Geometry classification of Japanese joinery
Object classification by geometry features

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1. Introduction

In traditional Japanese architecture wood is at the same time a structural element and finishing component where complex joinery is the masterpiece. The art of making Japanese joinery is disappearing with time due to the difficulties of making the joints in mass production, and the decreasing number of master carpenters able to realize them.

Strength and appearance are equally important in the fabrication of these joints and if modern machines can produce them, they might further expand the possibilities of wooden architecture which is attracting increasing interest in recent years. CNC is a great tool for joints industrial production, the constraint is that its router follows three axes XYZ and can only cut from one side of the timber when complex joints require cuts from 2, 3 or even all 4 sides of it. And even though there are now CNC machines with 4 and 5 axes, but their production cost is high.

The aim of this research is to classify the joints following the complexity of their fabrication process by hand tools and by CNC machine, to showcase the efficiency of each of them.

2. Observation

As of September 2023, there is a total of 1,688 literature related to Japanese Joinery in the two search engines Google scholar and CiNii, with the keywords “Japanese joinery”, “継手仕口” (Tsugite-Shiguchi) and “木組み” (Kigumi). According to both engines’ categorization only 125 of them are articles whereas the rest are general data including: books, dissertations, projects... (Itatahine and Komiyama, 2023)

This research focuses on books because they showcase the different types of joinery, their classification, and fabrication drawings. The books are written by famous architects, engineers, or master carpenters. The first books dedicated to joinery that were translated to English are “Japanese woodworking” and “Japanese joinery” published both in Japan in 1967 (Sato and Nakahara, 1983), after that “Kigumi” was published in 1970 (Seike, 1977), and then “Wood joints in classical Japanese architecture” was published in 1989 (Sumiyoshi and Matsui, 1991).

All these books were translated in English which makes them important references internationally, however many other books are available only in Japanese alongside with almost all articles published in Japan which makes it hard for a beginner in the language to study this topic.

3. History and development

Going back to history of Japanese joinery referred to as Tsugite-Shiguchi in Japanese language, there remain 21 manuals of them written in Edo period, the oldest one (held by Tokyo Metropolitan Museum) was published in 1728, and from these manuals were identified 129 types of Tsugite−Shiguchi with technical characteristics of each of them (Naito *et al.*, 1988). However according to “建築大辞典” (Kenchiku dai jiten) Architecture Dictionary there’s a total of 80 types of joints in traditional Japanese carpentry (Togashi, 2010) and since these two sources give different information the real number of joints should be further investigated.

From these manuals, templates of joints were categorized first based on their form, then their historical process of change and name evolution were further explained (Naito *et al.*, 1988).

One example of the historical process of change was found in the middle of Muromachi period where splice joints 継手 (tsugite) were supported by an element that was no longer used later on (Daiku dōgu kenkyūkai, 2011).

4. Classification

4.1. TYPES:

The variety of joints evolved from basic forms that were probably units known by the majority of carpenters, to systems of composite forms (Uchida, 1993). And according to (Uchida, 1993), there are five types of joinery classification;

The first one is by component usage, it groups joints according to the structure assembly sequence from the foundation to the framework, and it can include sub-

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classification indicating if the joint is visible or hidden and if it's structural or not.

The second classification is more recent, and based on the joints' configuration following the shapes I, L, T and X. Here the I splice joints are referred to as Tsugite 継手, and L, T and X connection joints are referred to as Shiguchi 仕口 and shiguchi has also a sub-classification to Kumite 組手 for X cross joints and Sashiguchi 差口 for L and T side joints (Daiku dōgu kenkyūkai, 2011).

The third classification is based on the joints' shape which is deconstructed into several basic shapes. And the fourth and fifth ones are based on assembly directions developed by construction companies, the fourth follows three properties: the joined element, the joint configuration, and its specifications whereas the fifth follows two properties: the joint configuration, and its shape-based categorization.

4.2. PROPOSITION

This research proposes another classification method by object geometrical features which measures the complexity of each joint according to:

- **The number of its faces**.
- **The number of sides it needs to be cut from.**

In geometry a face is a planar surface of a 3D geometric object and in this classification (see Table.1.) one part of each joint (male or female part) is identified by the number of its geometric faces, only one end part of the joint is counted because the other part has the same number since it is the geometric imbrication of the first one. The number of faces is a measure of complexity when hand tools are used because each face needs to be cut and planed, so the higher the number of faces the more time and skills are required to realize the joint.

The cutting sides (see Table.1.) represent the sides of the timber to be cut to realize the joint and it's a parameter specific to CNC machine. The router of CNC moves through 3 axis XYZ (length, width and depth) and it can cut following one direction at once straight from the top, so if the joint is complex the timber will require cuts from 2 sides or more, and with a 3 axis CNC the timber needs to be manually rotated to be cut from the other sides. Also, if the joint has inclined faces instead of straight other cutting tools need to be used.

For this research a sample of splice joints 継手(tsugite) was taken from the three books cited above which are (Sato and Nakahara, 1983), (Seike, 1977) and (Sumiyoshi and Matsui, 1991). The joints were collected in a database, organized by names and shapes, and classified in the following table with the parameters introduced above.

Table 1. Geometric classification of Tsugite 継手 joints

	Name	Faces	Cutting sides
1	Isuka tsugi	4	2
2	Sumi isuka tsugi	4	**4**
3	Ogihozo imo tsugi	6	2
4	Kakushi mechigai tsugi 1	6	1
5	Kakuhozo imo tsugi	6	2
6	Kaneori mechigai tsugi	7	2
7	Ari tsugi	7	1
8	Miyajima tsugi	7	2
9	Kakushi mechigai tsugi 2	9	1
10	Otemon splice	9	3
11	hako mechigai tsugi	10	2
12	Kama tsugi 1	11	1
13	Kakushi kanawa	12	2
14	Koshiire mechigai zuki ari tsugi	13	1
15	Juji mechigai tsugi	13	2
16	Hako daimochi	13	2
17	Hako shachi	13	2
18	Hako sen	14	2
19	Mechigai hozotsuki kama tsugi	15	1
20	Sao tsugi 2	15	1
21	Shiribasami tsugi	16	3
22	Kama tsugi 2	17	1
23	Okkake daisen tsugi	17	2
24	Kanawa tsugi	17	3
25	Daimochi tsugi (4 bolts)	17	2
26	Sao tsugi 1	17	2
27	Sumikiri isuka tsugi	18	2
28	Shachi tsugi	18	**2**
29	Kai no guchi	***19***	***4***
30	Hako tsugi	19	**3**
31	Daimochi tsugi (2 tenons)	21	2
32	Four faced kama tsugi	25	**1**

4.3. ANALYSIS

The 32 joints selected were ordered following the number of faces characterizing their geometry, from the simplest "Isuka trugi" of 4 faces to the most complex "Four faced kama tsugi" of 25 faces. However, the other order possible here is following the second parameter or number of cutting sides necessary to realize the joint with CNC machine, again here the simplest joint needs one side cut like "Ari tsugi" and the most complex needs 4 sides cut like "Kai no guchi".

It is interesting to note that the number of cutting sides is not related to the number of faces; it represents the cut path (negative extrusion) from one timber side or more necessary to realize a joint, which means that the simplest joint to realize with CNC machine is not the simplest to make with hand tools, so joints that seem complex might be easy to make by CNC.

The joints that have inclined faces in their geometry like "Shachi tsugi" and "Hako tsugi" are indicated in **bold** and underline (see Table.1.), they have one side of their geometry that cannot be made by straight direction cut of CNC machine, so they will need extra tools to be made industrially.

Another challenging joint for both CNC machine and hand tools is "kai no guchi" which number is indicated by **bold** and *italic*, because the timber used to make it needs to be round shaped and thus it is hard to fix it on a planar surface to cut it.

4.4. DETAIL

To understand how the geometric faces were counted, the example of "Ari tsugi" faces counting is showcased (see Figure 1) the goal is to mark all the parts that need to be removed to realize the geometric shape of the joint, noting here that "Ari tsugi" is one of the simplest joint with only 7 faces and so counting complex joints like "Daimochi tsugi (2 tenons)" requires more attention and a validation step.

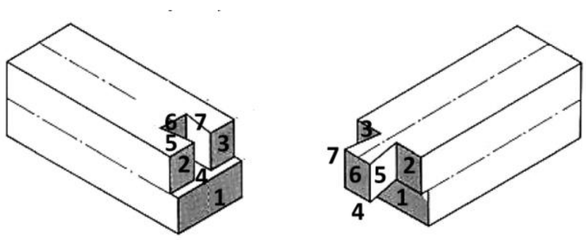

Figure 1. The number of faces of Ari tsugi joint.

Source: (Sumiyoshi and Matsui, 1991) modified by Author

For the cutting sides the key point is to visualize how the CNC router works following a straight direction cut from the top as shown in the cut **1** below (see Figure 2), then the timber needs to be flipped manually to make cut **2** from the top and here we can see that like the example of "Isuka tsugi" most of the joints have 1 side or 2 side cuts of same shape which makes them in theory relatively easy to realize industrially.

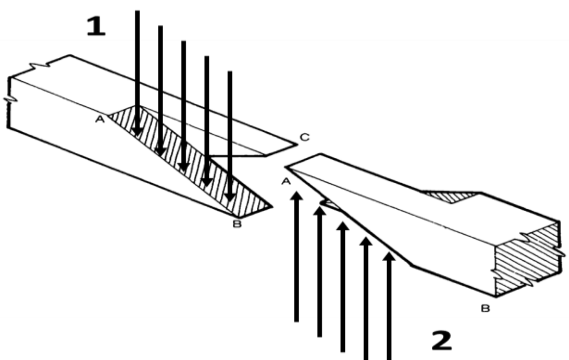

Figure 2. The cutting sides of Isuka tsugi joint.

Source: (Sato and Nakahara, 1983) modified by Author

When the cut is not perpendicular to at least one of the four profiles of a joint, it's not possible to realize it by 3 axis CNC (see Figure 3), for the "Sumi Isuka tsugi" joint if CNC is used like shown in **1** the cutting path of the router would be perpendicular to the profile which is incorrect compared to the joint shape shown in the drawing, so hand tools are theoretically more suitable to follow the correct inclined cut **2** (see Figure 3). Other machines that are more flexible on their cutting direction can be used like the electric saw, however the CNC machine can still be used if it has more than 3 axis.

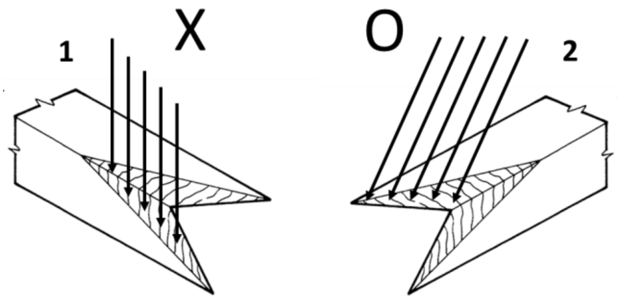

Figure 3. The inclined sides of Sumi Isuka tsugi joint.

Source: (Sato and Nakahara, 1983) modified by Author

5. Conclusion

Japanese joinery is a large panel of ingenious wooden connections that are attracting more international attention with the increasing sustainability awareness in the construction field. Since wood is a renewable resource, engineered timber products are environmentally friendly, can be prefabricated and fast to assemble on-site. The key word to revive Japanese joinery now is their 'adaptation' to mass fabrication tools.

When it comes to mass fabrication, CNC machine is a tool that has been used worldwide these last decades by construction companies to process timber, and thus researching a method to realize joints by it would open the gates to industrialize them.

Now the manuals about Tsugite-Shiguchi written in around Edo period are the main sources of the books that we can find nowadays with series of compiled joints that are used in this research to propose a new kind of classification. And here it's important to note that there was some ambiguity in the terminologies of some joints in the books available in English that might be due to their different translation sources.

Previous research concluded is that joinery evolved through history from basic forms to systems of composite forms specific to regions or carpentry guilds where joints are found them now. And this research enumerated several classification methods developed through time for different purposes.

Now this research proposes a new classification method suitable to measure the fabrication steps of the joints by both CNC machine and hand tools.

The principle is to study the geometrical features of joints and classify them first by the number of joint faces, for counting the hand fabrication steps, and then classify them by number of cutting sides for counting the CNC machine fabrication steps.

The result proved that the manual fabrication steps are not relative to the CNC fabrication steps and an easy joint to make by CNC might have several steps to realize by hand however it’s important to note here that manual fabrication is more precise since CNC cannot make sharp edges but it’s still interesting to start by CNC and finish by hand to gain time.

The classification above was done on a sample of 継手 (tsugite) joints and need to be performed on all the known joints to allow a proper general conclusion of the classification relevance and also fabrication experiments with CNC machine and manual tools need to be performed on timber to confirm the findings obtained.

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