Local-reconfigurable Freeform surface with plywood
From the perspective of Japanese Tsugite-Shiguchi

Koki Akiyoshi
Hiroya Tanaka Laboratory

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

ABSTRUCT
This research exhibits 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 performative Freeform structure of wood, and how to provide redundancy and stability to the whole architectural system. In order to challenge these problems, we examined three methods: 1) geometry discretion method, 2) material discretion method, 3) fabrication discretion method. 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.

BACKGROUND
Two-thirds of the land in Japan are covered by mountains and forests. By using this rich natural resource efficiently and effectively, Japanese people have built their own wooden culture. Nowadays, interest for these traditional wooden construction is increasing due to the nature efficient characteristics of wood, such as naturally renewable, fully recyclable, energy efficient, CO2-saving. This can be also said for foreign countries. Some people say that in the 21st century there will be a lot of high buildings, not of steel and concrete but of wood, in the world. On the other hand, compared to other materials, wood has never acquired a “general” method to construct Freeform structure.
First, the complexity of fabrication hinders the generalization of the wooden Freeform structure. Complexity means a lot of labor, which demands for 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 are used for a facade or a temporally 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 be more performative, 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 them. 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 advantage of using wood essentially lies in the reconfigurability it has, and Japanese wooden architecture has 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 has reconfigurability.

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".

METHOD

0,Tsugite-Shiguchi

This research is premised 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.

It is said that there are around 200 types of Tsugite and Shiguchi, but 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 beam can be divided into two parts in the middle (Figure 1).

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 beams together well (Figure 2).

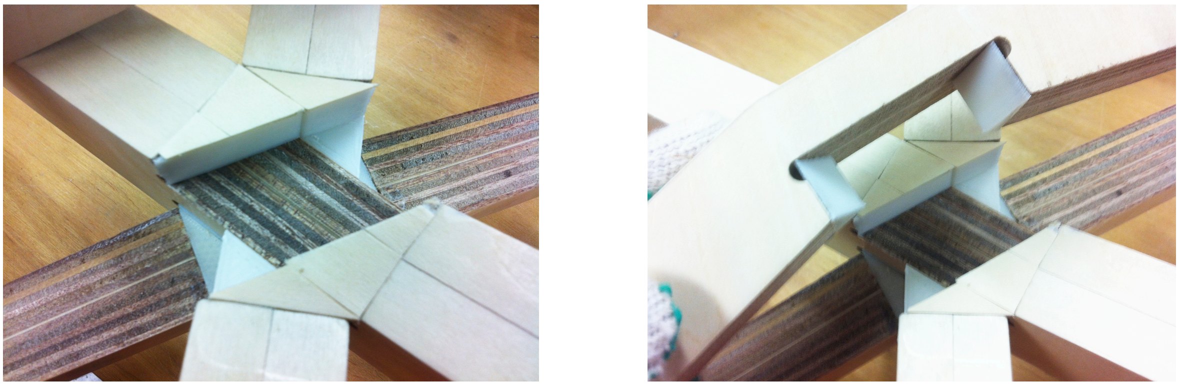

Figure 1
Shiguchi

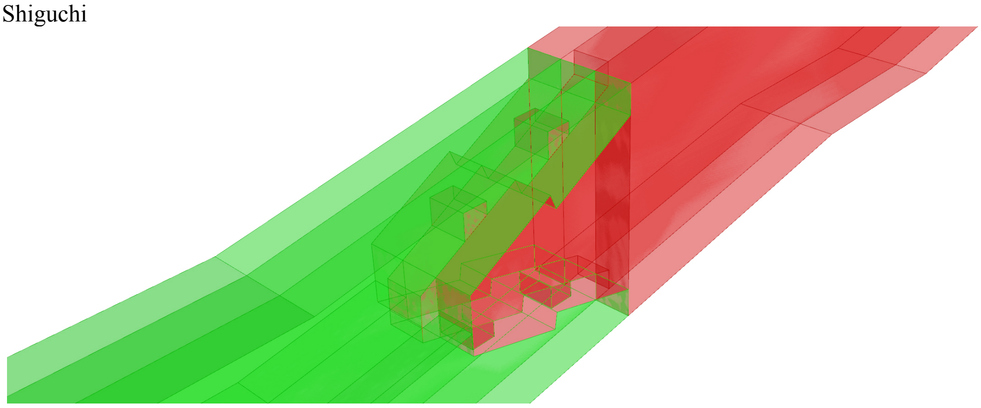

Figure 2
Tsugite

1,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 a Freeform surface that can be used as a structural framework. The second reason is that we intend to put skin.

Of course, CNC milling machines are able to cut curves as a numeric curve, 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 3).

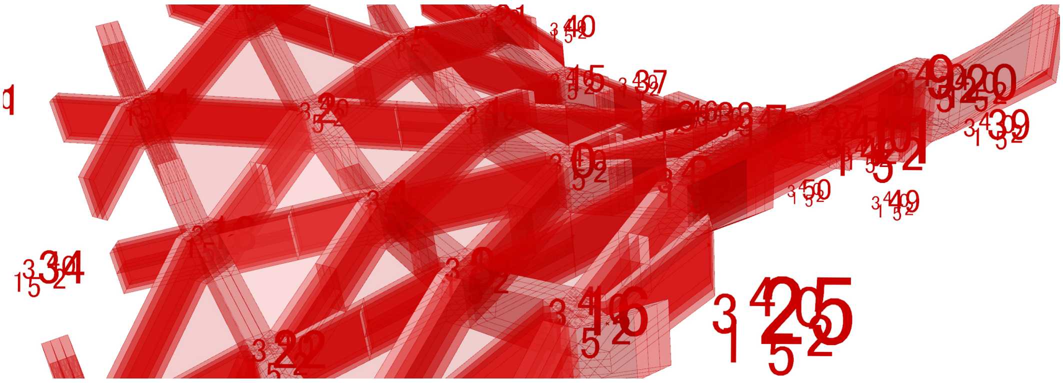

Figure 3
Discrete geometry

2,Discrete Materials

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

But, it is more easy and efficient to get curved parts to just cut 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 4).

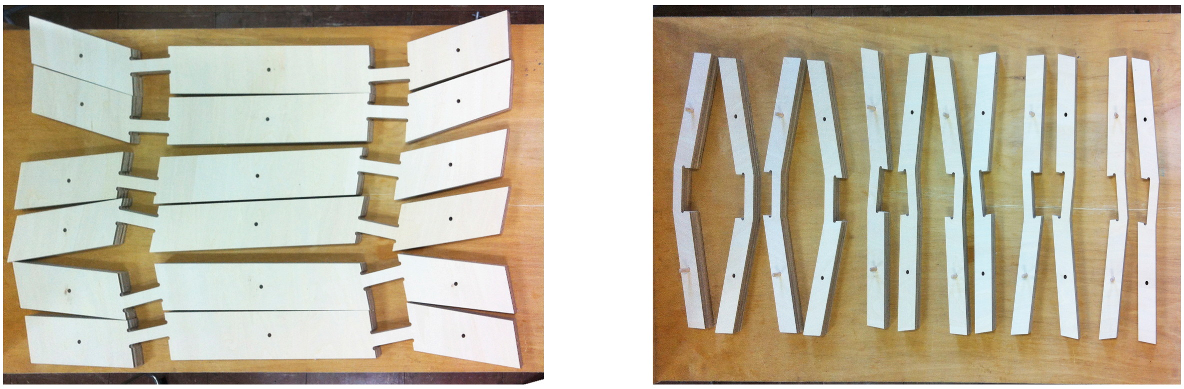

Figure 4
Discrete materials

3,Discrete Fabrication

We think that the most rational construction method is the integration of additive manufacturing and subtractive manufacturing. Of course, 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 more true when the scale of the structure becomes larger such as architecture.

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

By combining these two manufacturing, we can decrease the 3D-milling process. Only you have to do is “add” three-dimensional shapes (Figure 5). In addition, if we use the 3D-printed parts as a mold, the efficiency of the process should improve even further.

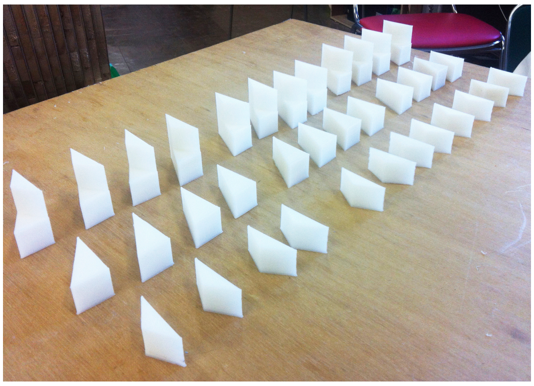

Figure 5
3D-printed parts

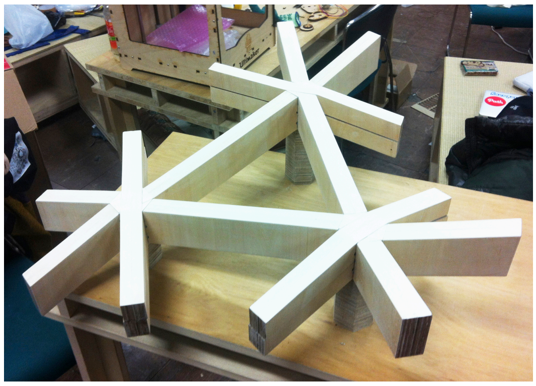

Figure 6
Wooden Fabric (2013) Koki Akiyoshi

Wooden Fabric
Based on the methodology above, we convert the user-made surface data to a constructable object in the real world (Figure 6).

Constraints
The beams, which are used in this research, can only bent 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 beams.

Algorithm
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 7).

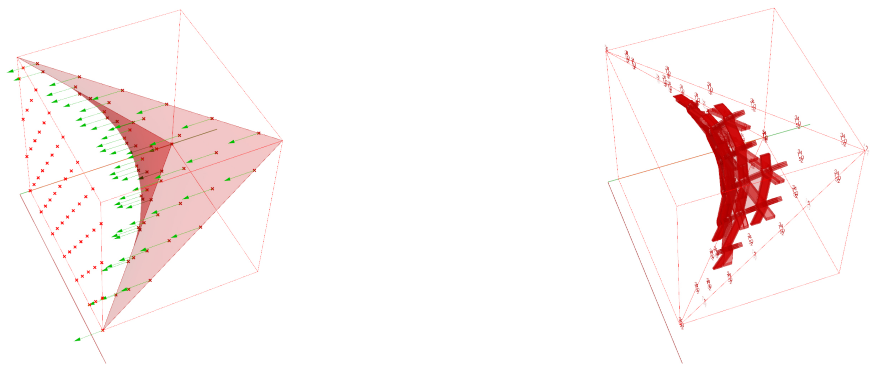

Figure 7
Algorithm
Discrete geometry

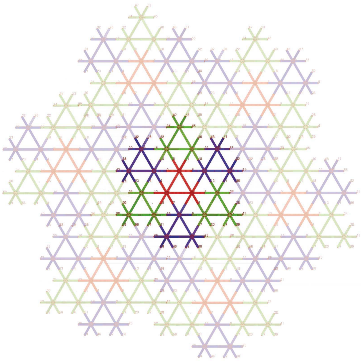

Figure 8
Discrete fabric

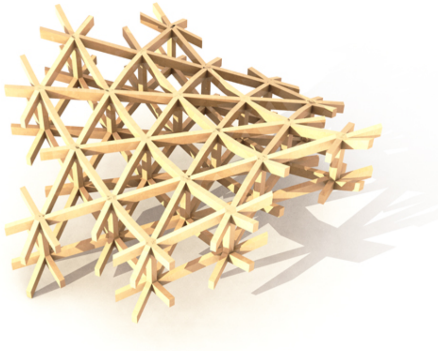

Figure 9
Double layered surface

CONCLUSION

In conclusion, we have been successful to produce a double layered surface filled with triangular mesh, made of plywood (Figure 9). The skin of the structure is not only filled with wood, but they can also be filled in a traditional way such as clay and earth. Therefore, the system can be used locally in combination with traditional constructing methods.

Moreover, the system has acquired a new character to the structure, local-reconfigurability. As clothes can patch up when they are ripped or spotted, this character enables an architecture to update by replacing and reconfiguring the module, if an error occurs in a part of the system.

FUTURE WORK

Using this system, we are building the architecture in next April. We are going to insert the wall in the old Japanese garage, in order to be used as the FabLab (Figure 10). Through this implementation, we are going to examine the performance of this system.

Figure 10
FabLab Hiroshima

REFERENCES

Lawrence Sass, Dennis Michaud, Daniel Cardoso : 2007, "Materializing a Design with Plywood,"Predicting the Future [25th eCAADe Conference Proceedings / ISBN 978-0-9541183-6-5] Frankfurt am Main (Germany) 26-29 September 2007, pp. 629-636

Taisuke Ohshima, Takeo Igarashi, Jun Mitani, Hiroya Tanaka : 2013,"WoodWeaver Fabricating curved objects without moulds or glue,"Stouffs, Rudi and Sariyildiz, Sevil (eds.), Computation and Performance – Proceedings of the 31st eCAADe Conference – Volume 1, Faculty of Architecture, Delft University of Technology, Delft, The Netherlands, 18-20 September 2013, pp. 693-702

Kenji Kanasaki, Hiroya Tanaka : 2013, "Traditional Wood Joint System in Digital Fabrication,"Stouffs, Rudi and Sariyildiz, Sevil (eds.), Computation and Performance – Proceedings of the 31st eCAADe Conference – Volume 1, Faculty of Architecture, Delft University of Technology, Delft, The Netherlands, 18-20 September 2013, pp. 711-717