digital joints
digital joints
ideas concerning the use of unconventional materials and cnc routing
(a work in progress)

developed by mikael avery, draft works, llc
preliminary investigation
This investigation begins with a set of orthogonal connection joints, orthogonal splicing joints and non-orthogonal joints, cut from 2x4s, as a means to test and develop an understanding of CNC methods and tolerances when working with twisted and bowed materials. The lessons learned here are then applied to a wider array of found objects in the next section.

The oblique scarf joint requires the most material length to create but also provides the highest level of strength of the three joints fabricated. For this example, the joint was not created with a lapping element, but instead, utilizes a third member to provide an additional lateral locking mechanism.

In order for the third, locking member to sit flush and hold the joint, this groove, found in both members and wrapping around both sides of the joint, was created.

In addition to the joint’s name, within the **Heading** there is a brief description of the joint, an image of the assembled construction and a key to its potential use. There are three categories in the key: the connection of sheet material to sheet material, the connection of framing members to framing members, and the joining of framing members to sheet members.

The **Body** of the page displays a graphic 3D view of the joint as well as plan view diagrams of each piece. Each separate tool path is outlined with a red dashed line, illustrating where each tool path begins and to what depth the machine cuts each contour. The flat side (the surface that is flush to the machine bed) is noted for each piece. Call out paragraphs are employed to draw attention to and highlight specific CNC manufacturing or joint specific construction elements.
Cogged Lap Joint

The Cogged Lap Joint provides additional strength over a standard lap joint due to the increase in material that the joint provides. As a result the two pieces do not sit flush with each other, which can limit the joints use. The joint is useful when both members are bearing a larger load.

Cross Lap Joint

The Cross Lap Joint, allows for a flush set connecting joint. Unlike the Cogged Lap, this joint requires that half of the material of each piece be removed, which decreases the strength of the overall piece.
Mortise & Tenon Joints come in many variations and forms. Within this assembly, there is a traditional mortise and tenon (c3), a through mortise and tenon (c4) with a socket for receiving the blind tenon of the locking pin (c5). As can be seen in the perspective diagram, attention is given to the location where the perpendicular surfaces are meeting and extra tool paths are created in order to ensure a flat, tight fit.

Due to the found nature of the pieces used in these explorations, every surface is considered rough and must be milled in order to ensure a tight fit.

Seen in many of these joints, the extra bump outs are called ‘dog bones’ and are created in order to provide the additional allowance needed in order to fit square corners through filleted corners, which are the natural result of the CNC router machining process.

The use of a CNC mill aids in the creation of blind mortises due to the ability to cut any shape to any depth, considered ‘pocketing’.

This blind tenon, when inserted into the pocket of piece c4, functions as a locking pin, successfully tying all three pieces together.
The lap joint seen here utilizes a stub tenon to aid in alignment and provides a modest degree of additional stability against forces acting in the perpendicular direction. For this joint, as well as the joint on the facing page, the lap is used as a way to strengthen the connection by increasing the length of surface in contact at the joint. Additional variations of this joint exist, for example the inclusion of a dovetail in place of the stub tenon. This alteration provides additional resistance to tensile forces.

One benefit of the stub tenon is the short length of the tenon, which requires less overlapping material and therefore helps to preserve as much of the original member’s length as possible.

Because this detail is not a through cut but instead part of a lap joint, traditional methods of joinery (by hand or machine) would require considerably more time and set up. The CNC machining process on the other hand allows for this type of detail to be created with a negligible increase in the total amount of time required.

The bulb-out at the end of the tenon provides resistance to tensile forces. The two stub tenons at the joints shoulders are included in order to increase the overall amount of material that is overlapping which in turn provides additional strength to the connection.

In comparison to the stub tenon, the gooseneck lap joint requires considerably more length of material to create. This, therefore, decreases the overall length of the members used and the final length of the piece created. In addition to its ability to resist tensile forces and its aesthetic appeal, the joint is included here because it is a great example of the flexibility and benefits of CNC machining both structurally and aesthetically.
The oblique scarf joint requires the most material length to create but also provides the highest level of strength of the three joints fabricated. For this example the joint is not created with a lapping element, but instead, utilizes a third member to provide an additional lateral locking mechanism.

The use of CNC machining in this joint facilitated an overall geometry that adds strength and visual interest to the joining of the members.

The shoulder, located at the base of the joint, allows for the full width of the angled member to rest on the upright member.

In order for the third, locking member, to sit flush and hold the joint, this groove, found in both members and wrapping around both sides of the joint, is created.

The joint shown above, and the following two examples explore many of the ideas implemented previously but with the incorporation of members meeting at an angle other than 90°. The notched lap joint, provides a large shoulder for the angled member to rest on, therefore increasing the strength of the joint at the critical moment of meeting.
Unlike the previous example, this joint does not employ a shoulder area for additional bearing strength. Instead, this joint was created to explore the ability of a through tenon to capture an additional, planar member. This planar member, than acts as a lock for the joint and begins to speak towards the addition of materials other than wood into the process.

Interestingly, both halves of this joint are identical, and it is the addition of the incline that gives the joint its additional usefulness.

In addition to the inclined plane, this joint also explores the use of a double dovetail to increase the tensile strength of the joint.

This cut was designed in order to slide the planar element into the tenon and act as a lock. The switchback shape was designed in order to compensate for the need to create a 1/8" wide slot using a 1/4" router bit. While the overall space between the sides of the joint is greater than 1/4", the space between the inner surfaces measures 1/8" and can therefore hold the material firmly.

This angled joint employs a ramped jig for its creation. By placing an inclined plane beneath the member, the machine is able to cut a conventional 2D joint into the piece which when jointed to its mate, induces an angle within the longitudinal axis of the members.
seven noted observations
The benefit of being able to work through a computer interface and output lines, poly lines and curves in a repetitive and extremely accurate manner is a well known benefit of CNC fabrication. The material collected for this project, on the other hand, is devoid of many of the attributes that make the above mentioned benefits useful. The pieces here are not of the same dimension; but instead they vary in thickness, width, length, and density to a great degree from piece to piece, even when collected from the same location.

When viewed from within this dichotomy, the main challenge of the investigation simply becomes; how to get these seemingly incompatible fields to speak to one another in a successful and compelling manner? In order to accomplish this task, I needed to adapt my understanding of how the CNC machine operates. Working between the digital and analog, meant going back and forth between rough computer models where initial ideas were tested and the physically milled pieces that would then be assembled to work out kinks that are not visible in the 3D model.

On the following pages, I outline the seven most compelling shifts in my understanding of design and fabrication that result from viewing these two components not as distinct factors separated into successive step, but instead seen in a constant dialogue, where each helps to explore and inform the other.
INDEXING OUTSIDE

One of the greatest advantages of working with CNC machinery is the ability to have the reference datum work independently from the material itself. With most conventional power tools, the cutting member and the material to be cut rely on a shared surface for indexing. For example, when using a table saw the blade is held stationary a specified distance from the machine's fence (giving a known distance) while the material to be cut is held against the fence and pushed over the blade. This relationship dictates that the shape, and therefore imperfections, of the material influence the final accuracy of the cut.

With CNC operations, however, the blade is referenced to an independent coordinate system that does not rely on anything outside of itself for its location. No matter how a piece is placed on the machine bed, the router will cut the exact shape dictated by the designer and CAD/CAM software. This allows for pieces that include major dimensional deformations and are considered unworkable to be machined. Capitalizing on this fact, all of the vertical pieces that went into the creation of the shelter’s northern facade, were indexed to a set of indexing marks that can be seen in the image on the upper left. Working in this way allows a designer to make decisions about the individual piece to be milled in real time and without the need for additional set up time, capitalizing on the repetitive accuracy of this tool.

FIXTURING

Fixturing is the act of holding a material down securely during the machining process. When utilizing sheet materials, as is often the case in CNC work, fixturing is commonly accomplished by screwing the material to the machine bed. In an attempt to leave the pieces as close to their found state as possible, with the exception of the intended joints, this project used cam clamps, spacing blocks, and corner jigs to create safe fixturing that is capable of working with the imperfections of the individual pieces. These devices utilize lateral pressure as the sole means of holding the piece in place.

In some instances, like the ramped jig pictured on the bottom right of page 33, safety dictates that the material must be screwed into the bed itself.

REQUIRED TOLERANCES

When working with found materials, consistency is hard to find, and there is a need to design in a certain degree of slack in the joining process. For example, each vertical member pictured above has a different width and in order to join them to the horizontal 2x4s, the width of the thickest member is used as a starting point for the design. In order to make up for this discrepancy in width, shims are used to ensure a tight fit for each piece. This results in a panel in which the irregularities are not only kept through the machining process but also highlighted in the final assembly.
CONNECTING POINTS Once the design is free from strict indexing and the boundary of an individual piece no longer dictates its usability, focus can be placed on where and how the materials meet. These connecting points and the lines that run through them start to hold a large prominence in the thinking through of the larger work; being seen more as a system of pieces than an overall form.

IMPERFECTIONS Natural imperfections in the materials provide much of the variation seen in the finished work. As shown above, the incorporation of the machine made forms on top of the naturally occurring imperfections represents an exciting dynamic that would not occur when using standardized materials. Here the precise machine work stands next to something imperfect, a relationship that shows, contrasts and capitalizes on the precision of digital tools and the imperfections inherent within natural materials.

RESISTING PERFECTION In contrast to the customary way of using digital tools, this methodology encourages working with the irregularities of a material. Instead of trying to force a piece into a predetermined shape, the design framework is made flexible enough to account for these imperfections and variations from the beginning; exchanging the perfection found in computer models for the variability found outside of the digital world.
VARIATION

Seen below is a stack of wood used in the construction of the Southern Screen. All of the pieces for this screen are sourced from the same location, but due to their various intended uses, the imperfections that caused them to be discarded and the diversity of the wood species, they are all of different widths and thicknesses. In these differences, the project acquires variation. Each piece is milled in the exact same fashion and assembled in the same way. Through the mechanical repetition, provided through CNC milling, variation is expressed. Here digital tools provide repetition not variation. This benefit extends beyond pieces that are of similar size. As illustrated on the adjacent page, CNC milling allows the same joint to be milled from a range of materials, regardless of their imperfections, dimensions and variations. The ability to incorporate the same detail within several areas of the project enables the larger idea concerning variation and repetition to be fully expressed and aids in the visual cohesiveness of the entire bus shelter.
**This Panel** utilizes the thicker, heavier 'skins' in which mortises are milled in order to receive a series of short 2x4s. In these 2x4s a series of roughly square mortises are also cut. Then the 2x4s are placed through the skin members and locked in place by shims. The shims highlight the irregularities in the materials and create a series of visual cues within the panel. Additional framing elements are incorporated to allow the panel to rest evenly on the ground as well as support the roof structure. As can be seen by the warning labels, the black lumber is reclaimed from an IKEA bed frame.

**The Roof** incorporates a series of short 2x4s joined with traditional Japanese splicing joints, modified for a CNC router, in order to build up the major roof supports. The detailed joint is left exposed on this end to reference traditionally designed rafter tails. The sheathing is made from layered, reclaimed beam 'skins'. Used due to their light weight and resistance to rot. The perpendicular bracing is built from additional beam cut offs and plywood remnants and provides lateral bracing for the roof.

**The Bench** and one of its main supports is also incorporated into the black frame. Here a piece of plywood receives the 'zippered' dovetail; while a series of reclaimed, bowed 2x4s, notched to receive the plywood, create a seating surface with both exterior and interior possibilities.

**The Garden Screen**, receiving the most direct sun, is designed to play with shadow as well as create a screened view of the surrounding environment. Scraps from a chair rail company and surplus 1/4 round trim are used in its construction.

**The Rear Surface** fully employs the 'zippered' dovetail. Old shelving, discarded as part of a remodeling effort, the pieces are staggered vertically in order to expose the joinery, create interesting views and utilize all available material. On the far end, plywood members incorporate the zipper and mortises in order to transition between two distinct panel types.