THREE-DIMENSIONAL MODEL AND NETWORK-BASED REPRESENTATION OF TRADITIONAL JAPANESE WOODEN BUILDING SYSTEM

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Abstract. Traditional Japanese wooden buildings are designed on the basis of a systematised building system. A typical systematised method called “kiwari” sets parametric/algorithmic rules that determine the dimensions and positions of components. These methods, which facilitate traditional wooden architecture, have cultural value. In this work, the authors report a representation method that is aimed at creating a three-dimensional model and a network-based representation of the traditional Japanese wooden building system. A systematised method that enables the construction of a quadruped gate using the traditional Japanese wooden building system is analysed through algorithm creation and visualisation of relations from the variables of the instances by the proposed system.

Keywords. Parametric Design; Japanese Traditional Wooden Building System; Knowledge Representation.

1. Introduction

Traditional Japanese wooden buildings are known to be designed on the basis of a systematised building system. An example of such a system, called “kiwari,” sets rules for the determination of the dimensions of parts based on the ratio to a pillar or a “taruki” rafter. These methods have also been applied to calculate the positions of parts.

There have been numerous studies on “kiwarisho”, which are traditional Japanese architectural reference documents. Mizoguchi (2006) provided a detailed analysis of how the five-storied pagoda of Horyuji Temple can be interpreted in terms of the building system that systematised column spacing dimensions and rafter distribution. By analysing the kiwari of a two-storied pagoda described in several kiwarisho, Shimizu (2005) conducted a historical investigation of the design system. Systematised construction methods recorded in kiwarisho in this manner play a particularly important part in analysing traditional Japanese wooden architecture. These systematised construction methods, although complex, are known to have a parametric/algorithmic quality. Kado (2011) showed that the traditional design methods used in these forms of architecture can be programmed as an algorithm and used in detailed three-dimensional (3D) modelling. Furthermore, Kado (2017) focused on the cultural value of these
methods, which make possible the construction of traditional wooden architecture, and attempted to define them as a form of knowledge representation by visualising them in a visual programming language (VPL), using dougong brackets as an example.

In this paper, the authors report a knowledge representation method that is aimed at creating a 3D model and a network-based representation of the traditional Japanese wooden building system. The study has two themes: first, considering a node that composes a network-based representation to obtain a formally structured representation and, second, describing features of this building system by analysing the represented network. These themes are studied through the creation of a 3D model of a traditional Japanese wooden gate.

2. Related works

As previously mentioned, there have been many studies on traditional Japanese wooden architecture related to kiwari. Several of these represent traditional wooden architecture using 3D models. However, the research mentioned above is the only example that represents a systematised method as a parametric algorithm and organises the method as a body of knowledge, focusing on its cultural value.

There are several examples of research on traditional Korean “hanok”, in which wooden architectural structures are represented in a parametric manner. In the study by Park et al. (2011), the researchers demonstrated a method for parametrically creating 3D models for the purpose of spreading and industrialising the production of architectural structures built using this method. This report describes the parametric characteristics of hanok and creates a hierarchical organisation of structures that are formed by collections of parts. Kim et al. (2011) also proposed a method for parametrically creating 3D models of hanok. However, their study focused on units for efficiently creating 3D models of several variations of hanok, and it had a different purpose from this research. In the report by Lee et al. (2017), the researchers described the automatic generation of a 3D model of the Daengung-jeon of Sudeoksa Temple. The researchers reported that the dimensions of the parts that make up this structure could be derived from the relation between the depth and width of the whole scale and the height of the column, and they also presented a network representation. This result is extremely interesting. Unfortunately, it is unclear whether this phenomenon is based on traditional design methods or on the rationalisation that was performed to generate the 3D models automatically. However, the result implies that it is possible to analyse construction methods that form the basis for this phenomenon through algorithm creation and visualisation.

3. Method

In this work, the focus is on a “yotsuashimon” quadruped gate that was built using a traditional wooden building system. A 3D model and network representation of the quadruped gate was created based on Daiku Tera Hinagata (Carpenter’s Temple Handbook), a handbook on traditional kiwari (Togashi, 2004). This handbook is based on archives of the Zouhoshoshinden and includes techniques
of other craftsmen, and it has been organised and edited for modern carpenters. Conducting research based on descriptions in the archives themselves was thought to be valuable, but it was estimated that a large number of person-hours would be spent on supplementing portions that lacked information, such as interpretation and details. Therefore, an approach was chosen in which the handbook was used as a reference.

The composition of the representation system for the 3D modelling and network representation is shown in Figure 1. The C/C++ class library includes the variable class, which handles dimensions, etc.; the PoseMatrix class, which handles pose; the Section class, which handles planar shapes and cross-section shapes of components and cut-outs in particular; the Shape class, which handles basic geometric information; the DesignMethod class, which handles design methods of components; the Part class, which handles component templates; and the Instance class, which handles actual instances of the components. One unique aspect of this 3D modelling method is that each class implements functions that can record the interactions that arise in the 3D modelling algorithm as dependencies. Executing programs that were written using this class library will output a network. The network is output in the DOT language, which is a language for describing data structures in network/graph form. This network was visualised using Graphviz, which is a visualisation tool for the DOT language. The 3D model is output in the Geometric Definition Language (GDL) format, which is the object description language used by ARCHICAD, a 3D computer-aided design (CAD) package for architecture developed by GRAPHISOFT. Figure 2 shows a legend for the classes described above for representing the classes as nodes in the network representation. Because using a VPL to write the program results in the program description itself being represented as a network, the proposed system may appear to be a roundabout way of programming. However, this method was chosen so that it would be easy to switch and analyse the elements output by the network. Another reason for this decision was that general-purpose VPLs for 3D modelling are not well-suited to systematically handling the relations found in traditional wooden architecture (Kado, 2016).
3.1. VARIABLE CLASS

According to the handbook, in traditional Japanese wooden architecture, the dimensions of the various components are determined based on the width of the taruki rafters. In the quadruped gate, the height of the rafters is defined to be 1.2 times their width. The distance between the rafters, called “isshi” is defined to be the height plus the width of the rafters. The interval referred to as “hashirama” between the “hashira” pillars is defined as 24 times isshi, and the width of the pillars is defined as 11/100 of hashirama. The Variable class represents those elements that can be expressed as numbers, including dimensional relations such as these. The relation between the width of the rafters and the width of the pillars is shown in Figure 3.

Figure 3. Relation between the width of the rafters and the width of the pillars.

3.2. DESIGNMETHOD CLASS

The DesignMethod class represents traditional design methods. The class is composed of one Shape class object, which represents the shape of the wooden material (“class” is omitted in the following discussion and is represented as “object”), a PoseMatrix object that describes its position and an arbitrary number of pairs of Shape objects and PoseMatrix objects that represent the shapes of cut-outs made during processing. This composition is defined as the base class, and specific design methods are implemented as subclasses of this base class. By providing base classes such as these to handle the common characteristics that each element must handle, it was possible to organise and formally represent the elements. This policy also applies to the Part and Instance classes, which are described later.

Figure 4 shows a network representation of the DesignMethod for a polygonal pillar with chamfering. The Section object denoted as “work section”, is determined by the width of the pillar, and the Shape object denoted as “work shape” is based on this section and the height of the pillar. The cut-out for the chamfering is represented by the four dashed lines, pairs 1-4. Although traditional wooden architecture also includes components with decorative designs known as “eyo”, in this research, only the outline of these components is represented in the DesignMethod object to the extent that these components did not affect other parts. In addition, these definitions do not include the shapes of joints between parts.
3.3. PART CLASS AND INSTANCE CLASS

The purpose of the Part class is to handle the behaviour of the component. The base class has a DesignMethod object, a dictionary of combinations of PoseMatrix objects that represent the relative position and pose of the part when other parts are connected to it, and keys for identifying the objects. For example, the Part class for pillars with attached “koshi-nuki” and “kashira-nuki” beams can be represented by the chamfered pillar DesignMethod mentioned previously and a PoseMatrix object regarding the koshi-nuki and kashira-nuki beams, as shown in Figure 5.

The base class of the Instance class, which represents instances of components, is composed of a Part class object, which forms the template for the instance, a PoseMatrix object, which represents its position and pose, and an array of Instance objects. This array stores the Instance objects that this instance object connects to when it is assembled. The inputs for representing specific components consist of a Part class object, which serves as the template, and several Instance objects for the objects that connect to that instance, and the keys for their connecting positions.

Figure 6 shows an example of a framework composed of pillars and beams, represented as a network using these classes. The inputs for specifying the position and pose were not shown in this network in the arrangement of the instances; this was because the position and pose were determined based on to which instances a given instance was connected. As described above, the fact that the Part object possesses the relative position of the part when another instance is connected to it represents this characteristic. A 3D model was constructed by multiplying the PoseMatrix objects that represent the position and pose of the arranged instances to derive the positions and poses of each instance and create a scene graph.
4. Study Case

Figure 7 shows a 3D model of the quadruped gates that was created using this representation system. The relations between the Variable, Part, and Instance objects of the network representation for this quadruped gate were visualised, and the systematised method that was used to form this gate was analysed.

Figure 8 is a visualisation of the relation between variables and parts. The nodes are connected by directional branches. A hierarchical layout that flowed from left to right was chosen. There are many Part objects that require a large number of inputs when performing 3D modelling, and it was expected that the network would be deep. However, as shown in the figure, the network was shallow, with only 10 levels, and wide. It is widely known that the width of the rafter is the reference point for the other variables. The width of the pillar, which is derived based on the rafter width, serves as a hub and is referenced by many other variables. The figure also shows that such parameters as the slack of the roof, the gradient of the roof, the gradient of the “hien-taruki” rafter, and the gradient of the “ji-taruki” rafter were independent variables.

The Part objects that composed the framework consisting of pillars and penetrating tie beams tended to reference the pillar width, and the roof section tended to reference the width of the rafter width. As a result, the Part objects that composed the framework were concentrated at the top of the network, and those that composed the roof section were concentrated at the bottom of the network.
This shows that it is possible to organise the Part objects by the variables that are required to define them.

This network also included the variables that were calculated by the design method of the part object affecting other variables. These relations are denoted as green branches. There is a common point that these part objects have an established design method. “Masu”, such as the “makito” and the “daito”, are known to be designed with an established design method named “itsutsu-wari” or “itsutsuhan-wari”. Detailed dimensions of masu that are denoted as “toguri height” and “shikimen level” are referenced by other variables. The design method for the curve of the eaves has also been established as the design method for the “kayaoi”. Variables that determined the curve were also outputs from the kayaoi node. The network shows that the systematised method does not necessarily flow to details from the whole.

It is also interesting to note that the part objects for the pillar and the side pillar were defined last in this network. Figure 9 shows the instances network. The network provides a visualisation of the dependencies, following the order of assembly from left to right. The pillar and the side pillar instance objects appear in Levels 2-3 in the network, which consists of 20 levels. This implies that they were assembled at an early stage. Similarly, for the roof section, the other part objects were defined after the kayaoi part object, which specifies the curve of the eaves, had been defined. In the arrangement order of the instance objects, the kayaoi instance object appeared later. No method was used in which the structure was designed as it was being assembled. This implies that the systematised method functions to specify the entire quadruped gate.

Figure 7. 3D model of Quadruped Gate.
Figure 8. Relation between Variables.
5. Conclusion

In this work, an overview of a representation system was presented for the purpose of creating 3D models and network representations for traditional wooden architectural structures, and the system was used to create and analyse a network representation of a quadruped gate.

In Section 3, an overview was given of the representation system. Seven classes were presented, and how to use them as nodes in a network representation was described. In particular, it is believed to be necessary to have an organised class structure to represent the systematised method formally as a network, which
is formalised as building system.

In Section 4, three network representations were shown: the relation between variables and parts, and the relation between instances. In the relation between variables and parts, variables that were calculated based on part objects that possessed established design methods, such as masu and kayaoi, appeared in the network. This showed that the systematised method does not necessarily flow in the direction from the overall design to the details. Furthermore, the part objects were arranged such that they appear to be pulled by the variables that need them as inputs, and that the parts were organised in clusters. This observation is more obvious if a spring layout is used, rather than a hierarchical layout. Observing this relation, together with the relation between instances, shows that in the relation between variables and parts, the part objects for the pillar and the side pillar are defined in a later layer. However, in the relation between instances, the instance objects are arranged in an early layer. The opposite result was found for the kayaoi. These results showed that the systematised method could be used to specify the overall quadruped gate.

By using the custom-developed representation system, it was possible to create a network to visualise the relations between the compositional elements that arise during the creation of a 3D model, from the variables to the instances. It was thus possible to analyse the systematised method that enables the construction of the quadruped gate using a traditional Japanese wooden building system. Future work is planned that will include an investigation of whether it is possible to use this method to represent and analyse architectural structures that were built using other construction methods, by attempting a similar analysis on other types of traditional wooden architectural structures.

References