Upcycling Tree Branches into Architecture and Design

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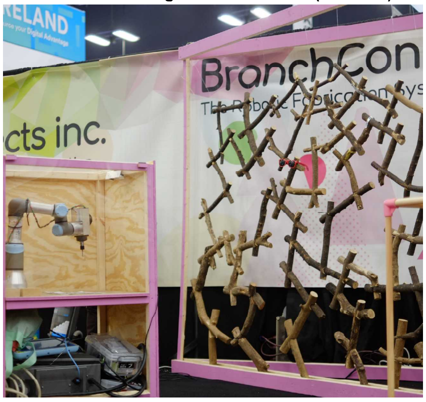
1. Collaborative Design and Fabrication (ACM TEI)



Screen wall exhibited at SXSW Interactive show 2018

2. Human-in-the-loop Fabrication

Dome shape fabricated with human-in-the-loop audio-visual feedback fabrication system

Instead of Recycle, Upcycle

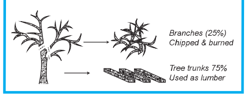
While recycling takes consumer products and breaks them into chips and powders, upcycling takes resources almost as they are and gives them better purposes, converting them into more useful objects than what they originally were. Recycling plastic bags, as an example, is to melt them and form new plasting bags. Upcycling plastic bags is to use them as kites or lamp shades. Traditional architecture naturally upcycle resources. In this case, the materials is not necessarily consumer products but natural resources, such as woods and rocks. We often find curved wooden beams in Japanese farmhouse called Minka. It is difficult to use such materials with original forms in modern buildings.

In such traditional architecture, a master builder was in charged of selecting right materials and placing them in right parts, called "*tekizaitekisho*" in Japanese. Nowadays, design process is more systematized with standardized parts due to legal regulations, however, curvy beams and raw surface of timbers are still in use but rare.

A curvy wooden beam in Minka: Japanese Farmhouse (Minka: My Farmhouse in Japan, John Roderick)

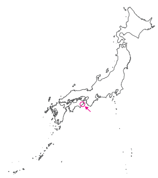
Here Comes Tree Branches

Tree branches accounts for 25% of a tree but they are chipped and burned. We take them as an example resource we can upcycle with modern information and communication technologies. With minimum processing of lap joints on them, we can transform them into building materials.



Koriki

Koriki is a traditional sustainable forestry in Japan since 300 years ago in Shikoku island where broad-leaved forests have been sustainably utilized. Koriki has received National Forestry Heritage in 2018 for its unique cutting patterns, as well as its selection cutting to balance various ages and species of trees. This selection cutting produces small-sized trees and branches as bi-products of the process. Currently the application is limited to fire logs and mushroom beds, which are not profitable, thus it is difficult to keep this traditional forestry management activity. Nowadays only few are in practice. Searching for high-valued applications to maintain the traditional forestry is indispensable. We received 200 branches with 4-7 cm and cut in a same length.



1. Collaborative Design and Fabrication (ACM TEI)

Concept: Roofing Together

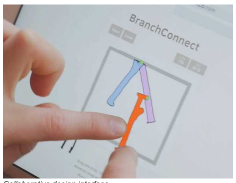
Learning from traditional architecture in Japan again, Yui is a traditional social system to work together and help each other in rural villages. In Shirakawa village, Yui is used for replacement of the thatched roofs since it is huge and very steeply sloped therefore needs a tremendous efforts. Thanks for hundreds of community members, the roofing process can be finished within two days.

Replacement of thatched roof in Shirakawa village Photo courtesy of http://digitalarchiveproject.jp/information

Likewise gathering and participating construction in Yui, we developed an online game application that lets multiple non-expert users explore layouts of tree branches. The goal of the game is to connect predefined target points on a frame with a limited number of branches. Users can pick a branch from the available set displayed on the bottom and create layouts by moving, rotating, and mirroring branches. The user continuously receives visual feedback and a score, guiding the user to a feasible design. The game is completed when all the target points are connected.

Workflow from Collect and Scan to Fabricate

Scan of branches attached to plate.



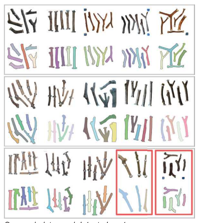
Collaborative design interface.

Fabrication with 3-axis CNC-milling machine.

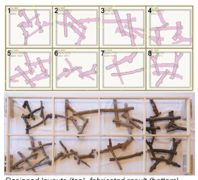
Joint assembly

Aiming for upcycling tree branches by everyone, we developed a workflow mediating manual labor work and digital processes, consisting of mainly four steps: Collect, Scan, Design, and Fabricate. Firstly, we physically collect tree branches and digitally scan them. The scanned branches are computationally connected and the resulting layout is analyzed regarding feasibility and fabricatability. Finally the intersections are converted to joints and milled by a typical 3-axis CNC router. The workflow was validated through two projects with difference approaches.

Preliminary Study

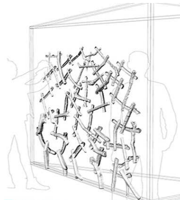


Scanned plates and detected contours



Designed layouts (top), fabricated result (bottom)

Demo Booth at SXSW



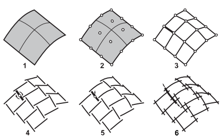
Designed layout (top), fabricated result (bottom)

As a preliminary study of the developed workflow from scan to fabricate, we organized a design and fabrication workshop to examine the feasibility of our system. It was hosted in a public community house close to a forest. The participants were four children (aged 4, 7, 9, and 10) and two parents. We set the goal to create a screen wall (2000 mm x 900 mm) divided into 8 sub-frames (500 mm x 450 mm).

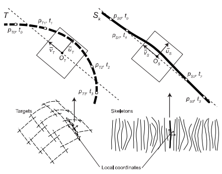
What we learned from the workshop is that participants preferred to complete a large wall without subdividing frames. In this case study, a 2D screen wall with a single large frame was designed and built to exhibit at SXSW (South by South West).

2. Human-in-the-loop Fabrication

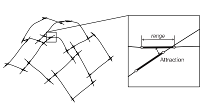
Reciprocal Pattern and Branch Matching



Grid on parametric surface. Each line is rotated around its midpoint, and extended so that it intersects with the neighboring branches.

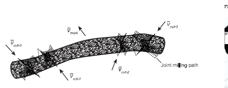


Defining the local vector spaces for target curve T and skeleton S, in order to orient S to T.

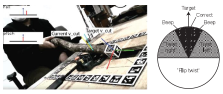


Simulation model where the branches move towards attraction points to tighten the joints. Joints are permitted to slide within a given range r.

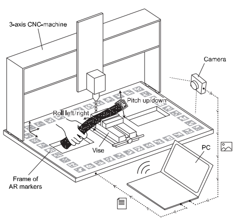
Human-in-the-loop Fabrication



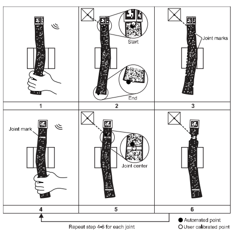
One branch with various cutting vectors for each joint



Audio-visual feedback for material positioning

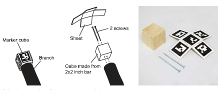


Fabrication set-up

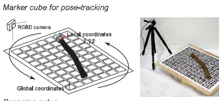


Detailed fabrication workflow

Material Preparation

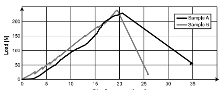


Marker cube for pose-tracking

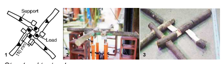


Scanning setup

Structural Test

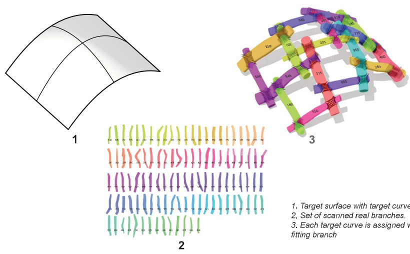


Results of structural test with two basic components.

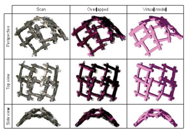


Structural test setup.

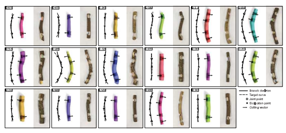
Results



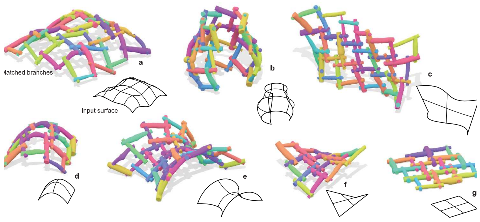
1. *Target surface with target curves in "loop" pattern.*
2. *Set of scanned real branches.*
3. *Each target curve is assigned with best found fitting branch*



Scan of fabricated dome overlapped with virtual model



Branch skeleton, target curve, virtual model with milling paths, and photo of fabricated branches.



Matching results with various input surfaces

Target Surface to Target Curves

The target surface is a user-defined parametric surface with a limit of curvature. It is translated to a network of target curves to be assigned with branches. The network patern creates "loops" which contributes to the overall stability of the joints.

Matching

The goal is to match real branches to the target curves of the construction pattern. The strategy is to first search for the best pose of every branch skeleton to every target curve, to create a matrix of the cost of every combination. Then we can assign a unique branch to each target, so that the sum of the fit values is minimized, by implementing the Hungarian Algorithm. We aim to position each branch skeleton S to each target curve T so that the directions of the two curves are aligned, and so that the strongest curvatures lie in the same plane. Local coordinate vectors are first defined for each curve. Then we use these to make the affine transformation to orient S to T. With these criteria there are 4 positions of every pair - mirroring and flipping the branch which maintaining the direction. The length of the branch is also considered. We first coarsely try the placement at every 5 cm, and then pick the closest fit and refine the pose at every 1 cm. Now we can select the best pose out of the four orientations, and the multiple segments for each target-skeleton pair. The cost is calculated as the average distance between joint points and the closest points on the skeleton curve.

Optimizing by Relaxing

There is a need to further negotiate between ideal target shape and existing material to make the surface fabricatable. The branch network is relaxed with a dynamic model, with the goal of minimizing and equalizing the distance where branches are supposed to intersect and make a joint.

Joint

The geometries of cross lap joints are calculated at each intersection. The joint is customized to the skeleton angles and the local radiuses. The cutting paths are defined from these outlines, with the milling bit radius as a variable parameter. Milling paths are automatically generated and exported as GCode.

Fabrication Setup

Each joint needs to be milled out from a specific side of the branch, defined by its position in the design layout. A 3-axis CNC machine can, however, only approach the material from above. We solve this by a human-in-the-loop process. A type of 6-axis capability is achieved by asking the user to place the branch with the intended cutting area facing upwards, aligning with the Z-axis of the CNC-machine.

Audio Feedback

To help position the branch correctly, the user receives audio feedback in form speech and a beeping sound which intensifies as the branch gets closer to the correct pose. For each joint, the user holds on to the branch and finds the "roll" and "pitch" of the pose with help of audio feedback. The the user fixes the branch in a vise. The milling path is informed by the final position, and sent to the machine.