Digitizing Wood | Analyzing Wood Grain in 2x4s using Facial Recognition Software Strategies

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Zippered Wood is a novel take on wood joinery and deformation in which digitally generated formally specific joint patterns are cut into boards that are joined to produce predictably precise bends. Within this system research is being done to maximise the usability of the 2x4's and the strength of the zippered wood. By using waste stream 2x4's for zippered wood we inherit problems that are not common in their traditional use. Namely those are the knots and screw/nail holes in the wood. Once the pieces are milled these areas create weak points in the veneer. Through our testing we have found that these areas are prone to cracking during the gluing process and create potential failure points along the piece.

In response to this we have begun to develop a simulation algorithm to strategically map the zipper tooth surface within the 2x4 to find the optimal placement in relation to any defects identified in the grain of the 2x4. This process, Digitizing Wood, uses an image of the 2x4 to locate the knots and defects in the wood to determine the optimal location. Using standard facial recognition techniques and imaging processing algorithms the knots and defects are marked. The marked regions and the zipper tooth surface are run through an evolutionary solver to optimize the placement in the 2x4. Once complete the finished piece is stronger and more materially efficient in its use. The Digitizing Wood strategy seeks to improve the effectiveness of the Zippered Wood system.

INTRODUCTION | THE NEED TO DIGITIZE WOOD

The research presented in this paper began in support of a larger project. Specifically, Digitizing Wood is a software and hardware process designed to optimize the selection of light frame timber members and waste materials sourced from construction demolition. The members analyzed using the Digitizing Wood process are deployed for the submitting team's Zippered Wood research; a novel approach to wood joinery and deformation in which digitally generated formally specific tooth patterns are cut into boards that are joined to produce predictably precise bends. The addition of Digitizing Wood to our workflow, allowed the team to process wood more efficiently by scanning potential material, locating imperfections (knots, nail-holes, etc.), and adjusting tool paths to avoid problem areas. The Zippered Wood technology operates within existing light frame construction systems. The goal is to productively disrupt typical building protocols by introducing curved and/or twisted wood elements into the language of construction. We took light frame construction's most basic building component, the 2x4, and turned it into an agent of change that can be freely modified and deployed within the existing construction logics to render framing more responsive and resource responsible. The Zippered Wood process works at the aggregating scales of wood grain, wood member, wood system, and construction waste reclamation. The Digitizing Wood project is focused at the scale of the wood grain. It is used to enhance the ability of designers and builders to evaluate reclaimed waste timber sourced from construction demolition.

Digitizing Wood began as a software and tool hack, deployed to optimize the manufacturing process of the Zippered Wood pieces. 2x4s are modified using a CNC mill to cut a computationally derived 'tooth' pattern into a chosen 2x4. A thin veneer is left between the teeth. (Fig. 1) This location is where each modified member flexes, and where each is mated to a coordinated modified 2x4. When put together (joined), the two milled boards displace one another. The resulting composite 2x4 is able to bend and twist at locations of thin veneer. In doing they generate the simulated shape. The quality of the lumber, and consequently the veneer, used in this process become major factors that determine the quality of the resulting zippered piece. Fortunately, older wood reclaimed from house demolitions is often from older growth trees. It can be and often is of higher quality than the 2x4's available today. However, it is not simply the quality and density of the wood fibres found in these members that determine strength, durability, and flexibility of the zippered members. The quality of reclaimed lumber sourced from house demolitions is neither consistent nor predictable. Any knots or screw/nail holes create weak points in the grain. These violations break the grain so it is no longer continuous along the length of the board. This leads to increased stress at localized bending points. As a result, the zippered pieces are prone to cracking at these locations. Because reclaimed waste lumber is used in our process, the potential problem areas described are often unavoidable and must be taken into consideration when locating the digitally simulated tooth pattern within a given 2x4. This relatively straight forward problem became the driver behind the research presented here, and motivated the team to look for

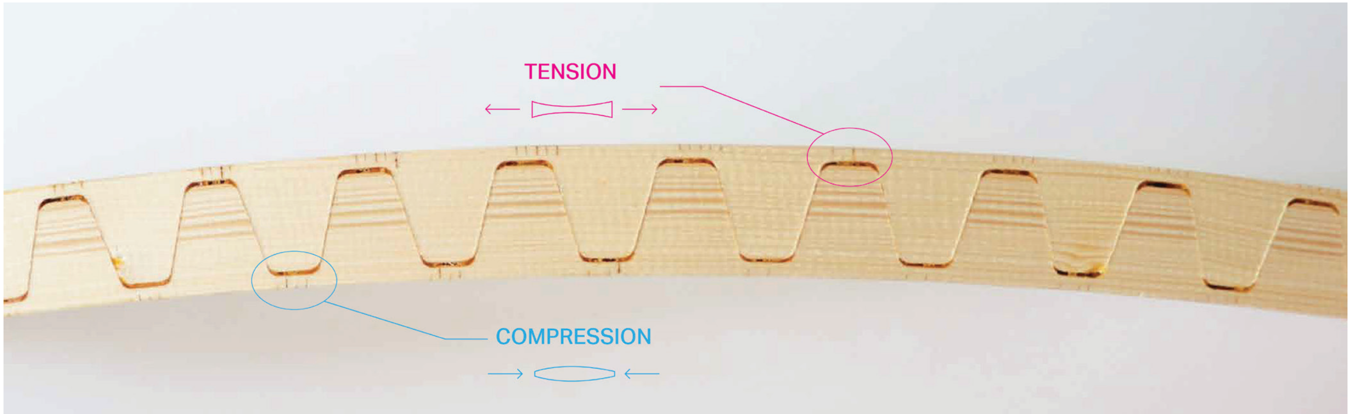

Figure 1. Location of thin veneer left after the milling process and forces acting on it. Image provided by authors

the best way to optimize the location of the digital tooth pattern with the goal of how to best utilize the clean grain areas of 2x4s.

CONTEXT | A GROWING VANCOUVER AND WOOD INDUSTRY

Metro Vancouver is a rapidly growing city. Vancouver started as a resource extraction port for the various industries operating in Canada. Located on the Fraser River, Vancouver became the starting point for prospectors traveling north to the gold fields. It also became an ideal location for processing the vast amounts of timbre pulled from the interior of British Columbia. These factors, and Vancouver's deep-water port, created a rapid urban expansion of the city. Light frame residential house construction boomed and the economy grew alongside. As the city grew, Vancouver experienced another boom. It's idyllic location and open immigration and real estate laws turned into one of the largest and most sought after real estate markets in the world. Land values have soared. These values continue to escalate as property assets are bought, sold and traded. This has led to a mass densification of the city core and the surrounding suburban areas. One result of this is a continuous and growing source of construction and demolition waste. In 2015 alone the Metro Vancouver construction industry produced approximately 218,000 tons of waste wood including 29% untreated dimensional lumber[1]. The waste generated contains a majority of the high-quality graded lumber that was originally produced in Western Canada. It is within this waste stream that the Zippered Wood research is operating within. Its goal is to repurpose this high-quality lumber, along with the other dimensional construction wood waste that is produced, into usable and digitally modifiable wood members.

The practice of evaluating and grading wood based on knots and other defects is not a new concept in the lumber industry. Lumber for both export and domestic use have consistently been graded. That grading is typically based on a dimensional lumber member's suitability for specific tasks[2]. It is within this system that lumber is classified and marked for structural purposes, non-structural purposes, furniture grade, or surface finishes. In total there are six different grading categories. In Canada and the Pacific Northwest, wood bearing a grade of No. 3 or better was used in light frame house construction, and for other wood material applications[3]. This coincides with the mid-20th Century Vancouver housing boom. Now that same high-grade dimensional lumber, much of it stable and useful, is oversaturating landfills as more houses are being torn down.

SCANNING SYSTEMS | PRECEDENTS OF SCANNING TECHNOLOGIES

Our desire to tap into this stream of waste lumber generated a need to develop a strategy for evaluating reclaimed wood. During testing phases of our deformation process, we found that many of the zippered pieces were prone to breaking at the location of defects (knots, nail holes, etc.). These defects had to be taken into consideration when placing the digitally generated tooth patterns into the 2x4s we planned to mill. The primary challenge was understanding how to reconcile between the specific geometry of the teeth being milled and the grain and defect profile of each board. Both are unique for every piece. This high degree of variability does not allow for standardization of placement, or a consistent strategy that can be accomplished manually when milling the 2x4s. Our answer to this problem was found in the unique characteristics of the zippered tooth pattern. Because each zippered piece only bends in specific locations (the veneer between the teeth) those locations could be mapped. The mapped locations of an entire tooth pattern, and its relationship to the detected defects, could then be tested and optimized. Once mapped, the information is fed back into the model, and informs the milling process. We developed a strategy in which we could digitally generate a map of the locations of all the defects in the 2x4. This gave us the ability to control the resolution of how the defects are detected.

Digitally Scanning wood for knots and details has become standard practice in lumber processing, and an emerging technology within architecture. Large scale lumber processing uses microwave detection machines to scan sawn lumber and logs . Based on the resistance measured in the microwaves

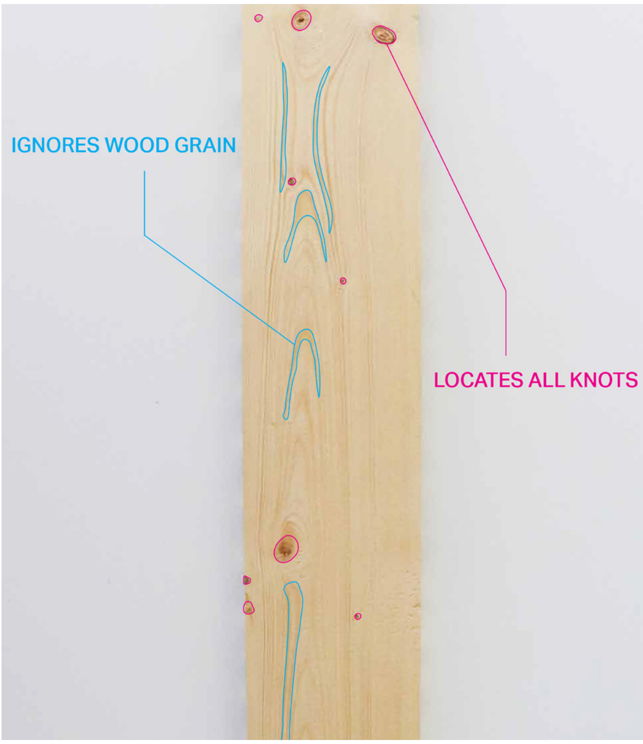

Figure 2. Areas detected as potential knots. Image provided by authors.

travelling through a given log, an image is produced that can accurately map knots and other defects within the wood. While useful for large scale applications and managing wood waste at the first stage of production, this complex operation is not needed for our application. We only look at the face grain of the 2x4 when mapping and locating the zippered tooth pattern. Knots and defects travelling through the 2x4 do not matter outside the location of veneers. When properly located, the knots and defects will only be in the teeth. This drastically reduces the complexity of how we would scan the 2x4. We only need an image of the face grain at the location of the bottom veneer portion of the zippered wood member.

We began by looking at projects that primarily used scanning and imaging techniques. In 2016 the AA used 3D scanning techniques for their Wood Chip Barn at Hooke Park. The barn structure is comprised of forked trees that were scanned and cut from the forest surrounding Hooke Park[4]. The trees were individually scanned to create a highly accurate 3d model. This model was then run through software for analysis and to aggregate them into a composite. For the AA team the goal was an arched structure. Their software used the unique geometry of each trunk, and information on the locations of the ends of the cut trunks to map out the optimal placement of each piece.

In 2017, Princeton University's School of Architecture completed their new Embodied Computation Lab. This lab space features a façade of reclaimed scaffolding planks from New York City. Part of the research done at the lab is on heat transfer through wood. The team wanted to test whether rough lumber with different densities would transfer heat at different rates[5]. Wood grain is denser at knots, so the team worked to develop a method to isolate and track knots on the planks. The team used sophisticated machine learning algorithms that they trained to detect images of knots. Once the locations of the knots were mapped, the grain around them was sandblasted. The sandblasting removed the lighter density material and emphasized the grain pattern. Once complete the boards were installed to create the façade. This sophisticated use of machine learning techniques and scanning technology creates an efficient method for accomplishing the task.

Both projects (by the AA and the Embodied Computation Lab) are using advanced scanning and analyzation strategies as ways to generate specific form. Our Digitizing Wood research is taking inspiration from these projects to find ways to approach the challenge of analyzing waste dimensional lumber for knots and other defects.

TESTING STRATEGIES | IMAGE SCANNING AND ALGORITHMIC PROCESSING

The digital working environment for Zippered Wood is Rhino and its parametric computational solver plug-in Grasshopper. The same environments are used for the Digitizing Wood algorithms, thus maintaining a streamlined workflow throughout the project. To begin testing we needed to input the grain of the 2x4 into our digital software. We turned to the XBOX Kinect. We used the optical sensors of the XBOX Kinect to scan the face grain of the 2x4 and produce an image. The XBOX Kinect is controlled through a Rhino plug-in called FireFly. FireFly is able to utilize the multiple functions of the Kinect's optical sensors. The Kinect is attached to an overhead gantry that centers the lumber under the camera and travels along the length of each 2x4. While the Kinect travels it takes image samples of the grain that are then processed into a single image of the face grain. This image becomes our digital representation of the 2x4 and is used to determine the location of the digital tooth pattern.

Once the image of the 2x4 is complete it is input into a two-stage grasshopper definition. This definition will analyze the grain pattern for any knots and defects, then use that information, along with the digital representation of the tooth pattern, to determine the optimal tooth location within the 2x4. The first stage of the definition uses basic pattern recognition techniques borrowed from facial recognition technologies. Facial recognition algorithms are usually comprised of two main parts; separating and identifying a face from a background, and matching a scanned face and its features to a database of known faces[6]. Our definition only performs the first of these two tasks. We are not concerned with how individual defects look, only distinguishing between a defect and the background grain pattern. Our definition analyzes the pixels within each image and looks for patterns and regions based on a known quality.

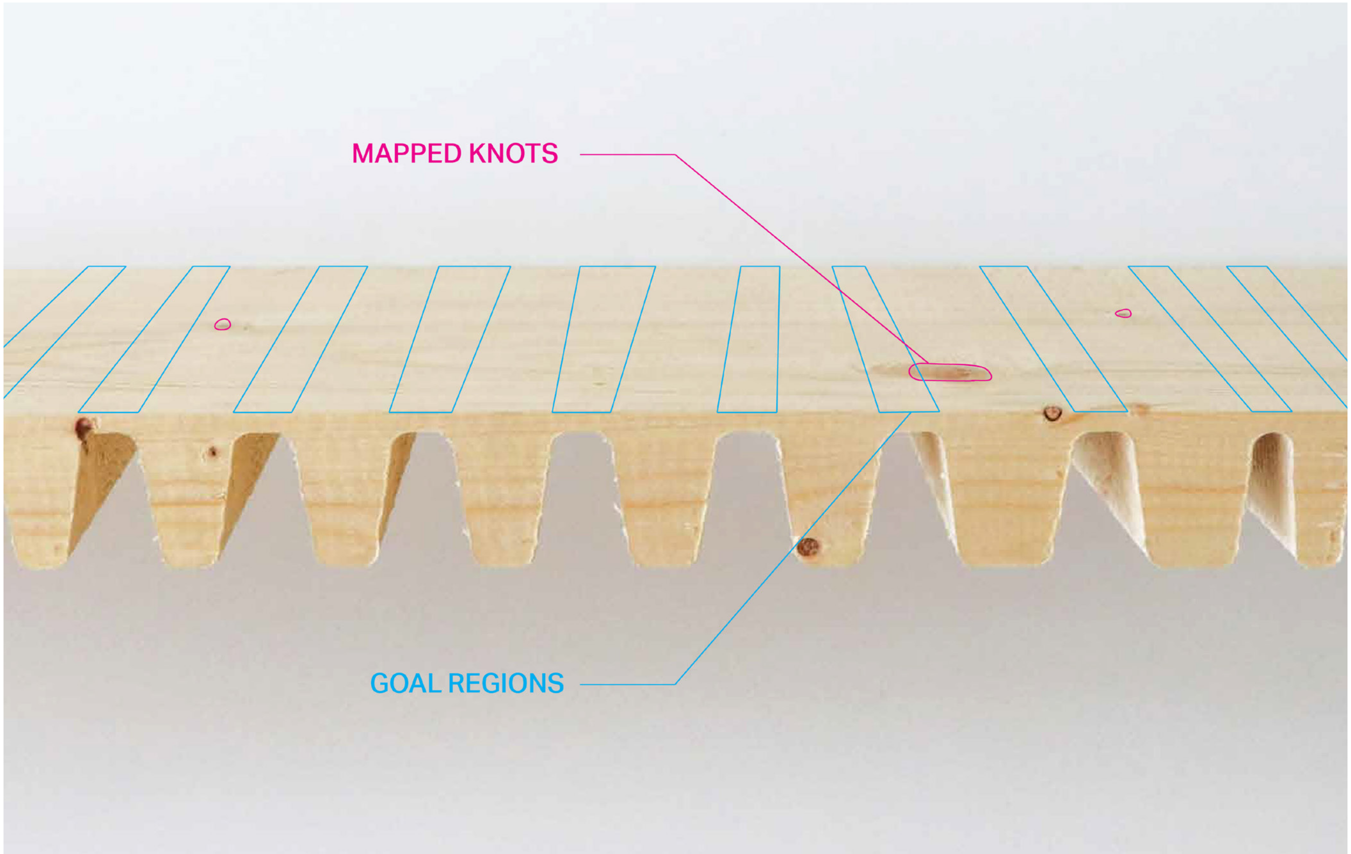

Figure 3. Optimized location of veneer regions. Image provided by authors

One defined quality is the contrast between the colors of the grain the colors of knots and of holes in the 2x4. (Fig. 2) In both reclaimed and new wood (typically Douglas fir or hemlock) the knots and holes appear significantly darker than the grain. This becomes the identifying marker for the algorithm. During setup a base contrast tolerance is set and the image is then processed with a score given to the contrast value of the pixels. This score is then compared to the tolerance value (established by the HiLo team). If it is above the tolerance, the pixel locations are marked as defects. Once the entire image is scanned the tolerances can be adjusted to account for different levels of contrast between the grain and the defects. Because the knots and holes in the wood will not exceed a certain size due to the grade quality of the wood, the size of the detected area is also calculated. If the calculated area is above a certain value, it is discarded as a false identification. These false identifications might occur when the contrast between the defects and the grain is low or there are sections with heartwood or dark grain showing. These areas will be detected as perceived defects, but since they do not degrade the integrity of the veneer they are discarded. Once the identification phase has been completed, the data is then passed on to the second phase.

Phase 2 uses Galapagos, an evolutionary solver within Grasshopper, to optimize the location of the digital tooth pattern. The locations of the defects have been mapped out, and closed regions defined to represent the limits of each defect. The tooth pattern is input and the space profile between each tooth is traced as a closed region. This is where the veneer will be left. These profiles are extracted and projected onto the image of the 2x4. The evolutionary solver then performs a simple operation of moving the 'veneer regions' along the 2x4, solving for the minimum range value determined by the total overlapping area between the defect regions and the veneer regions. (Fig. 3) Once the optimal location has been determined the distance of the leading edge of the tooth surface relative to the start of the 2x4 is given. That distance is then used in the manufacturing phase of Zippered Wood to locate the optimal tooth surface for the milling operations.

RESULTS | PRELIMINARY TESTS AND FORECASTING FUTURES

Preliminary testing has been done with this method with encouraging results. Tested members were milled accurately and the simulation detected both knots and holes from nails and screws. These defect regions were accurately placed within the solid portions of the zippered member. This preliminary success has prompted expanded use of this technology within full scale Zippered Wood projects. A first pavilion prototype has been successfully constructed using Zippered Wood members.

(Fig. 4) During testing of the zippered members, breakage due to defects in the wood was drastically reduced. This structural improvement and reduction in faulty members allowed the team to complete the pavilion with greater efficiency. The new process also increases our confidence when using reclaimed waste construction lumber. We are actively able to optimize our use of the lumber and reduce our own waste. We no longer have to mill extra members to allow for breakage. This means we can increase our production numbers from a given amount of lumber, all while increasing efficiency. Future larger scale pavilions are currently under development, and the refinement of the process is ongoing.

We believe that the Digitizing wood project is a novel approach to wood knot and defect analysis techniques. It is also a technique that has a low barrier for adoption. We are productively hacking and misusing software and facial recognition strategies to increase the potential of waste lumber, and the agency designers can have in construction futures. Design is quickly trending towards a more integrated digital and analog world. We observe that construction resists change and is trending behind the curve. Also problematic is the lack of integration between design and construction. The design space of architects must continue to interface between multiple platforms and technologies. We believe that through the use and advancement of processes like the Digitizing Wood and Zippered Wood technologies, a new digital construction space can be integrated into the conventional construction methods we inherit. All without significant interruption of the latter. Our new method of construction is used to combine the analog and digital in a way that allows for a productive disruption of the light frame timber industry. We strive to use our research to create a digitally flexible 2x4 (through scanning and formal manipulation). We aim to allow designers to freely manipulate the base element of light-frame construction and insert it back into the analog world of construction without adding the need for specialized skills in the assembly phase.

ENDNOTES

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Figure 4. Completed pavilion by HiLo Lab. Image provided by authors.