Simple software creates complex wooden joints

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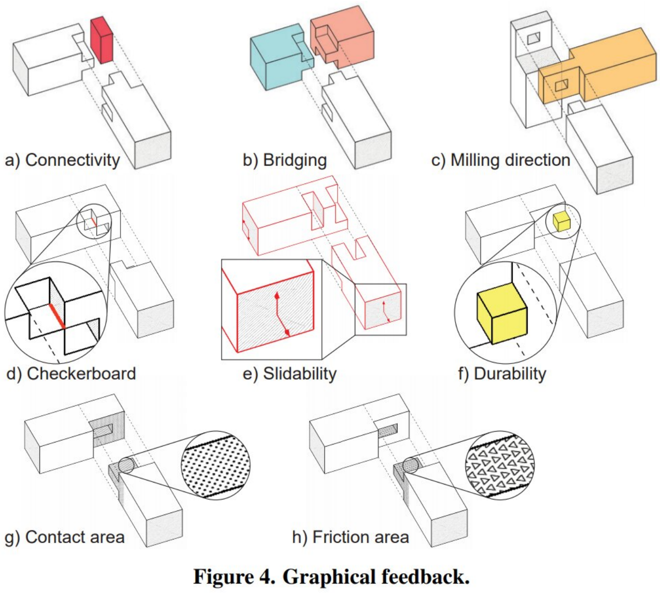
Complex interlocking components mean no tools are needed. Credit: Larsson et al.

Wood is considered an attractive construction material for both esthetic and environmental purposes. Construction of useful wood objects requires complicated structures and ways to connect components. Researchers have created a novel 3-D design application to simplify the design process and also provide milling machine instructions to produce the designed components. The designs do not require nails or glue, meaning items made with this system can be easily assembled, disassembled, reused, repaired or recycled.

Carpentry is a practice as ancient as humanity itself. Equal parts art and engineering, it has figuratively and literally shaped the world. Yet despite its ubiquity, carpentry is a difficult and time-consuming skill, leading to relatively high prices for hand-crafted wooden items like furniture. For this reason, much wooden furniture is often made by machines to some degree. Some machines can be highly automated and programmed with designs created on computers by human designers. This in itself can be a very technical and creative challenge, which was previously out of reach to many.

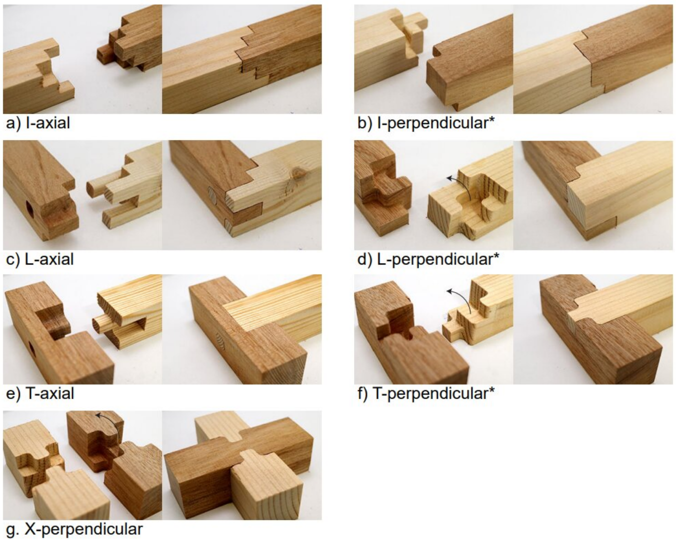
Researchers from the Department of Creative Informatics at the University of Tokyo have created a 3-D design application to create structural wooden components quickly, easily and efficiently. They call it Tsugite, the Japanese word for joinery, and through a simple 3-D interface, users with little or no prior experience in either woodworking or 3-D design can create designs for functional wooden structures in minutes. These designs can then instruct milling machines to carve the structural components, which users can then piece together without the need for additional tools or adhesives, following on-screen instructions.



Tsugite has an intuitive interface to present users with design options. Credit: Larsson et al.

"Our intention was to make the art of joinery available to people without specific experience.

When we tested the interface in a user study, people new to 3-D modeling not only designed some complex structures, but also enjoyed doing so," said researcher Maria Larsson. "Tsugite is simple to use as it guides users through the process one step at a time, starting with a gallery of existing designs that can then be modified for different purposes. But more advanced users can jump straight to a manual editing mode for more freeform creativity."



All seven unique ways that two pieces can be joined in Tsugite. Credit: Larsson et al.

Tsugite gives users a detailed view of wooden joints represented by what are known as voxels, essentially 3-D pixels, in this case, small cubes. These voxels can be moved around at one end of a component to be joined; this automatically adjusts the voxels at the end of the corresponding component such that they are guaranteed to fit together tightly without the need for nails or even glue. Two or more components can be joined and the software algorithm will adjust all accordingly. Different colors inform the user about properties of the joints such as how easily they will slide together, or problems such as potential weaknesses.

Notably, Tsugite will factor the fabrication process directly into the designs. This means that milling machines, which have physical limitations such as their degrees of freedom, tool size and so on, are only given designs they are able to create. Something that has plagued users of 3-D printers, which share a common ancestry with milling machines, is that software for 3-D printers cannot always be sure how the machine itself will behave, which can lead to failed prints.

"There is some great research in the field of computer graphics on how to model a wide variety of joint geometries. But that approach often lacks the practical considerations of manufacturing and material properties," said Larsson. "Conversely, research in the fields of structural engineering and architecture may be very thorough in this regard, but they might only be concerned with a few kinds of joints. We saw the potential to combine the strengths of these approaches to create Tsugite. It can explore a large variety of joints and yet keeps them within realistic physical limits."

Another advantage of incorporating fabrication limitations into the design process is that Tsugite's underlying algorithms have an easier time navigating all the many possibilities they could present to users, as those that are physically impossible are simply not given as options. The researchers hope through further refinements and advancements that Tsugite can be scaled up to design not just furniture and small structures, but also entire buildings.

"According to the U.N., the building and construction industry is responsible for almost 40% of worldwide carbon dioxide emissions. Wood is perhaps the only natural and renewable building material that we have, and efficient joinery can add further sustainability benefits," said Larsson. "When connecting timbers with joinery, as opposed to metal fixings, for example, it reduces mixing materials. This is good for sorting and recycling. Also, unglued joints can be taken apart without destroying building components. This opens up the possibility for buildings to be disassembled and reassembled elsewhere. Or for defective parts to be replaced. This flexibility of reuse and repair adds sustainability benefits to wood."

More information: Maria Larsson et al, Tsugite: Interactive Design and Fabrication of Wood Joints, *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (2020). DOI: 10.1145/3379337.3415899

Provided by University of Tokyo