Local-reconfigurable Freeform surface with plywood

From the perspective of Japanese Tsugite-Shiguchi

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This research exhibits a novel construction method for Freeform surfaces with plywood, without using metal joints and bending. By introducing the perspective of Japanese Tsugite-Shiguchi, the research aims for a drastic change from node-oriented thinking to module-oriented thinking. This paper focuses on the investigation of how to simplify fabrication processes, how to realize the environmental capabilities of Freeform wood structures, and how to provide redundancy and stability to the whole architectural system. In order to challenge these problems, we examined three discretion methods. As a result, we have been successful to produce a double-layered surface, filled with triangular mesh, implemented only by cutting one sheet of plywood. Moreover, the system has also acquired a new nature: local-reconfigurability, wherein it can react and adapt to fit local parameters and requirements.

Keywords: *Digital fabrication, Freeform timber, Without metal and bending, Discrete surface, Minimal components for mega-assembly*

INTRODUCTION

Two-thirds of the land in Japan is covered by mountains and forests. By using this rich natural resource efficiently and effectively, Japanese people have built their own wooden culture. Nowadays, interest in traditional wood construction methods is increasing in the world because of the nature efficient characteristics of wood. It is naturally renewable, fully recyclable, energy efficient, and reduces CO_2 emissions. On the other hand, recently open-source housing projects, such as WIKI-HOUSE and MIT Larry Sass's research, have become well known in the maker movement.

Of course, there are simplified fabrication processes for building houses. However, in areas with harsh climates such as hot and humid Japan, these systems cannot sufficiently respond to climates because they can only express identical forms. Therefore, the problem is that the existing wooden construction methods have difficulty in realizing the Freeform surface, which is able to be represented using computer graphics.

To see the previous research to realize the Freeform structure by wood, there are three major shortcomings.

- First, the steam bending and 5-axis machining processes, which are almost entirely related research avenues that have been employed as fabrication methods, are far too complex to be available to the general public. The complexity of fabrication hinders the generalization of the wooden Freeform structure. Complexity means a lot of labor, which demands immense time, cost, and skilled professionals.

- Moreover, in order to be actively used, the method needs to have an architectural performance. In previous studies and methods, almost all of them were used for a facade or a temporary pavilion. Think of the human body. Our body is not only made of bones but also consists of skin and flesh. The skin responses to the outer environment, while flesh regulates it, and the bones support them. In order to perform better, the structure should also have the ability to put skin and pack flesh in addition to building the bones.

- In addition, the most serious problem is that once you assemble, it is hard to deconstruct. This is most glaringly apparent in the Frei Otto's Mannheim Pavilion. If a problem occurs to a part of the building, you will have to replace the whole wall or structure. In other words, the system does not have redundancy.

The purpose of this paper is to simplify fabrication processes, realize the greater performance of Freeform structure, and provide redundancy and stability to the whole architectural system. The advantage of using wood essentially lies in the reconfigurability it has, and Japanese wooden architecture have been metabolized by grafting the damaged member and replacing it by relaying the new member. In order to use this nature of wood, the system should consist of minimal components, which are reconfigurable. In the following chapters we will try to solve these problems by looking from the perspective of Japanese Tsugite-Shiguchi and will also demonstrate three approaches through prototyping -"Wooden Fabric" (Figure1).

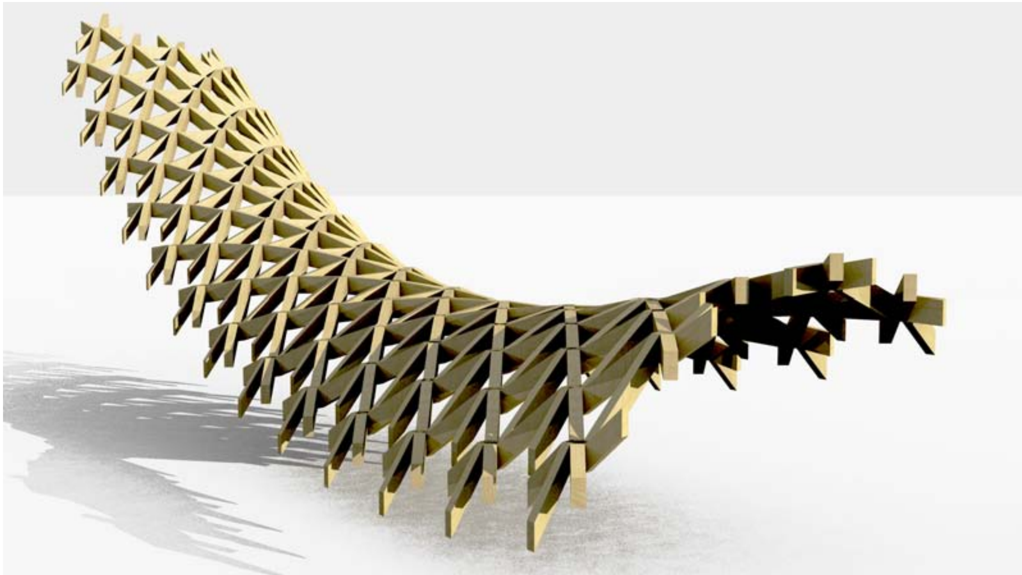


Figure 1
WOODEN FABRIC
by KOKI AKIYOSHI

Figure 2
Shiguchi. Collaboration with additive manufacturing and subtractive manufacturing.

METHOD

Tsugite-Shiguchi

This research is based on the perspective of Japanese Tsugite-Shiguchi, which is a variety of Japanese traditional joining techniques without using nails and glue. Tsugite is a technique to connect materials to augment the lack of length of materials, while Shiguchi is a technique to connect materials at a specific angle. In this respect, we employ this method as a key concept to realize the system, which can easily be reconfigured and reconstructed.

It is said that there are around 200 types of Tsugite and Shiguchi, however, we invented new types of Tsugite-Shiguchi for the system. This is because we decided to assemble three beams as a node, with Shiguchi. In the existing pattern of Shiguchi, a method to combine three beams in a two-dimensional plane did not exist. With the new type of Shiguchi proposed in this paper, one out of three beams can be divided into two parts in the middle (Figure 2).

Instead, the new type of Tsugite had to be designed so that the divided beams can be connected next to normal beams. So, we designed interlocking details to fit each beam together well (Figure 3).

Discrete Geometry

To realize feasible segmentation, the target geometry has to be resolved in a discrete way. In this paper, we used triangle meshes to do this. The primary reason to use a triangle for this research is that we intend to acquire strength due to the goal of creating

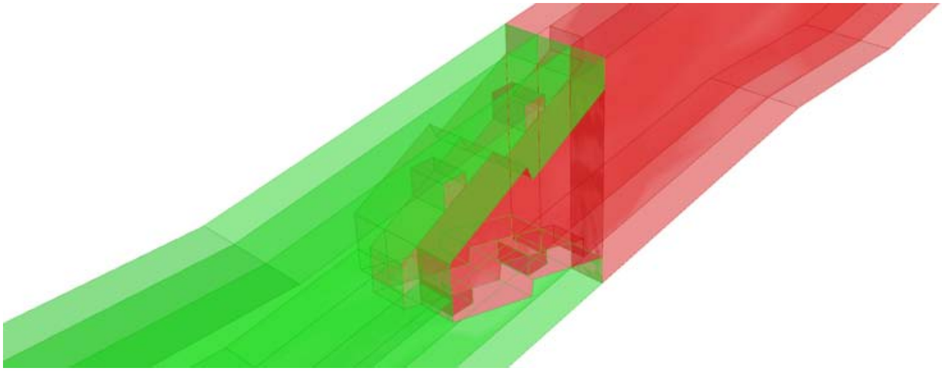


Figure 3
Tsugite. It is a further evolution of the present Daimochi-Tsugi.

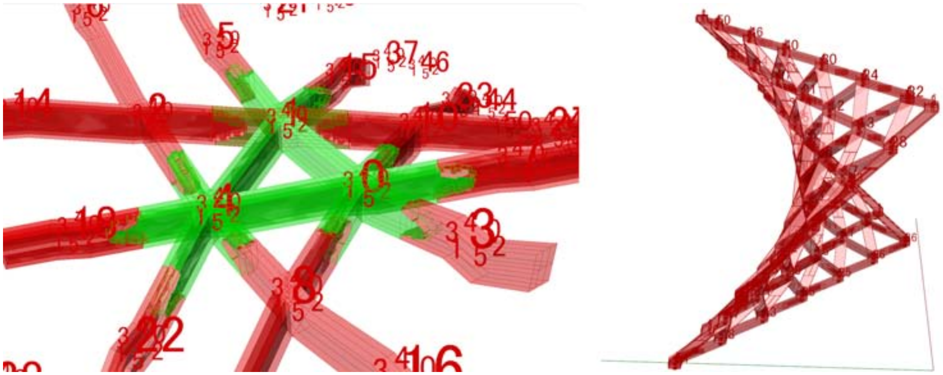


Figure 4
Discrete geometry. For example, the minimum surface is imported.

a Freeform surface that can be used as a structural framework. The second reason is that we intend to add surface covering, or "skin".

Of course, CNC milling machines are able to cut curves as numeric curves, however, the region defined by curved materials is the Freeform surface. But, by approximating each curve to a poly-line, the region can be defined by only using planar surfaces. In this method, you can see the module as three beams meeting at a node and not as six beams meeting at the node (Figure 4).

Discrete Materials

Beams we used in this research were not square timber such as two-by-fours, but custom-made timber derived by cutting one sheet of plywood. If you use mass-produced square timber, you are sure to bend it.

However, it is easier and more efficient to get curved parts by just cutting the curved stuff from one sheet of material. The relationship of the milling machine and plywood is similar to the relationship of scissors and paper. You only have to cut shapes from the paper every time you need them. In addiction, because plywood is originally made by laminating thin materials, if you need thicker materials, it is possible to make your original square timber by cramping the parts together (Figure 5).

Discrete Fabrication

We think that the most rational construction method is the integration of additive manufacturing and subtractive manufacturing. Of course, the 3D-printer can create complex objects out of nothing. However, when you want planar shapes, it is obvious that the easiest way to produce them is to cut and derive from mass-produced materials. This becomes even truer when the scale of the structure becomes larger such as architecture.

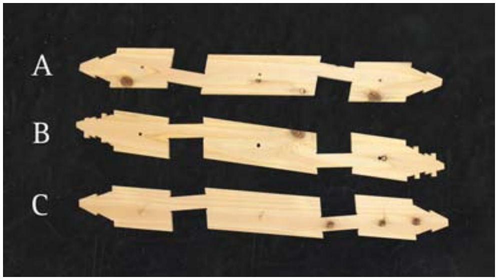
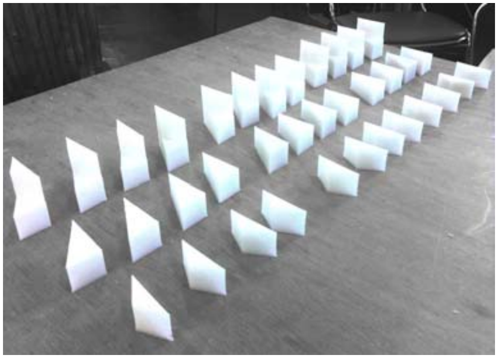


Figure 5
Discrete Materials. Taking dowel holes for guidance, pressure bonding with A, B, and C.

On the other hand, in terms of complex 3D-milling, you will need a machine such as a 5-axis milling machine, a robotic arm, or something expensive. In fact, the using of these machines will most probably increase the cost and time of the process dramatically.

Figure 6
Discrete Fabrication. 3D printed joint parts.



By combining these two manufacturing techniques, we can decrease the 3D-milling process. Only you have to do is ADD three-dimensional shapes (Figure 6). In addition, if we use the 3D-printed parts as a mould, the efficiency of the process should improve even further.

Figure 7
Wooden Fabric. This prototype is based on 7 modules.

Figure 8
Wooden Fabric. "Local-reconfigurability"

WOODEN FABRIC

Based on the methodology above, we invented a new construction method and software, which converts the user-made surface data to constructible objects in the real world (Figure 7) (Figure 8). The construction method is based on the module looks like a snowflake, which is consists of three long members and three short members (left in Figure 9). The longer one has male joints, the shorter one has female joints on its two edge points (right in Figure 9). Each module is able to connect to six adjacent modules by interlocking each Thugite.

To use this module-oriented method, in other words discretion method, the structure is locally defined, able to construct locally, and also able to reconfigure locally. Thus, if you construct Freeform structures using this system, like Lego bricks, you only have to join each part without needing any complex blueprints.

Constraints

The beams, which are used in this research, can only bend in one direction. This is an important requirement of this system. Hence, we have to constrict directions of bending, using congruent isosceles triangle as the smallest unit for dividing the mesh, so that torsions will not occur on each beam.

Algorithms

First, we make a bounding box from the surface that user created, deconstruct the box, sort the plane parallel to the surface, and define that as the projection plane. After dividing this projection plane to the homogeneous grid, the grid is projected onto the surface. Then, vectors from vertices on the projected surface parallel to the normal vector of the projection plane are generated. (Figure 10).

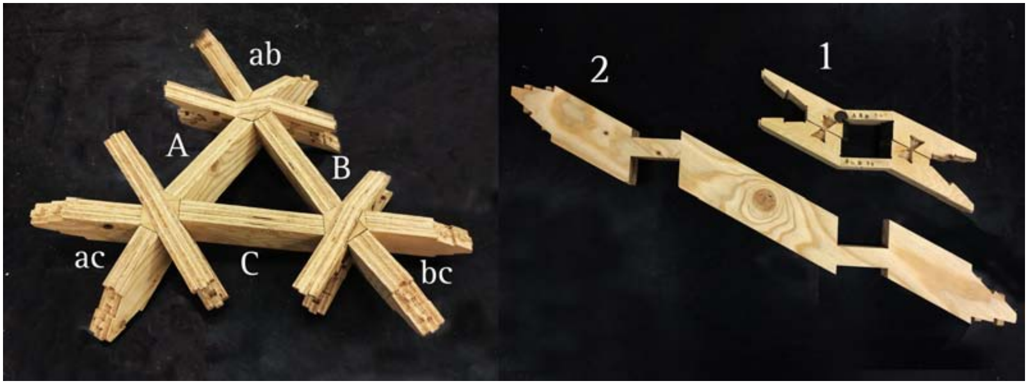


Figure 9
Wooden Fabric. (left) Each module, consisting of three long and short members, is able to connect to six adjacent modules by interlocking each Thugite. (right) 1: Shorter has female joints 2: Longer has male joints on its two edge points.

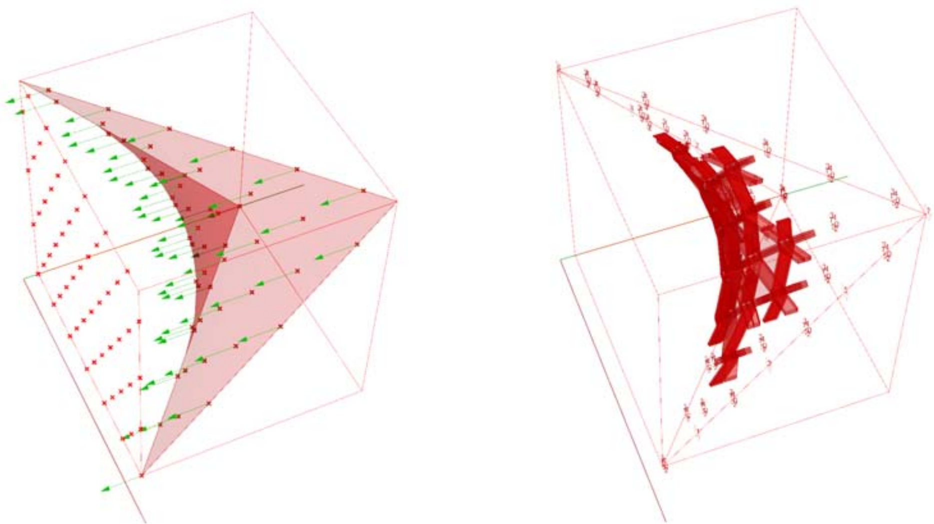


Figure 10
Algorithms. (left) Generated points are projected to the imported surfaces. (right) Surfaces are generated by connecting projected points.

Figure 11
Fablab Hiroshima-Akitakata.

Figure 12
The whole shape of the architecture is generated by prototyping through the workshop with users.

Social implementation through the workshop

Using this system, we are building the architecture next August. We are going to insert the Freeform wall in an old Japanese garage, in order to be used as the workshop offering digital fabrication (Figure 11). For this project, we ran the workshop for the users of this shop. We used the clay as a means of modelling because most participants do not have enough literacy to realize what they imagine (Figure 12). However, using 3D scanners, they can import 3D scanned clay models to the software and fabricate real Freeform wooden structures by just pushing the run button of the machine. Eventually, prototypes, which are produced by the users through this workshop, are going to integrate and become increasingly sophisticated, until the final forms are reached. Through this implementation, we are going to examine the performance of this system.

CONCLUSION

In conclusion, the system has acquired a new aspect, local-reconfigurability (Figure 13). As clothes can be patched up when they are ripped or spotted, this character enables the architecture to be updated by replacing and reconfiguring the module, if an error occurs in a part of the system. On the other hand, if you want to build your house, you would get a loan because it will cost over thirty thousand dollars in Japan. However, using our system, it will able to begin to build the house depending on your budget because the whole structure is defined locally. This is to say, the incremental construction is being realized. This will contribute to rebuild areas destroyed by disasters and to develop impoverished areas. Besides, addition and subtraction to a building can also come easily.

Moreover, we have been successful in producing a double-layered surface filled with a triangular mesh, made of plywood (left in Figure 9). The skin of the structure is not only filled with wood, but it can also be filled in traditional ways with clay and earth. Therefore, the system can be used locally in combination with traditional construction methods. This will contribute to forming townscapes that reflect and complement the environment.

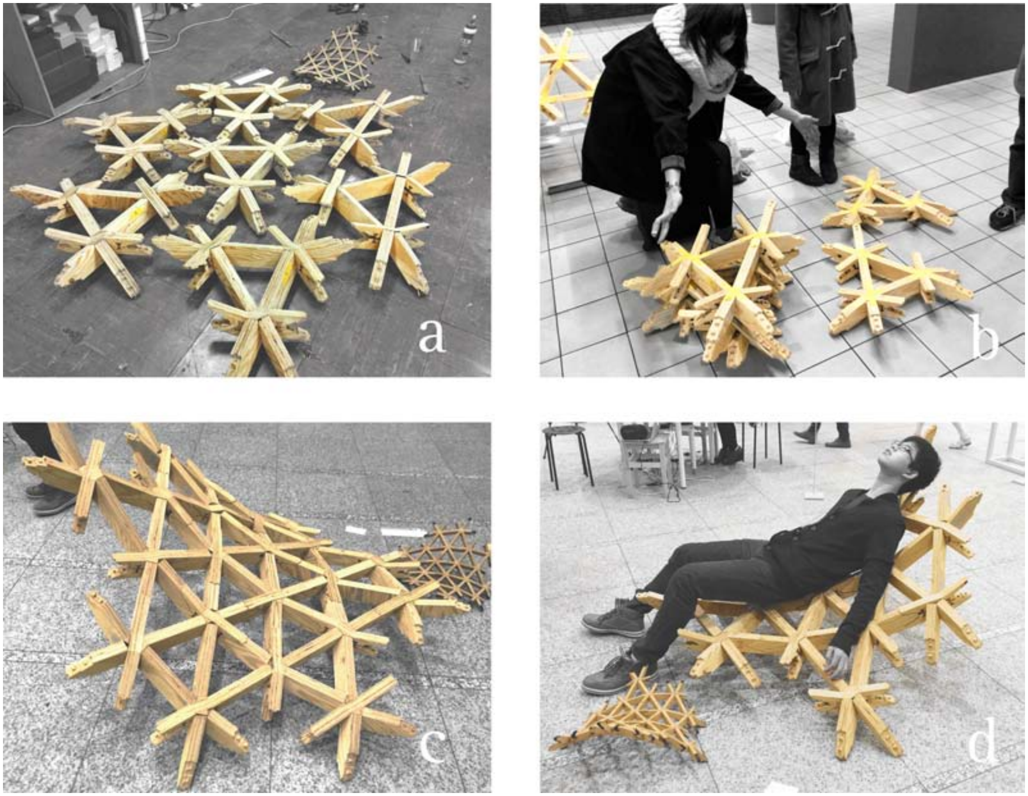


Figure 13
We have also proved that our system is able to construct structures "locally" and structures is strong enough.

REFERENCES

Kanasaki, Kenji and Tanaka, Hiroya 2013 'Traditional Wood Joint System in Digital Fabrication', *Proceedings of the 31st eCAADe Conference – Volume 1*, Delft, The Netherlands, pp. 711-717

Menges, Achim 2011 'Integrative Design Computation: Integrating material behaviour and robotic manufacturing processes in computational design for performative wood constructions', *Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)*, Banff (Alberta), pp. 72-81

Ohshima, Taisuke, Igarashi, Takeo, Mitani, Jun and Tanaka, Hiroya 2013 'WoodWeaver: Fabricating curved objects without moulds or glue', *Proceedings of the 31st eCAADe Conference – Volume 1*, Delft, The Netherlands, pp. 693-702

Sass, Lawrence, Michaud, Dennis and Cardoso, Daniel 2007 'Materializing a Design with Plywood', *25th eCAADe Conference Proceedings*, Frankfurt am Main, Germany, pp. 629-636