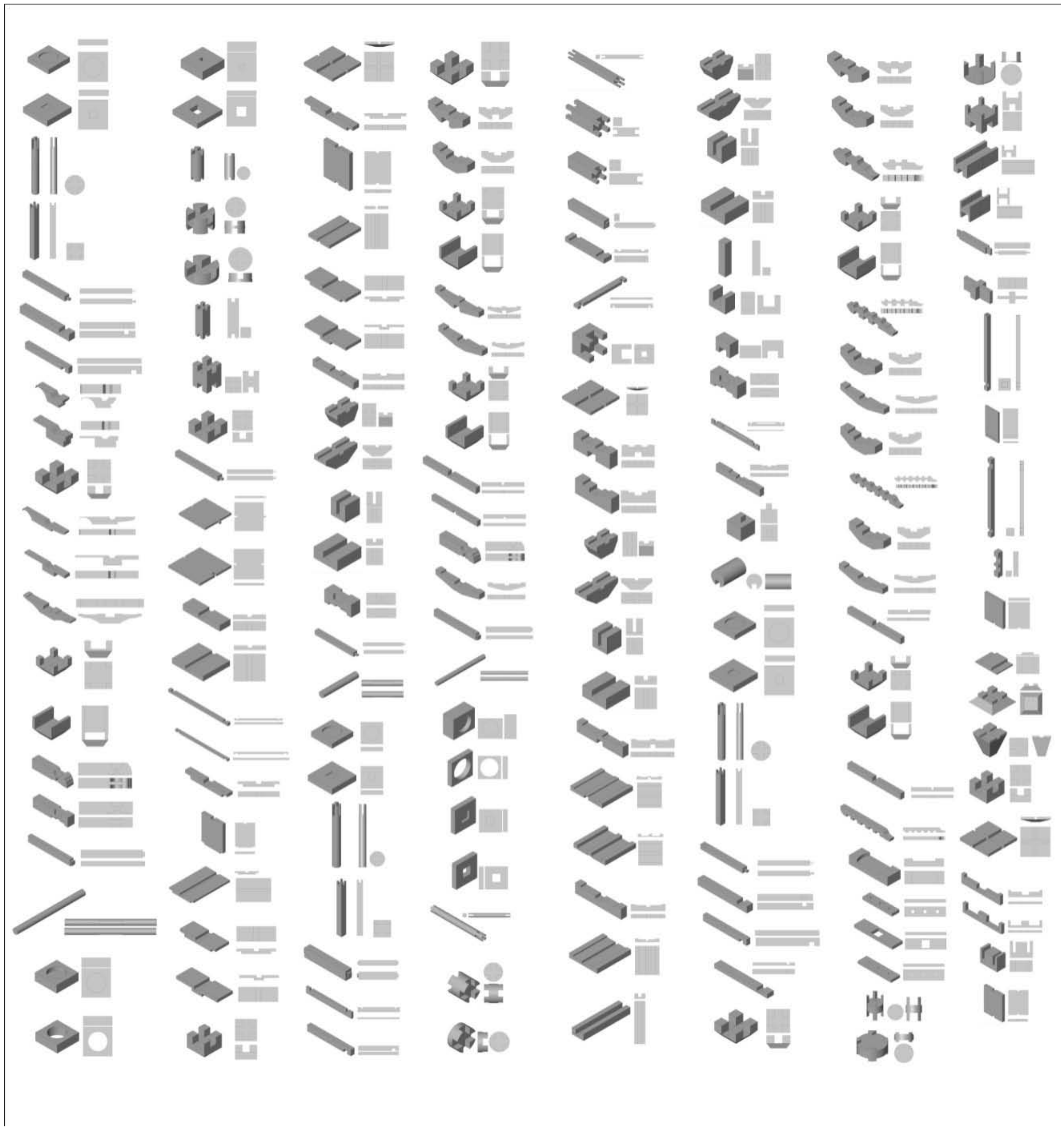


Figure 3. 22 Components library

Components within the digital catalog will be a strong tool to guide the design process of various iteration of shelter through assembly and disassembly of each component to create a flexible formation through unique compositions embedded in each type of joinery. The prototype structure constructed through the assembly of numerous components will transform its size, function, form and disassemble into several options of sub-structures such as furniture layout and individual resting units. The categorization of the each component will further enhance the usability of digital catalog according to its function and assembly method.

11.3 Assembly Constraints and Categorization

This section of chapter will elaborate on the constraints and restrictions of each component in terms of its assembly and construction method through the grouping according to their function in building structure. Categorization of components enhances the usability of the components in building construction. By categorizing each component to its function, user can have a clear understanding in selection of each component. The existing components will be divided into three main types of bracket systems: group J for *Ju-Sim-Po*, group I for *Ik-Gong* and group D for *Da-Po* styles. Total of 180 components will be divided according to its possible use in a building construction in relation to those of traditional Korean architecture. Traditional Korean wooden structures divided into 4 areas of building groups: Floor, Column, Bracket and Roof. Since the structure uses Post-and-Beam construction, wall members are simply a board creating door, screen and partition. Following the concept of traditional Korean architecture and its construction method, individual components will be divided into 4 categories: Floor, Column, Bracket and Roof. Traditional wooden structures of Korea were referenced in its components characteristic: size, orientation (vertical or horizontal member), joinery and finally its function.

Grouping of Existing Components: size and orientation

Figure 3.23 is the grouping of existing 44 components based on their function in traditional Korean wooden structure. For the floor group, only foundation stone is added. This is because the basic construction method is Post-and-Beam structure where floor plates are not behaved as structural elements. Columns and crossbeams fall under the column group. Crossbeams are the connectors of free standing columns. Therefore they are not considered as part of bracket but columns. Roof group consist of girder, purlin support and purlin. Rest of the components is under bracket group.

Grouping of Existing Components: size and orientation

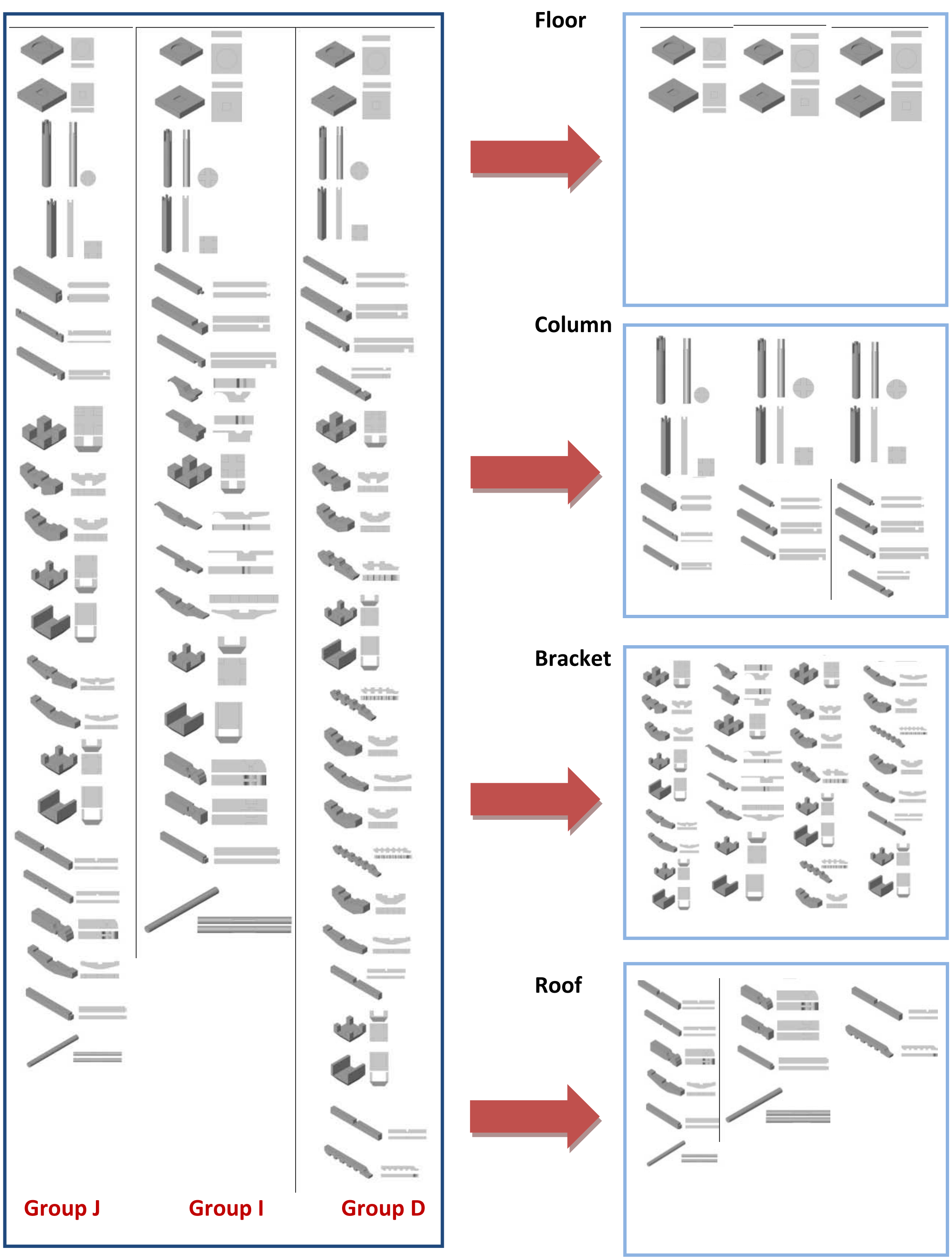


Figure 3. 23 Existing components grouped by its function

Modified components will be grouped correspond to their mother component. For example, modified components generated from the existing component in floor group will remain in same group category. Following figures (fig.3.24 ~ fig.3.27) show the grouping of each component and its modified components under the same group. However, the modified components changed its function and dimension through the parametric modifications and change in four design factors. Therefore, the components will not be satisfied under their original group. In case of the new components, reshuffling of the grouping will relocate each component according to their proper function and dimensions. Figure 3.28 indicates the reshuffling of the components that have distinct forms and dimensions unlike the rest of the components. These components will be brought out as unassigned category so the reshuffling can be processed according to the function. The evolving of the component and its new generative constructions now cross reference the components function and its dimension.

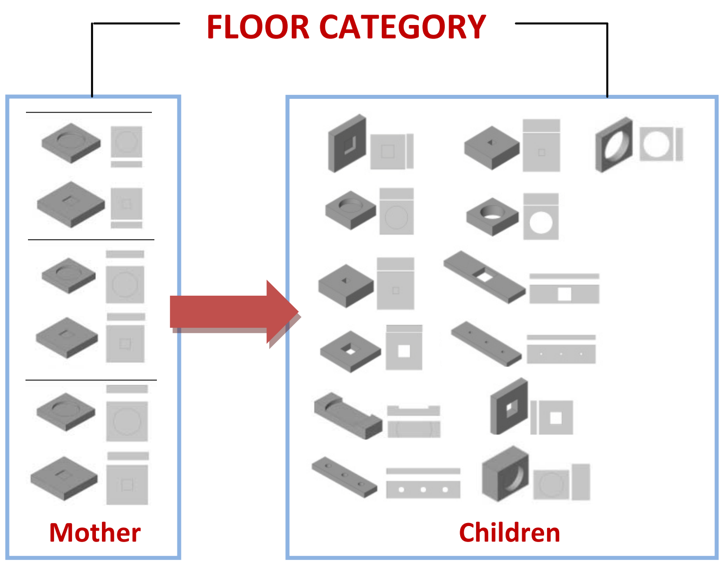


Figure 3. 24 Under Floor group: modified components of existing components falls under the same group

Each existing components with its modified components, total number of 180 components will be grouped under four main categories which defines timber structures of traditional Korean architecture: FLOOR, COLUMN, BRACKET and ROOF category. Followings are the grouping of 180 components under four main categories.

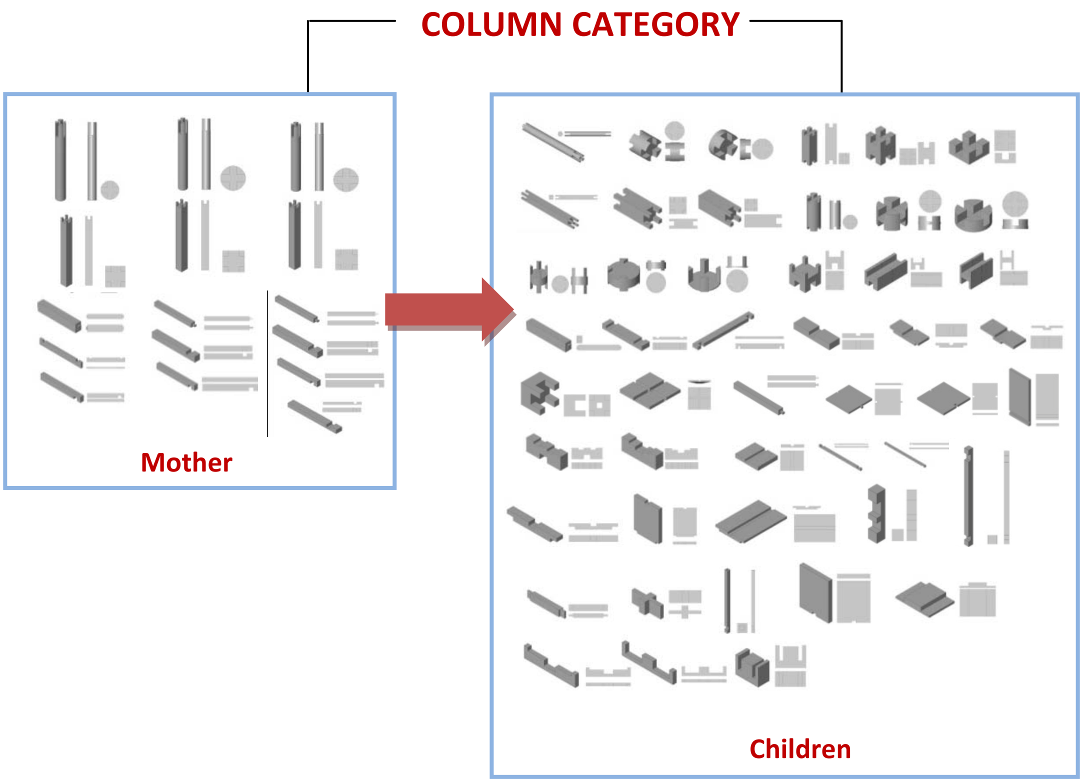


Figure 3. 25 Under Column group: modified components of existing components falls under the same group

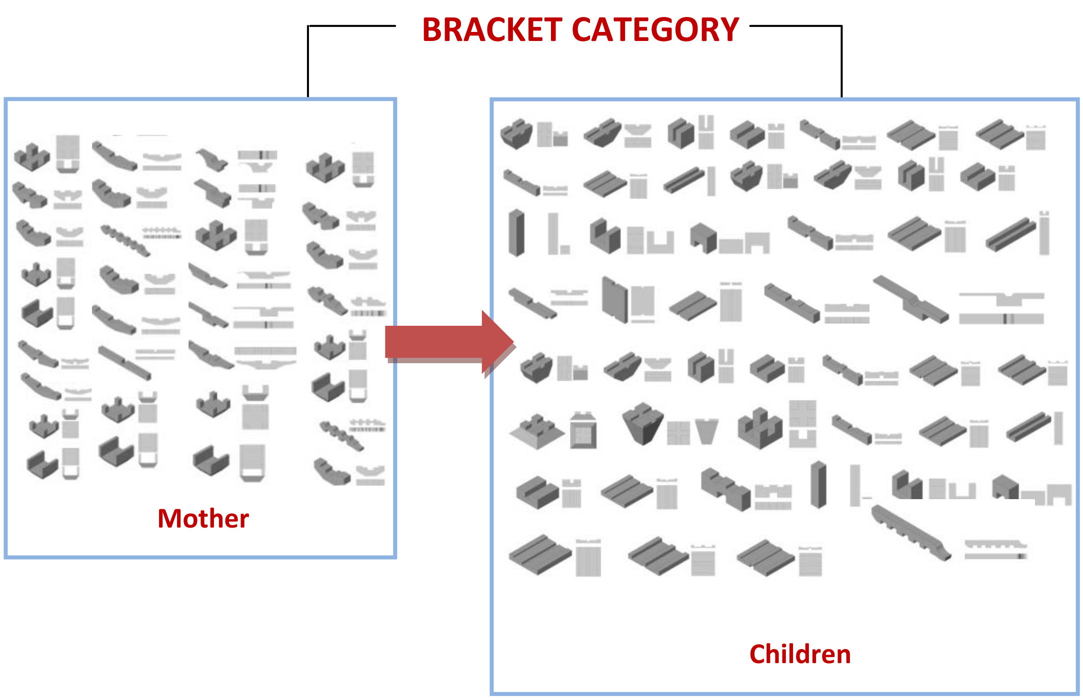


Figure 3. 26 Under Bracket group: modified components of existing components falls under the same group

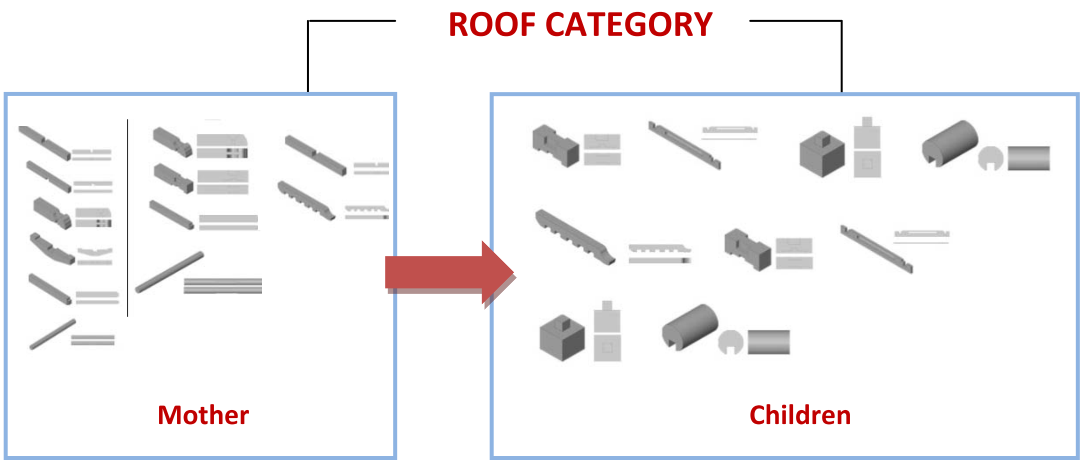


Figure 3. 27 Under Roof group: modified components of existing components falls under the same group

Figure 3.28 explains the functional change from its mother component to child component. Modified component I_03_b (right) is generated through dimensional changes from the existing component I_03. However, due to the change in its dimension, I_03_b no longer can be function as column. Therefore, I_03_b doesn't suitable to be under Column category. Component I_03_b is much suitable under Bracket Category now.

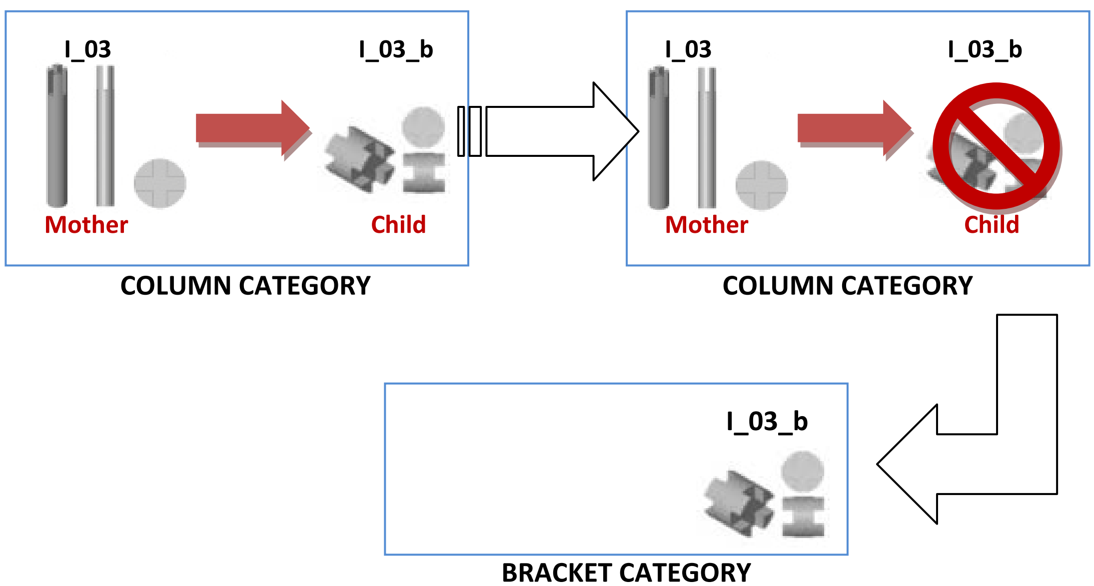


Figure 3. 28 Diagram of component changing categorized group due to its restrictions in height and structural ability

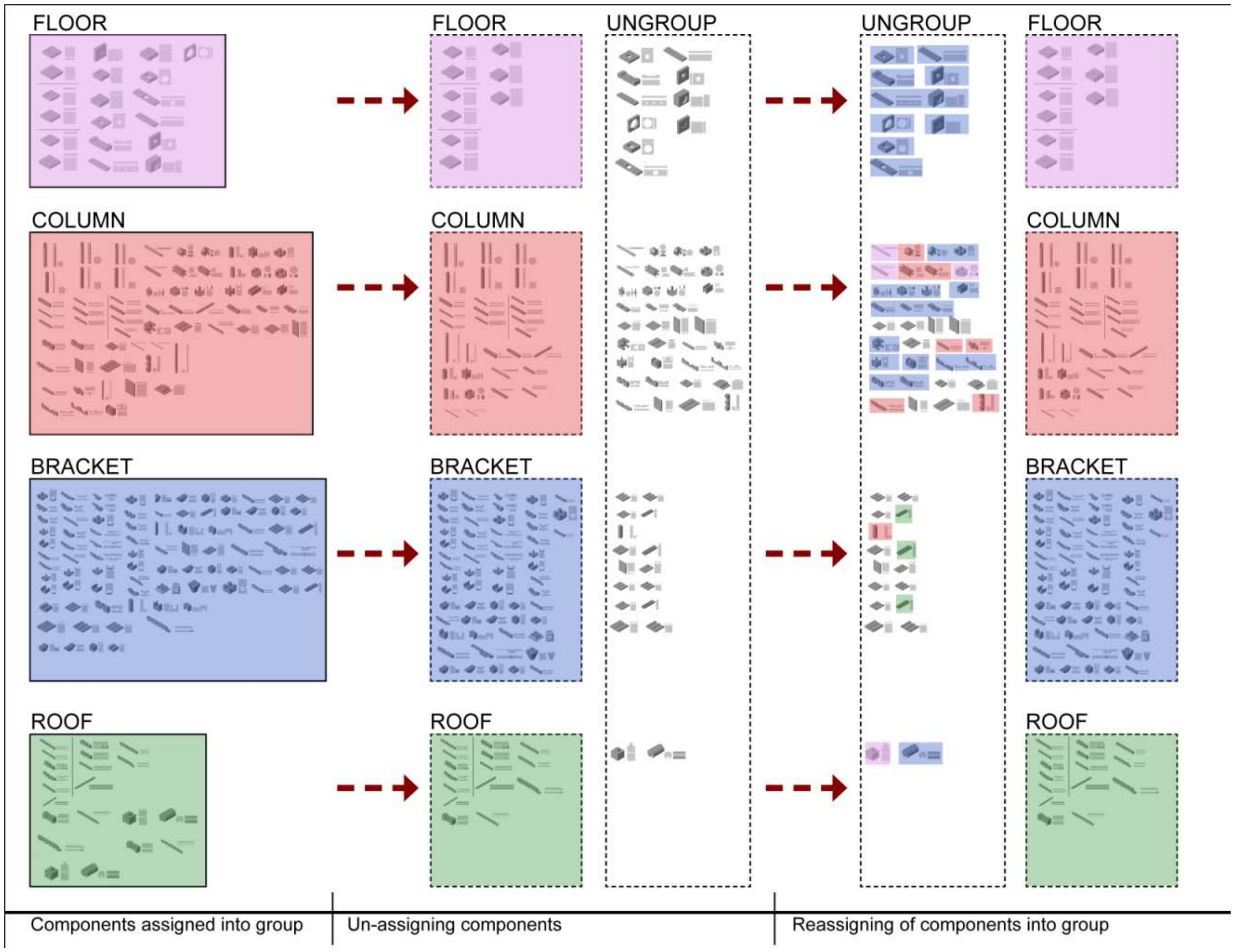


Figure 3. 29 Reshuffling of components according to the function and dimension

Figure 3.29 indicates the reshuffling of the components that have distinct forms and dimensions unlike the rest of the components under the same grouping. These components will be brought out as unassigned category so the reshuffling can be processed according to the function. The evolving of the component and its new generative constructions now cross reference the components function and its dimension. Grouping of the components accordance to the function can guide the users to easily pick and choose the component to be applied during the design process. Wall/floor panels group was added to the original four groups such as floor, column, bracket, and roof, in the process of generating total 180 components with changing the design factors of the original 44 components.

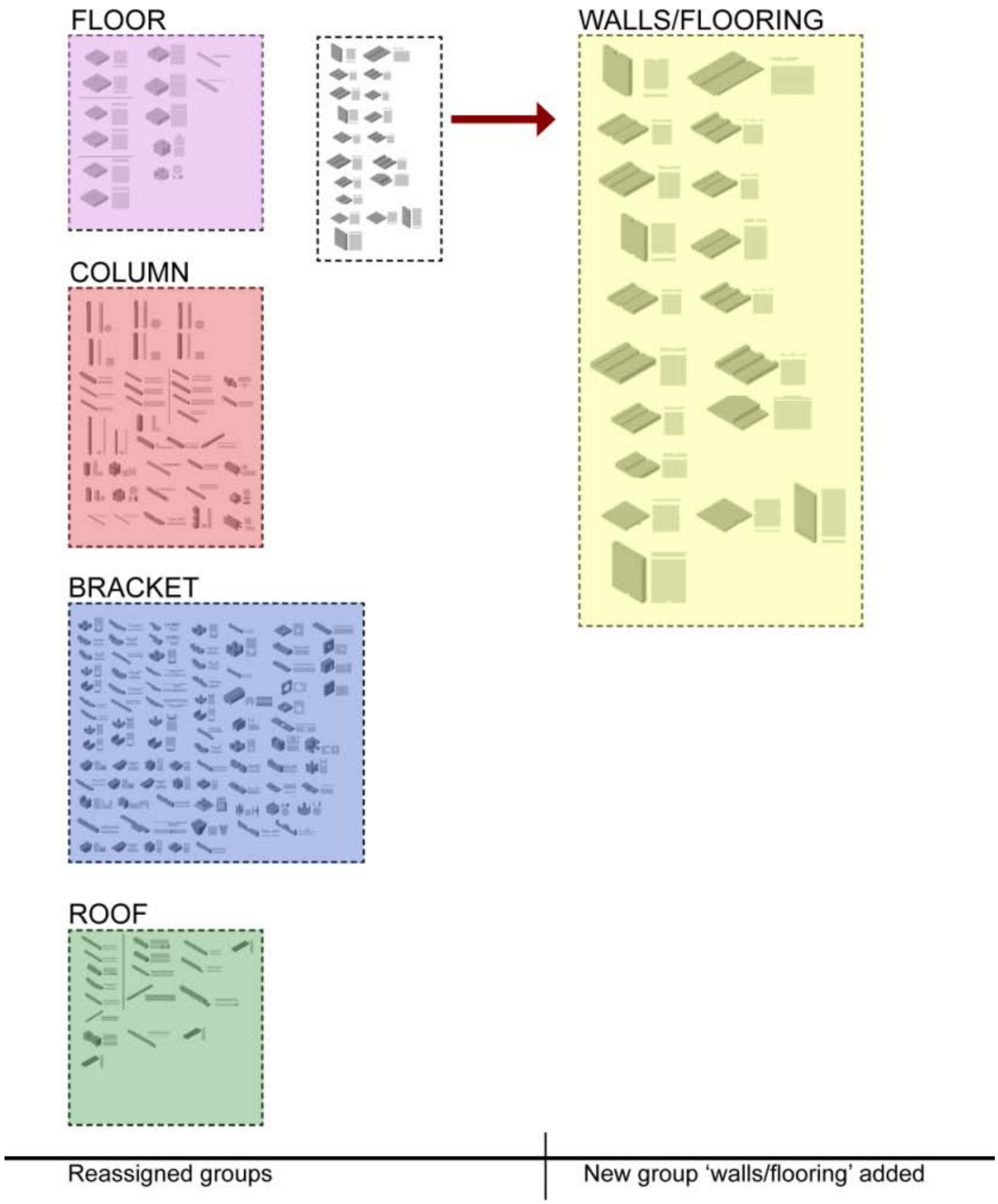


Figure 3. 30 Five groups in digital catalog: Floor, Column, Bracket, Roof and Walls

Total number of five groups was generated through the reshuffling of the components. Wall and floor paneling group was created through the new components generation. Although walls and floor panels were disregarded from the group in an early stage due to traditional categorization of the structure, in digital catalog, walls and floor panels were added for user preference.

11.4 Prototype Building Design

Design of prototype shelter was made through assembly of components in five groups (floor, column, bracket, roof, and wall/floor panels) under the digital catalogue. By analyzing individual components with its connection and method of construction, specific types of components were chosen for experimentation. A prototype of disaster shelter is designed with 17 component types and 80 individual components as shown in figure 8.

1. I_02_a
2. J_15_a
3. I_04_a
4. I_05_a
5. J_04_b
6. D_05_a
7. D_05_c
8. I_05_b
9. I_05_c
10. J_14_b
11. D_01_b
12. I_02_b
13. J_02_b
14. D_04_c
15. D_12_a
16. I_05_c
17. I_08_b

Once the components were selected based on the categorization of each, modification in size and dimension were calculated according to satisfy the overall scale of the structure for Prototype A. As for pure experimentation stage, the size of the instant shelter was limited to less than 12’ X 12’ for structural performances. Therefore, a overall dimension of Prototype A building is 10’ X 10’ X 10’

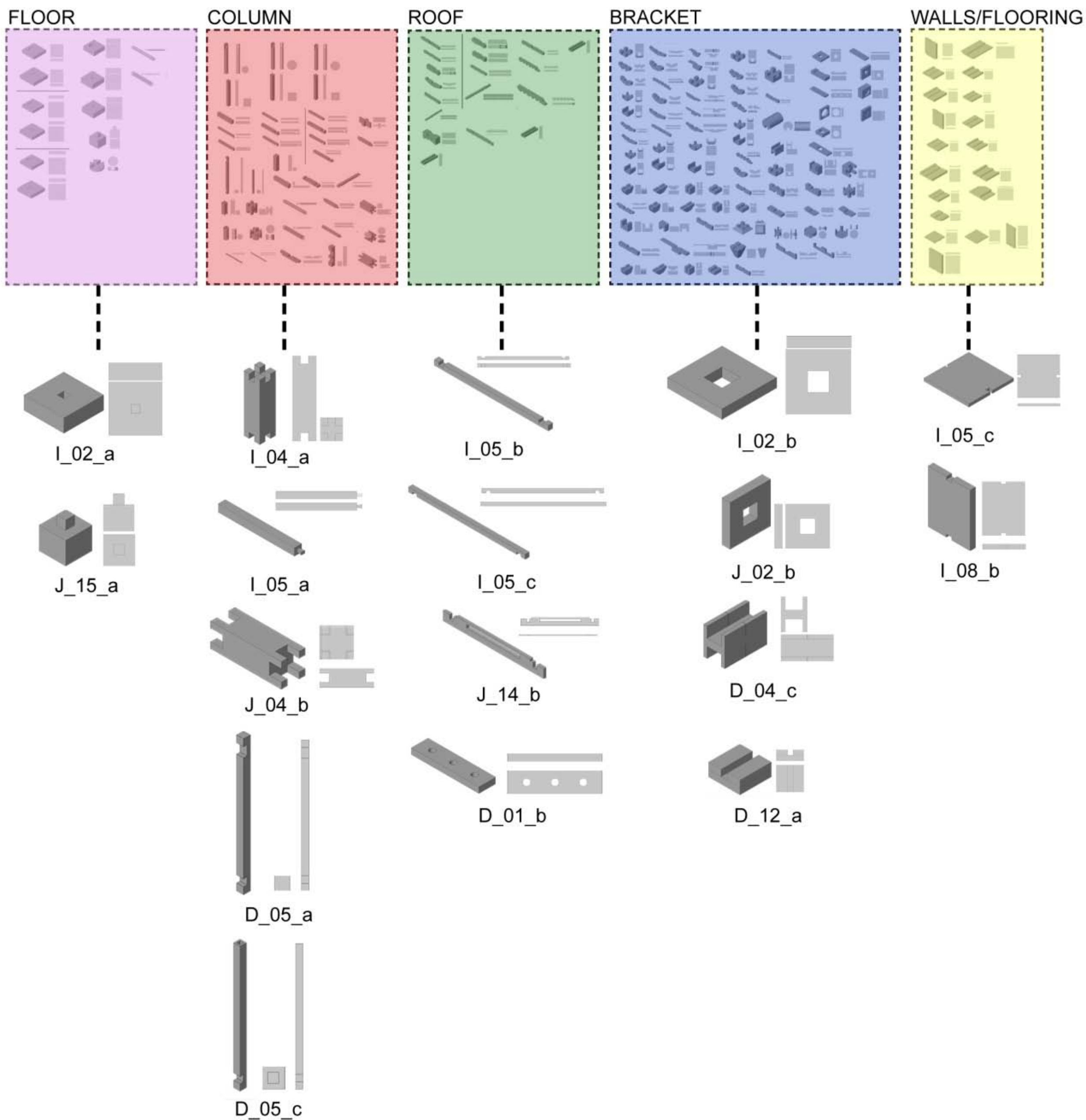


Figure 3. 31 Components used in the design of a transformable structure

Figure 3.31 shows the components used for the prototype shelter design. Design of a prototype structure minimized its use of components to best display the easy assembly and disassembly of the components. Therefore only minimum number of components was used.

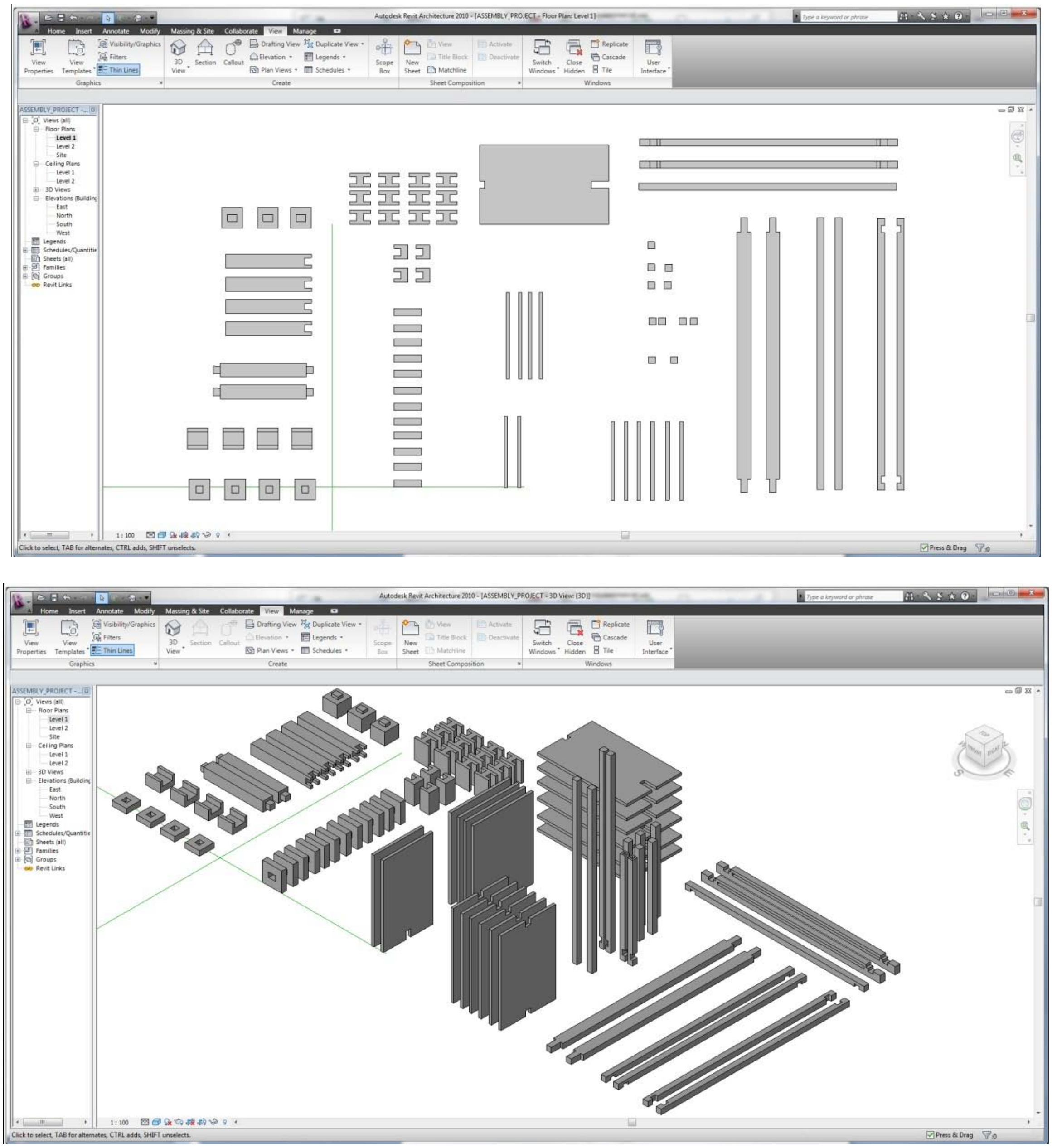


Figure 3. 32 Layout of components in prototype A

Individual family type of components in digital catalog was loaded into Revit project for its assembly process.

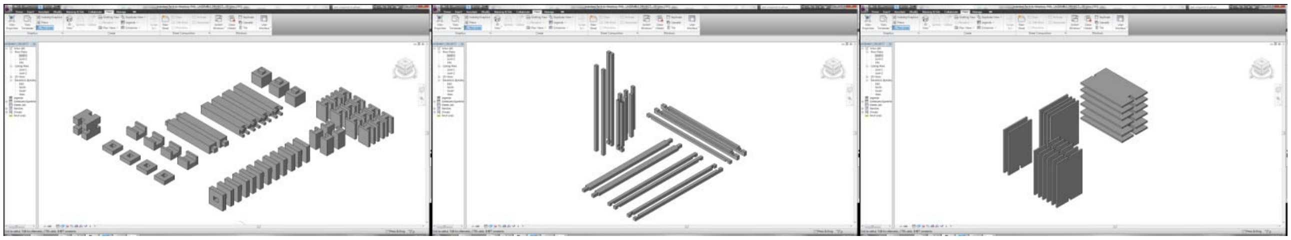


Figure 3. 33 Components divided into each categorized group according to its function

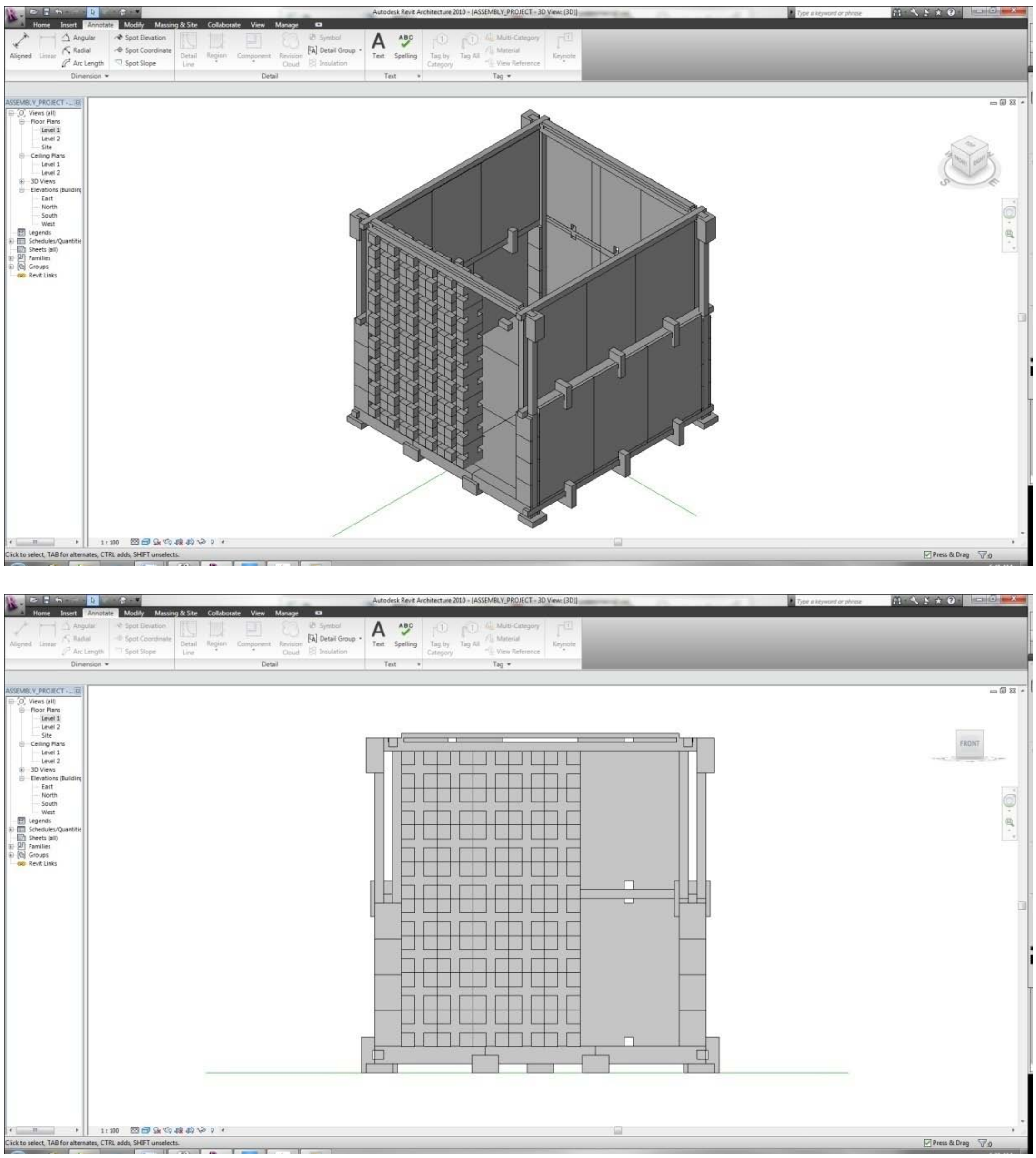


Figure 3. 34 A simple 3-D construction of a prototype A

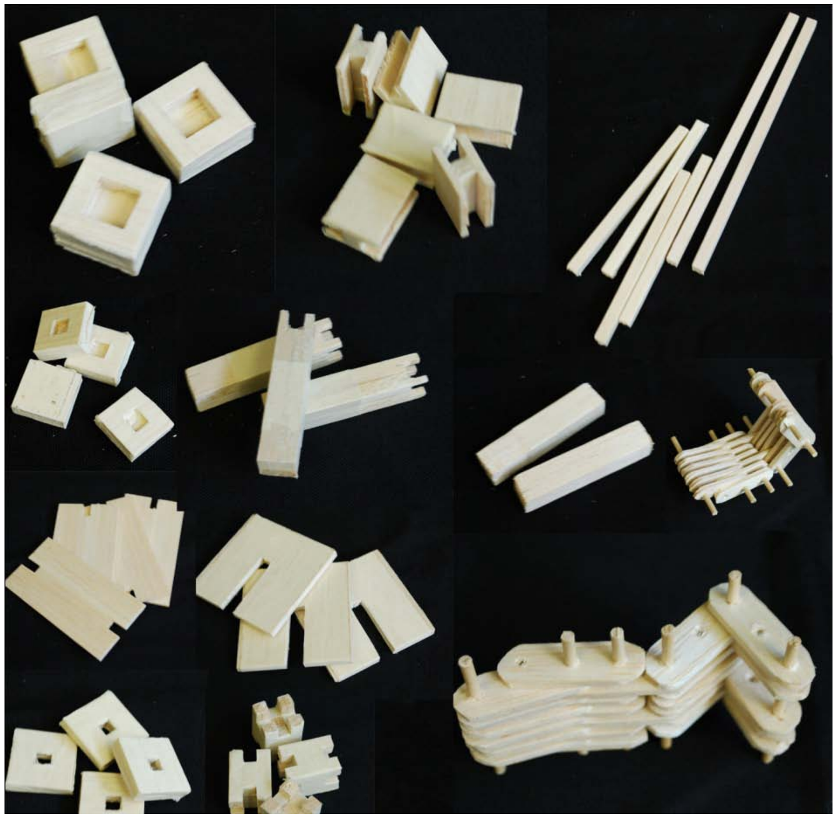


Figure 3. 35 Study model of components used in prototype A

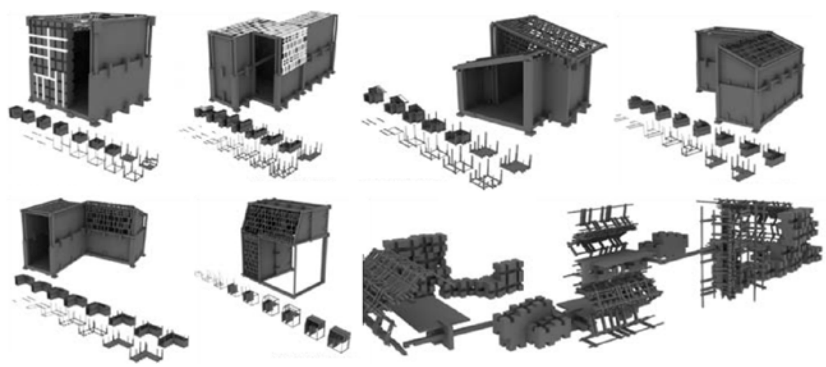


Figure 3. 36 Morphological transformation of a structure

The assembled prototype A can be dismantled and recreate as a sub-units or furniture layouts. It transforms into a different prototype as shown in figure 3.36 Not only the shelter design changes its form into sub-structures but also it can change its form as a shelter design such as through adding and subtracting extra components.

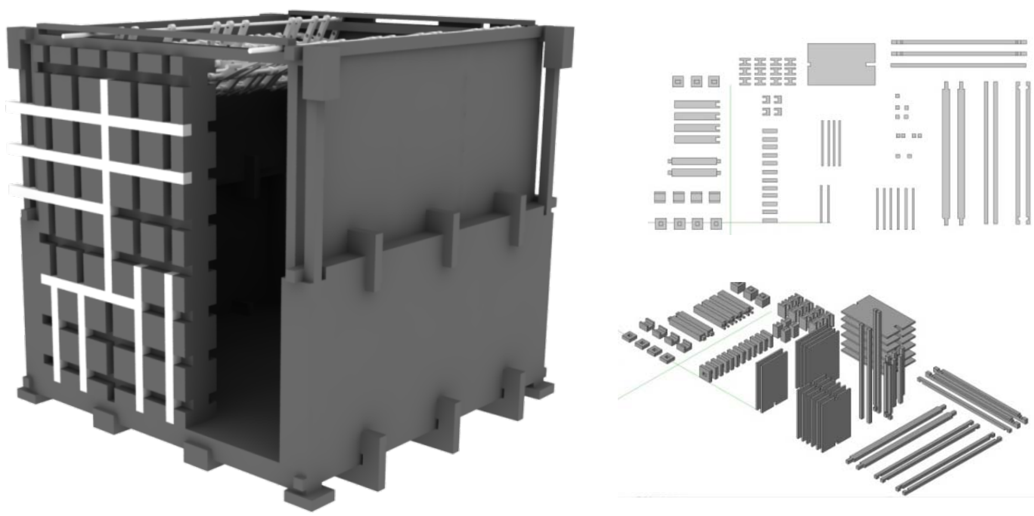


Figure 3. 37 Prototype A

Prototype A

The prototype structure in fig.3.37 is a simple 12X12X12 structure. Due to the structural performance of each component, prototype structure was created as a small structure. For the future design work, structural analysis of each component is required. Figure 3.38 is the process of construction using the components.

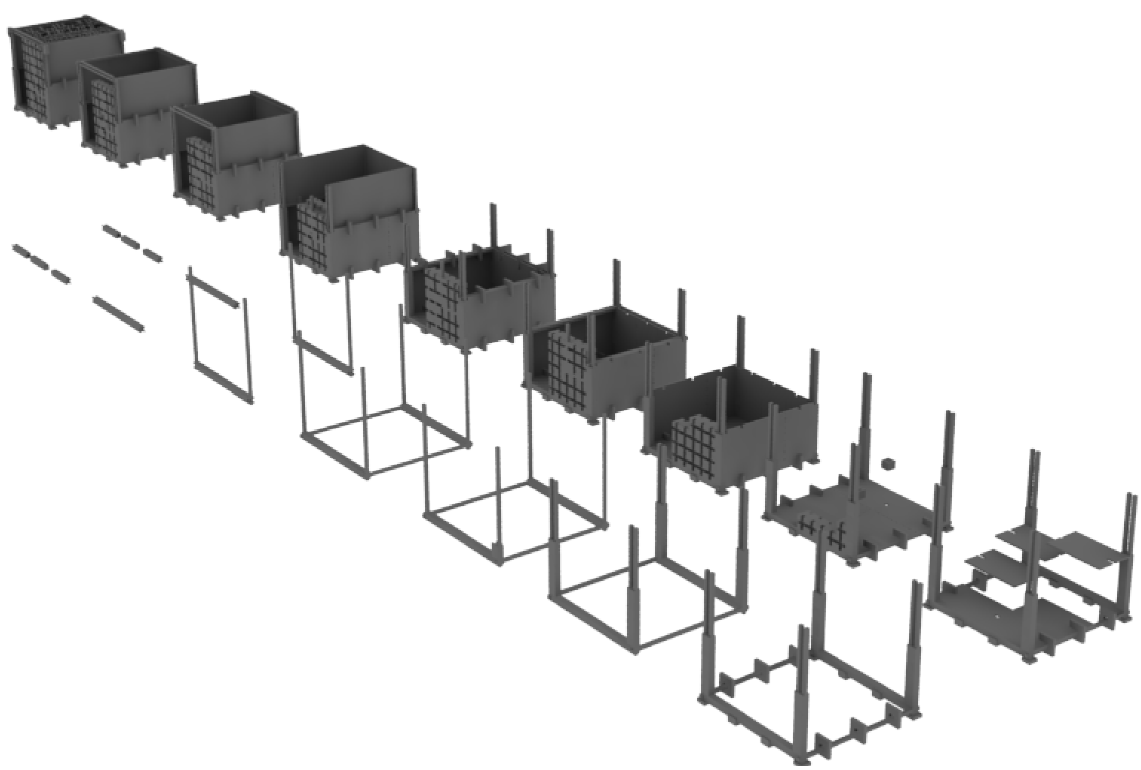
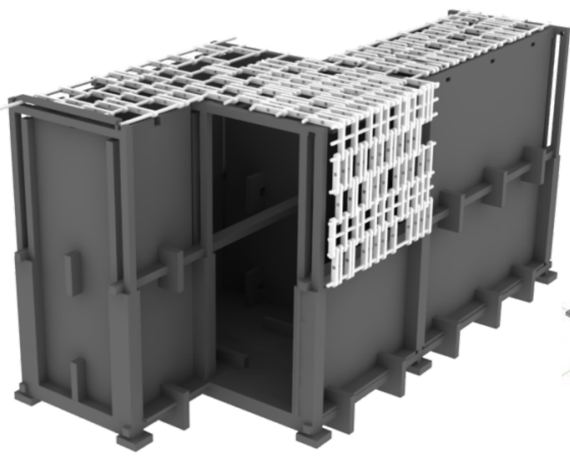
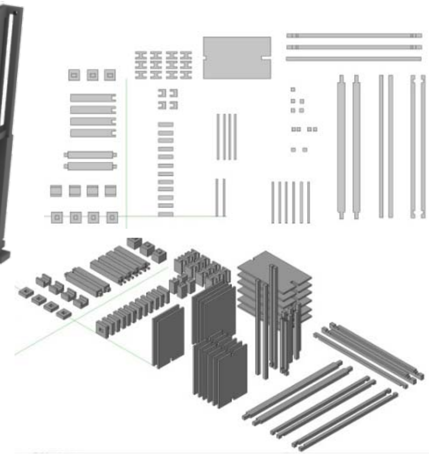
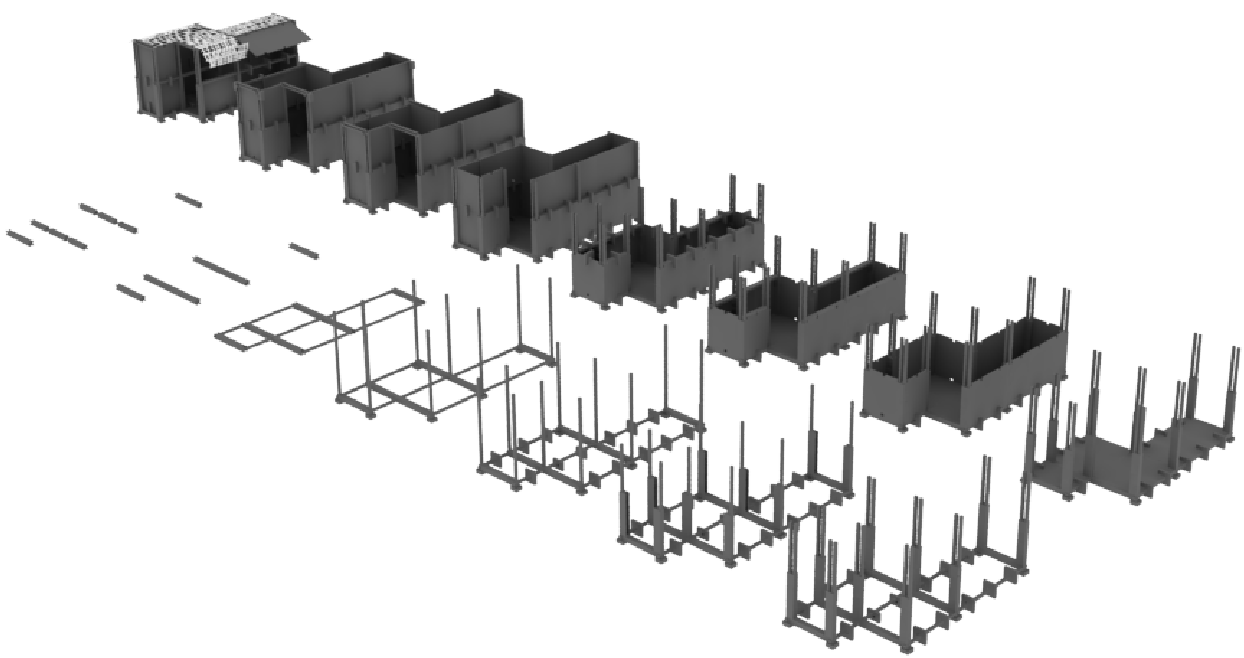


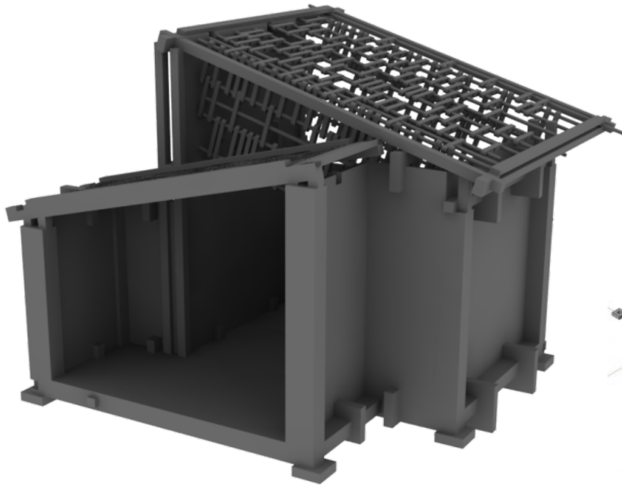
Figure 3. 38 Construction process

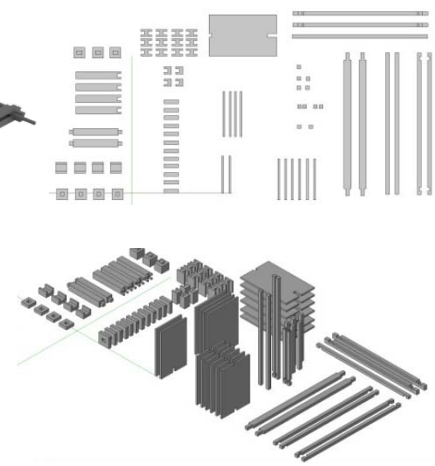
The followings are the transformation of prototype structure A.

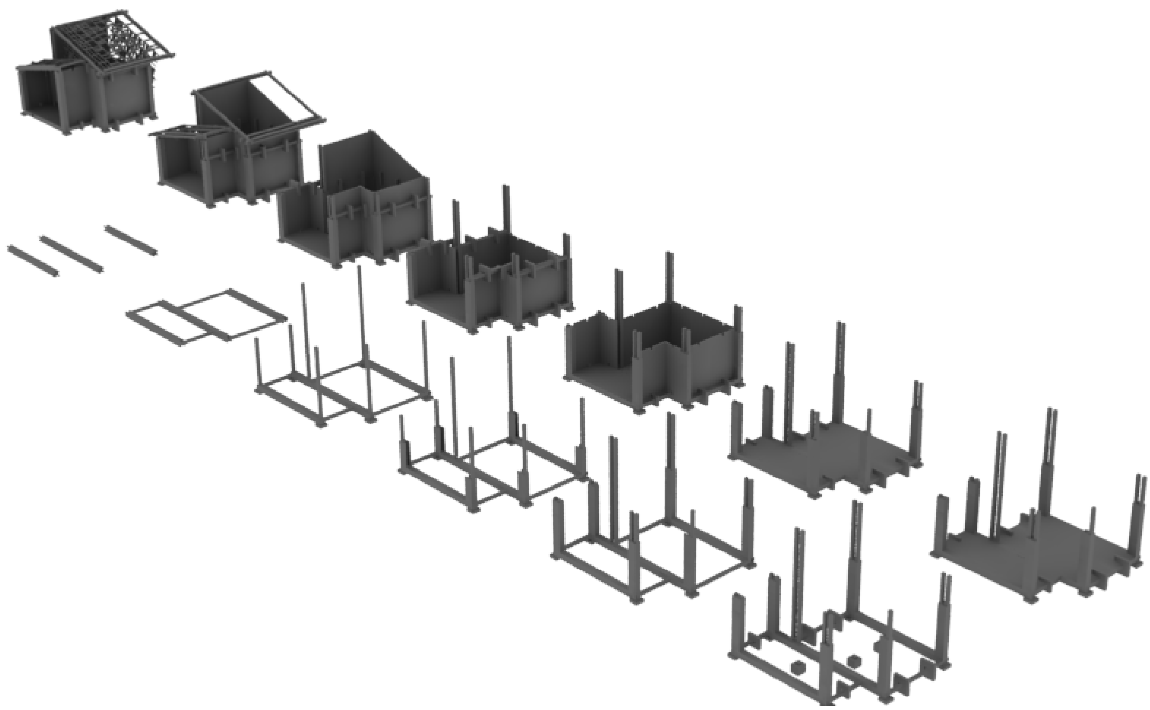


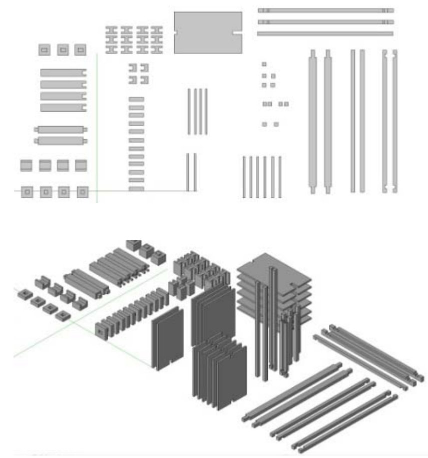


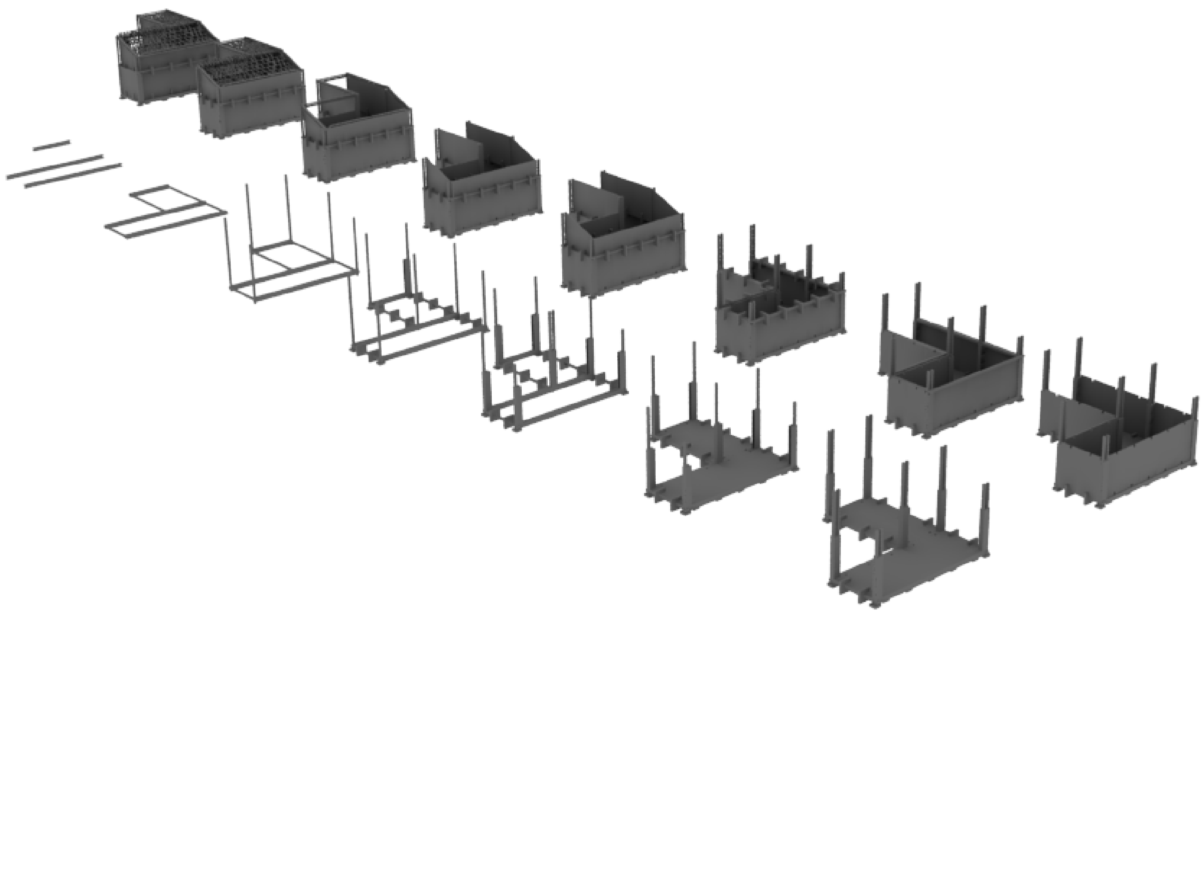


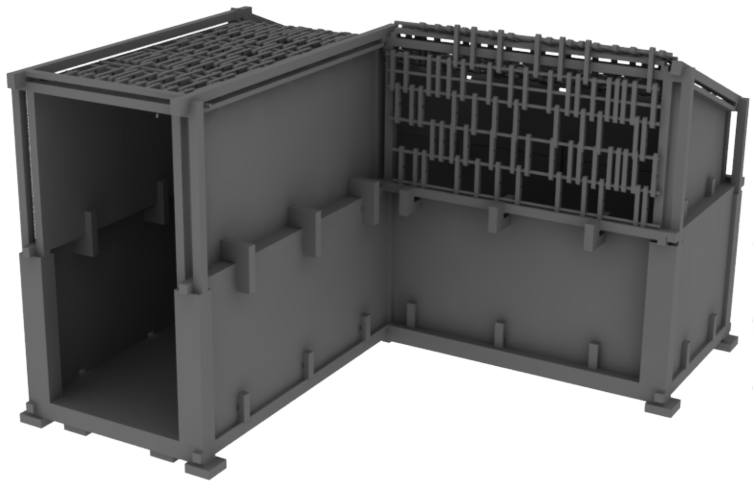


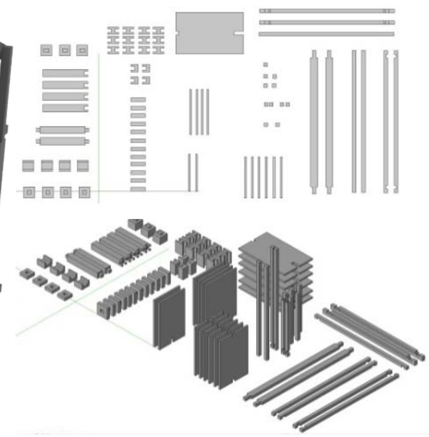


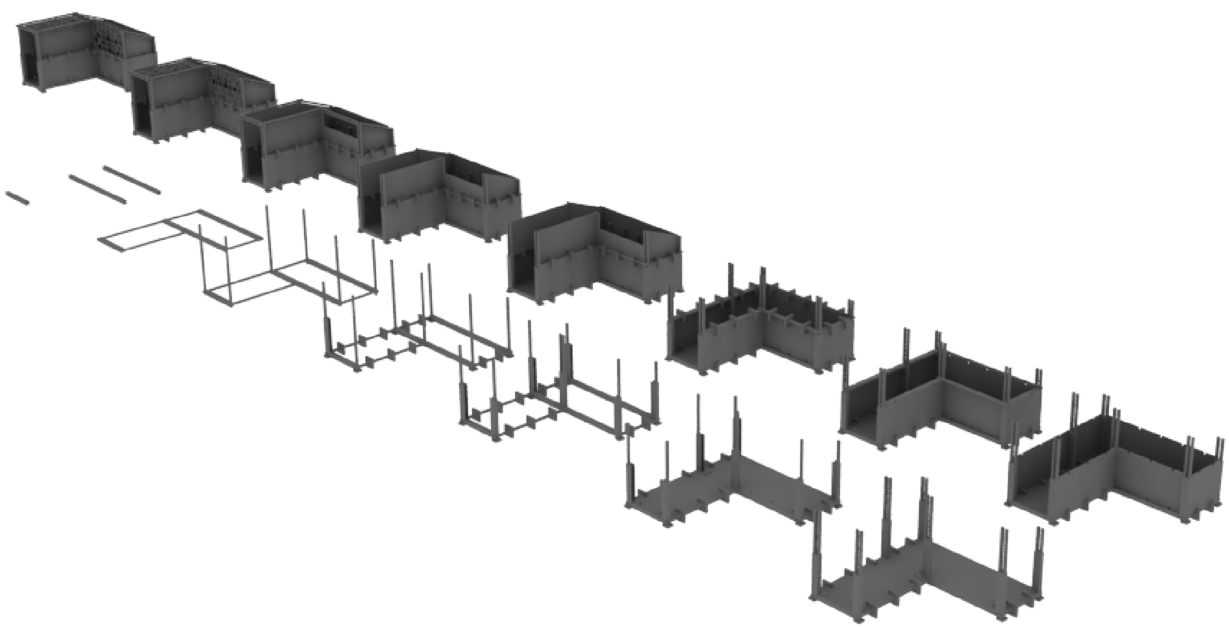


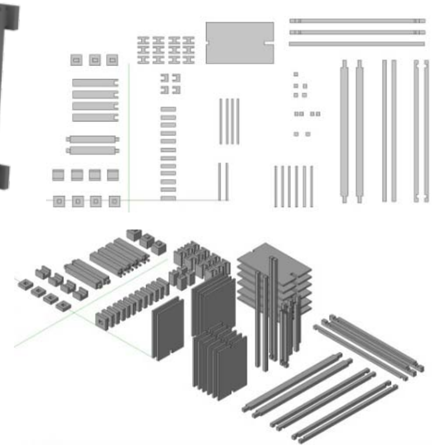


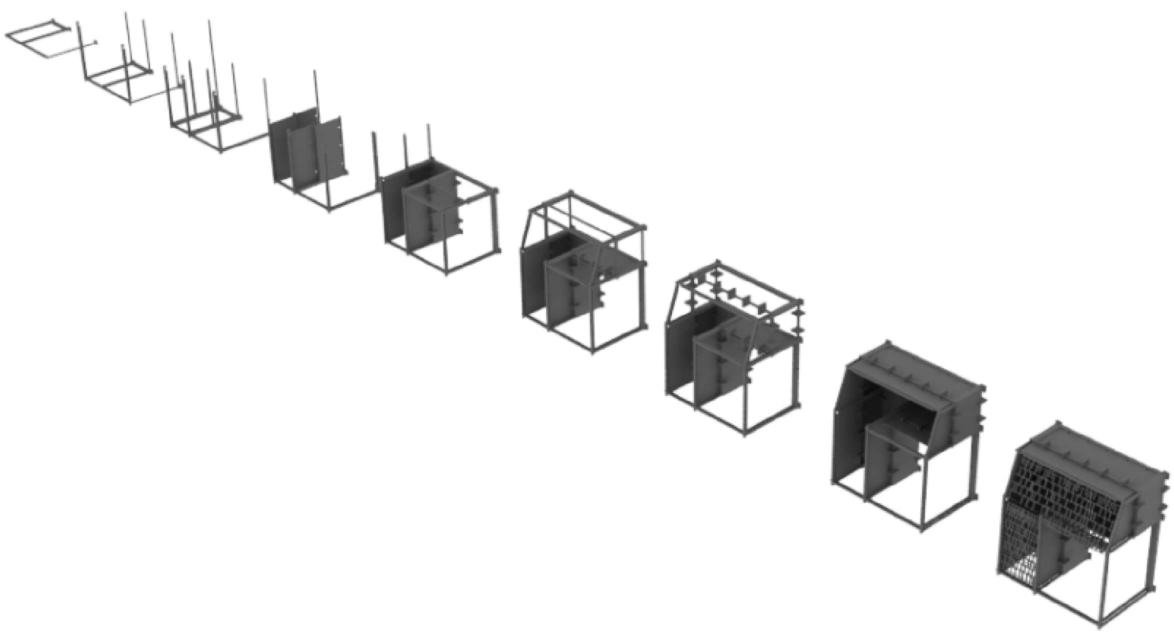


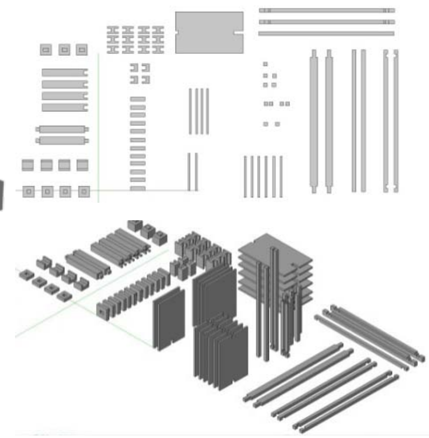


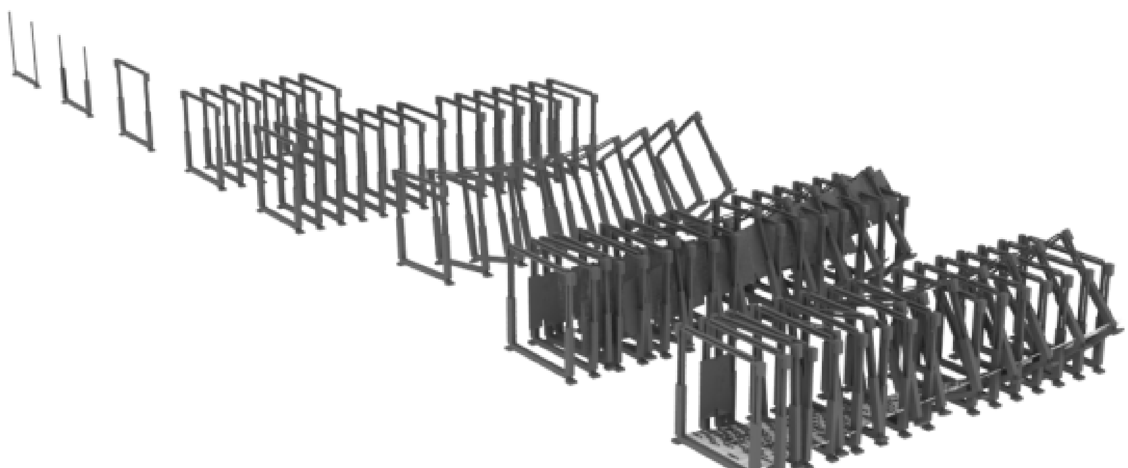












CHAPTER 4

CONCLUSION

In this paper, digital catalogue was utilized in the design process of a prototype disaster shelter. With the use of 17 components from 5 categorized groups, prototype design can be transform through the reconfiguration of the components. Design of furniture or individual resting units can be effectively used for the public after use of the shelter. Morphological transformation of a disaster shelter through the application of traditional Korean joinery system was performed to suggest a flexibility and mobility in a prototype disaster shelter design. It shows the possible application of BIM parametric environment in prefabrication and individual component generation. The parametric conditions in Building Information Modeling (BIM) allow flexible changes in form, dimension and assembly of the components. The unique setting of working with the components, BIM software allows its users to easily modify the general characteristics of components through their parametric changes. The significance of this research is in maximizing the reusability of the building components through their parametric changes and rearrangements with applying traditional Korean joinery system. Traditional Korean architecture is referred to as “moving architecture” due to the efficiency and economy in its constructing process that allows the reuse of building components with its flexible joinery system in assembly and disassembly process and prefabrication method. In this paper, all the 44 components of Korean Joinery system become a series of modules in a digital catalogue for the parametric changes and the rearrangements among the components within BIM environment. Categorization of joinery resulted in focusing on a specific unit in traditional Korean architecture-the bracket systems. The three main types of bracket systems found in traditional Korean architecture are *Ju-Sim-Po* style, *Ik-Gong* style and *Da-Po* style of bracket system. Each style of bracket system was highly favorable throughout Korea. Especially in the case of traditional wooden structures of Korean architecture, flexible joinery and connections in building components benefit effective relocation of its building to other site through dismantling the components. Traditional Korean architecture does not involve any steel connectors rather purely joined through various types of wooden joinery system.

The significance of digital catalog is in that each component can be user dependant. The catalogue allows a user to assign various parameters to the variables of each component according to its usage. By assigning different parameter, the component has flexibility for generating various joint connections enhancing the morphological transformation of a prototype shelter design.

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