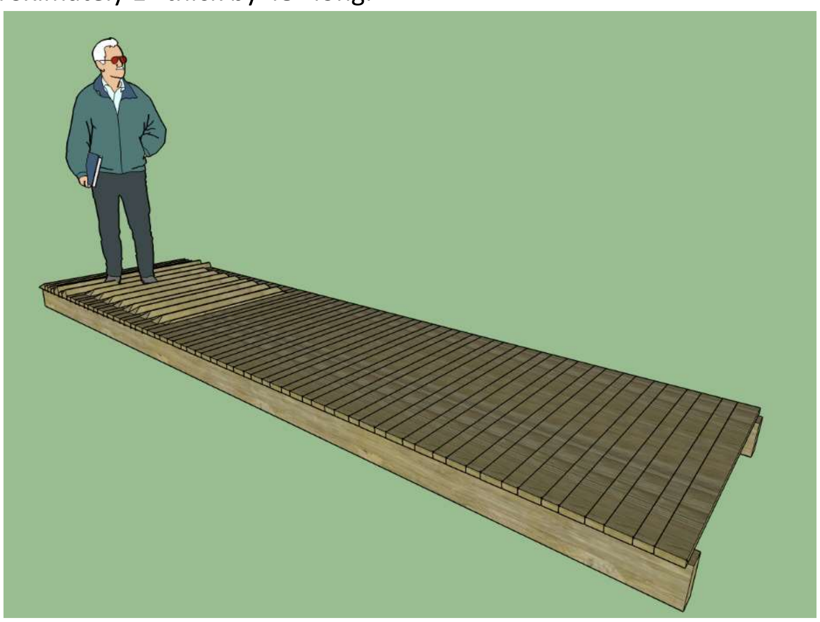
This writing outlines the design and construction of a hand built bridge. The bridge is to be part of the Oak Park hiking trail maintained by the Land Trust of North Alabama. It's located at approximately 34°44'55.57"N by 86°32'43.85"W. The bridge will span a shallow drainage route formed by a dirt berm that appears to have been put in to divert runoff from the mountain away from homes below. The bridge will be approximately 14 feet long and about 4 feet wide. The drainage route is normally dry and the highest the bridge will be from the ground is about 3 feet.

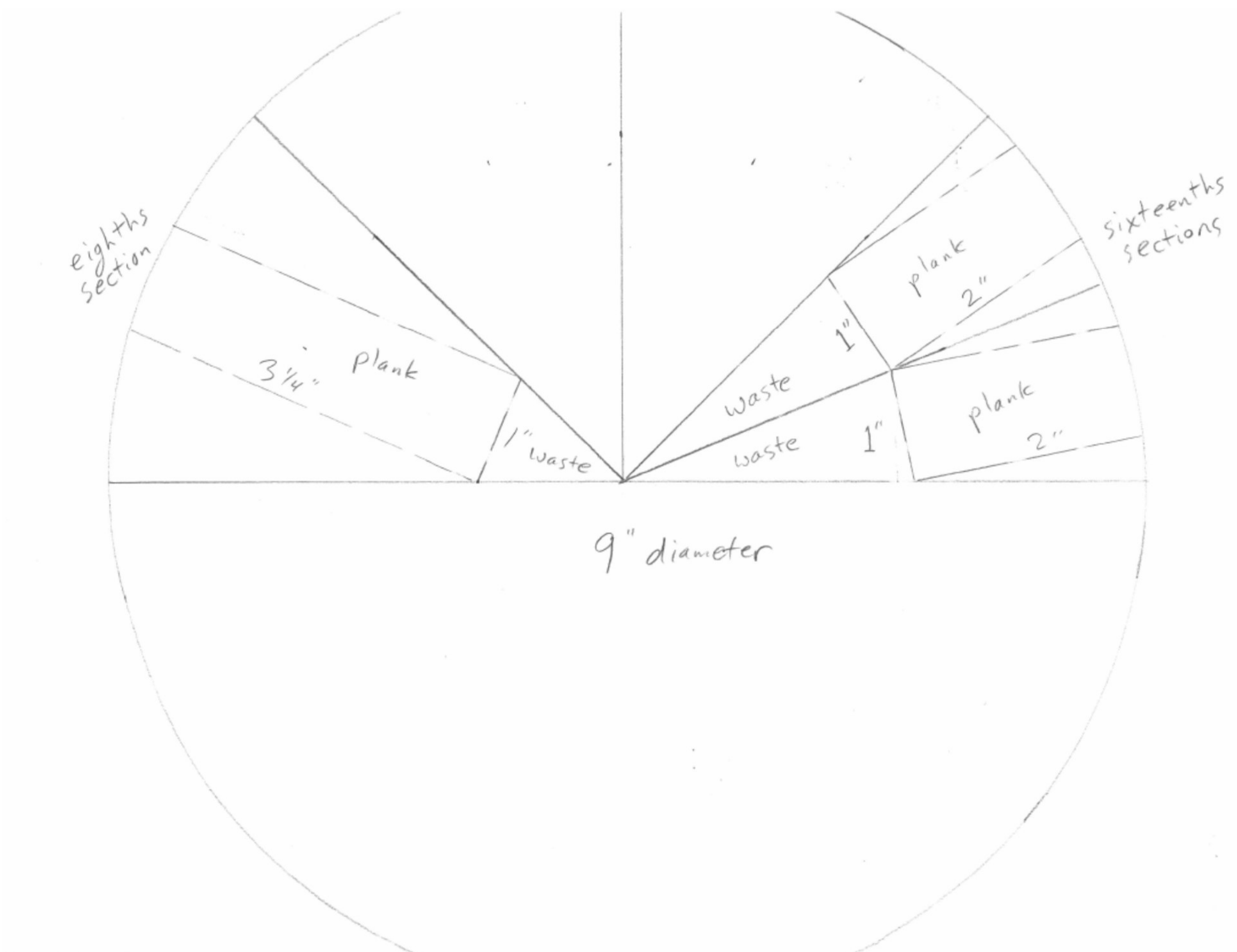
The bridge will be constructed with hand tools, meaning human powered tools, no gasoline or electric motors. Because that's environmentally friendly and because it's entertaining. The bridge will be made with black locust (Robinia Pseudoacacia) wood. Black Locust is known for its resistance to decay when exposed to the elements, so we should get good longevity without using chemical preservatives. A local source was found on Land Trust property on Chapman Mountain where a few black locust trees are slated for removal to make room for a pavilion.

The bridge will be a simple structure consisting of two straight beams that span the drainage route and a walkway of planks on top of the beams. The beams will be approximately 3" wide by 6" deep and the planks will be approximately 1" thick by 48" long.



It is desired to convert the black locust trees to lumber without using a powered sawmill. Hence the required pieces will be made by a combination of splitting, hewing and sawing by hand. The beams will be hewn either from one log, by first splitting the log down the middle, or from two separate logs. Which process is used depends on the size of the logs and the straightness of the grain.

The planks will be made by splitting logs which have been first crosscut to the desired length. Metal and wooden wedges will be used (wooden wedges are referred to as gluts). The planking logs will be split in equal parts radially, first into halves, then into quarters, then into eighths and so on until the approximate thickness (1") is neared. This creates pie slice shaped pieces. The narrow part near the pith of the log is then split off, and the bark and light colored sapwood removed. We ought to remove all the light colored sapwood because the decay resisting properties lie only in the extractives that naturally occur in the darker heartwood. I think a froe would be appropriate for splitting these waste pieces off. We measured the circumference of one of the black locust trees at 35 inches. That gives a diameter of just over 11 inches to the outer bark. We chopped a notch into heartwood and I guesstimate that was about 1 inch deep. Luckily Black Locust has one of the greatest ratio of heartwood to sapwood (fewest annual growth rings of sapwood) of any domestic species (see reference 1). So let's assume our logs have 9" diameter worth of heartwood. How much planking can we get out of each round log if we want 1" minimum plank thickness? I think we'll split them into eighths or sixteenths. Sixteenths ought to give us sixteen 2 inch wide planks. Eighths should give us eight planks about 3.25 inches wide. If I (conservatively) assume we can make 3x8=24 inches worth of plank width from a single 4' long log segment, then we'll need to process 7 log segments to get the required 14 feet of planking. So we need about 7x4=28 feet total worth of trunk just for the planking.



Here is a quick structural analysis of the bridge members. To check the strength of the beams, I'll apply a central point load of 1,000 pounds to one beam (so the total bridge design load would be 2,000 pounds). From reference 1, the Modulus of Rupture for Black Locust is 19,400 psi. (That's actually higher than any other domestic wood except for Hickory at 20,200 psi.) This is like an ultimate strength in bending. I think I'll actually go with the Fiber Stress at Proportional Limit (FSPL) which is like the yield strength in bending. That's 12,800 psi for Black Locust (reference 1). Wow. That's actually higher than

hickory (at 10,700 psi). That's the highest of any domestic wood. Neat. So if I assume the beams are 2 inches wide and 6 inches deep, then what central point load corresponds to the FSPL?
P = 12,800 psi x 2 inches x (6 inches)^2 / (1.5 x 15 ft x 12 in/ft) = 3,400 pounds.
Wow. I've got more than a factor of three safety. I'm not going to worry about strength reduction due to time under constant load because this is a hiking trail so the bridge won't hold any appreciable continuous load. And our beams will probably be larger than 2x6. I think 3x6 would be a good compromise between hewing effort and toting uphill effort with 9" diameter heartwood.
To check the strength of the planks I'll use the same formula to calculate maximum load. Assume the small plank size of 2 inch width.
P = 12,800 psi x 2 inches x (1 inches)^2 / (1.5 x 4 ft x 12 in/ft) = 350 pounds.
I think that'll do. Some of the planks may end up being 3 inches wide, which should hold 500 pounds by that formula. And in reality foot and bicycle loads will be distributed over multiple planks. Also our planks will be thicker than the nominal 1" to conserve hewing effort as described below.

The riving and hewing lumber conversion process is best achieved with green (high moisture content) wood. Hopefully we can get the beams and planks to shape in one weekend. The following weekend we'll need to transport the materials by trailer over road to Oak Park. There we'll unload and have to carry everything up the trail to the bridge site. This is one of the reasons that I enjoy working with hand tools like crosscut saws, hand augers, and adzes. They're a lot lighter to tote up the hillside than chainsaws and electric drills. And you never run out of gas or battery charge. In my opinion hand powered tools are safer. You can still seriously injure yourself with an axe, or by dropping a tree on yourself. But you don't run the risk of a chainsaw kicking back into your leg or hand.

How much is all this lumber going to weigh? Reference 1 gives a specific gravity of 0.69 for black locust at 12% moisture content. It'll be a little heavier when green, maybe 80% moisture content. Water is 0.0361 lb/in^3. So 12% moisture content black locust is around 0.0249 and adding 70% more moisture gets us to 0.0423 lb/in^3. So that 9" diameter 15' long log we made the beams from should be around 484 pounds. Each 3x6 beam should be around 137 pounds. That's pretty heavy, I think two or three people should carry one beam up the trail at a time. The planks won't be too bad, probably around 5 or 6 pounds each (0.0423x1x3x48=6 lb). We can tie them up in bundles of 6 or so (less than 40 pounds in a bundle) to carry them up the trail. But that still might take ten trips to get all the planks up there.

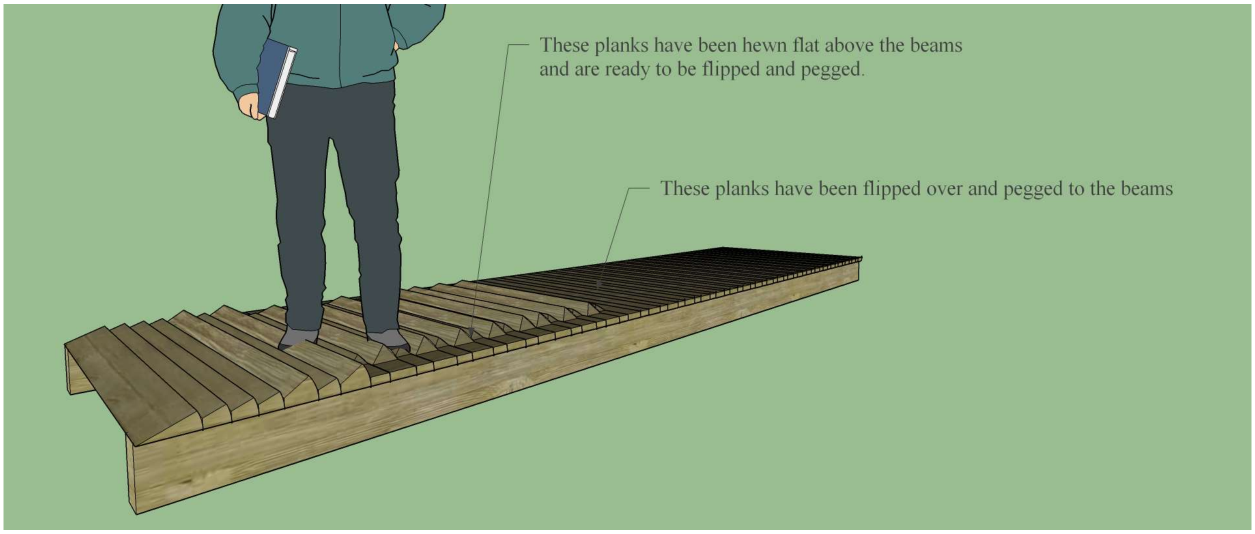
We'll need to make footings to rest the ends of the planks on. I think the wood will last longer if it's not in direct contact with the ground, so let's set the ends of the beams on rock. Luckily there is already suitable rock footings on the natural side of the drainage path. We'll just need to find some local rocks and set them at the right height on the artificial dirt berm side to match the trail location.

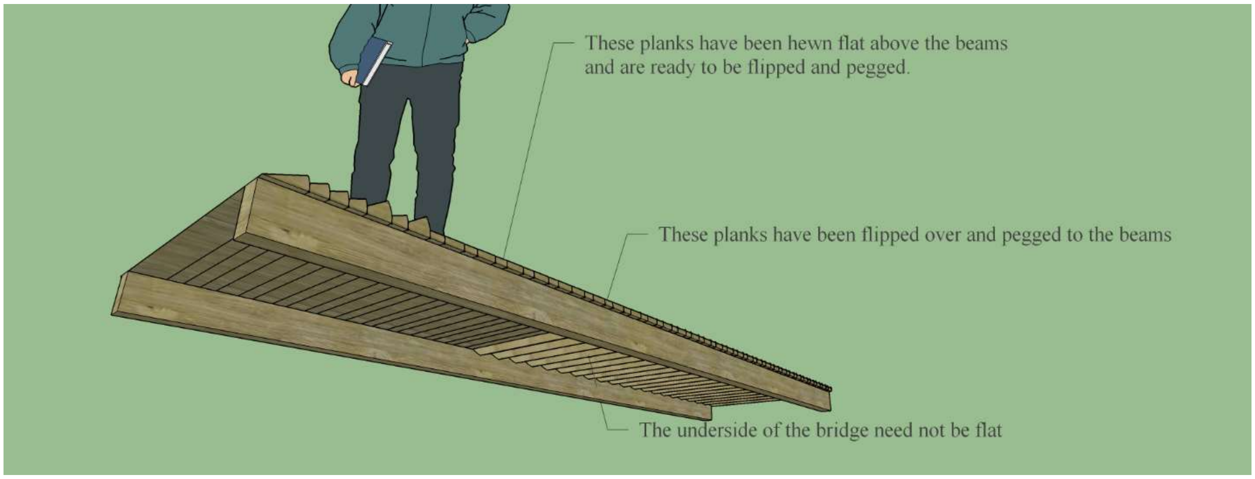

The tape measure shows the two supports
on the uphill side where the bridge will sit.

The planks will be attached to the beam using wooden pins. The wooden pins will be air dried Osage Orange (Maclura Pomifera) with a nominal diameter of 3/4 inch. Osage Orange was chosen for its natural decay resistance (similar to Black Locust, see reference 1) and strength, and because I had some short pieces in my garage that were already dry. It's good technique when building with green wood to use dry wood for pins because the green wood will shrink as it dries so the holes you bore will squeeze down on the pins. We could've made locust pins, but then those would be green (high moisture content) and would shrink down with the planks. Plus I thought the color contrast would be a nice added design touch. The locust will be honey colored when freshly hewn, but should season to a greyish color eventually. The osage orange is still bright orange in my garage, but will transition to a dark orange and eventually become purplish with exposure to sunlight. The pin holes will be bored with a 3/4 inch auger and hand brace. The holes will be bored at an angle towards the centerline of the bridge. Kind of a "toe-nailed" effect so that the planks are held down against the beams since we're using wooden pegs that don't have a head like a nail or a screw would. The angle isn't critical, maybe somewhere around 20 degrees from the vertical would work. After installation the surface of the bridge will be flattened and smoothed (probably with a foot adze) and at that time the pegs will be clipped off even with the surface. Actually, I may not have enough Osage Orange for these pegs. I think we may need more than a hundred pegs. If I (conservatively) assume 2 inch wide planks, then we need 6 planks per foot x 14 feet of bridge x 2 pegs per plank = 168 pegs. We may end up using some black locust pegs in construction.

The pegs will be made by splitting out pieces slightly under 3/4 inch square and then shaving the corners off to make an octagon slightly over 3/4 diameter for an interference fit. A drawknife and shave horse are necessary for this work. An alternative method for final shaping is to point one end of the square stick and then hammer it through a hole of the proper size in a piece of metal. A metal plate (dowel plate) can be used for this, or a length of pipe of the appropriate inner diameter.

Making all these pieces by hand will require a lot of hard work. To minimize unnecessary work and maximize efficiency, the planks needn't be perfectly flat on both sides. The bottom of the bridge needn't be flat, just the top. So after positioning the beams on their footings we will start laying the planks across them upside down. We can then stand on the planks and hew off just the corners above the beams so that there is a flat, continuous surface there. Once that is done we can turn the staves over and they should rest on the beams such that the top surface is now relatively flat. The underside of the planks will not be continuous, but that doesn't matter. Then we can begin to bore holes and drive pegs, one in each end of each plank.





For the final walking surface, it is not necessary to make the plank tops perfectly smooth. It's only necessary to remove any large splinters and any big steps between planks to lessen trip hazards. In fact leaving a rough riven and hewn surface adds to the handmade character of the bridge and provides better traction in wet weather.

First Draft: March 2017 by jacob.chancery@gmail.com

References:

1. Understanding Wood: A Craftsman's Guide to Wood Technology
   R. Bruce Hoadley, Taunton Press, ISBN-13: 978-1-56158-358-4

2. Design of Wood Structures, Second Edition
   Donald E. Breyer, McGraw-Hill, ISBN-10: 0-07-007675-8

Tools Used:

- Crosscut Saw
- Double bit axe
- Hatchet
- Wedges & Gluts
- Wooden Maul
- Froe
- Foot Adze
- Brace and 3/4” Auger bit
- Mallet
- Drawknife