EXPERIMENTS IN MODERNIZING COB CONSTRUCTION

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I had the fortune to build a cob home in the early 2000s in central North Carolina without pulling the proper building permits, and to end up with a local building inspector who worked with me in bringing it up to code once it was discovered by the tax assessor two years after completion. Even 20 years ago you couldn't "hide" a house. I then lived in that house for about five years until circumstances compelled me to move on. I fell in love with building with earth, and cob especially, because of its beauty, durability, accessibility, and adaptability. But from these combined experiences of building and living with cob, I came to realize both the potential of building with cob and the serious limitations facing it as both a housing material and as a construction process.

I continued being involved with cob in various ways, but I was also planning in my head for another house project that would address my concerns. For this new project I wanted to address the following three items:

1. **The legality of cob**. Building with earth has the potential to last centuries, but if its presence is not sanctioned by the state, then its longevity is meaningless. Getting a building permit for cob seemed like a pandora's box, even with a general contractor's license, but I wanted to wade into this mire and see if I could get to the other side. This would involve finding an adventurous architect and structural engineer, and backed by the new IRC cob code as supplemental documentation.

2. **The energy efficiency of cob**. Like other earth buildings, although its thermal mass is respectable, cob has a terrible R-Value (about R=0.25/in), and getting it past the energy code is one of the main impediments to making it legal, as well as making cob homes comfortable for all seasons. Without insulation, earth buildings' thermal mass becomes their Achille's Heel, keeping homes too warm the second half of summer, and too cold the second half of winter. Any insulation would need to retain breathability for the cob and take advantage of its thermal mass for temperature regulation. Hempcrete applied to the exterior that could accommodate a lime plaster finish was the best choice for these needs that I could find.

3. **The labor intensity of building with cob**. For cob construction to become comparable in price to conventional building, the intense labor requirements would need to be greatly reduced by mechanization. After testing several types of machines, including a mortar mixer, a cement mixer, an excavator, and a skid steer with various attachments, I settled on a skid steer with a cement

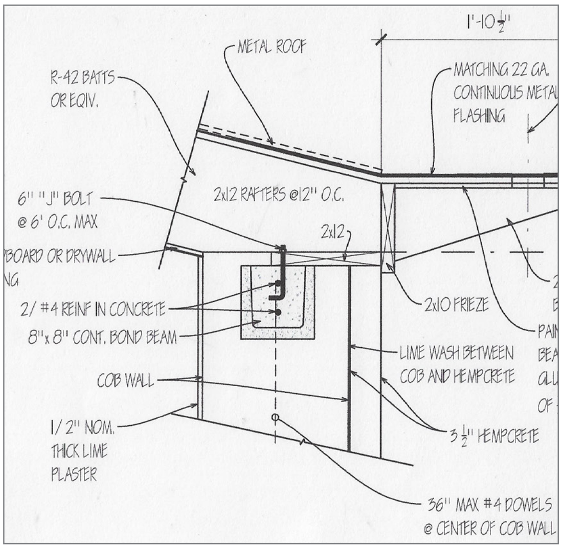

Figure 1. Cob/Hempcrete wall section.

mixer attachment as the most effective means of generating large volumes of cob that could be placed directly on the walls or nearby on scaffolding to be placed by hand or shovel. Furthermore, to increase the height of each lift, protect the unfinished walls from rain, and to minimize placement and trimming requirements, I settled on a lightly framed adjustable forming system with a temporary roof to raise the wall 18” at a time.

The logistics of getting a building permit for cob

My journey to getting a building permit for cob entailed the following steps:

a. Finding an architect willing to design with cob and be willing to act as the inspector for the cob wall sections during the construction process, needed for what the building code refers to as an “alternative material” build where the design professional ensures the quality of the work.

b. Finding a willing structural engineer to determine the needed compressive strength of the cob walls based on the architectural plans. This requires something of a comfort level for the structural engineer. The max loads for our design was for a cob compressive strength of 62psi, so our engineer called for a minimum of 100psi, or roughly 150% above max load level.

c. Finding a structural engineering lab to do the testing. This could theoretically be the same engineering firm, but our engineer did not do testing. Our first batch of samples came in too low. The lab called for the samples to be placed in 8” sections of 4” diameter PVC pipe as this is how concrete samples are typically created, however, with cob the pipes were difficult to fill and took forever to dry. Even after the recommended 28 days, the lab technician told us the samples still had significant moisture in the center and this likely compromised the strength of our samples. We blamed this wetness on the poor drying medium of the PVC tubes. For the second batch we experimented with a wider variety of clay/sand ratios and also tried using hemp fiber, and placed them instead in 4” wood cubes as called for in the IRC cob code. We found a significant improve-

Figure 2. Making cob with a skid steer 1-4.

ment from using both traditional straw and hemp fiber in our cob mix (we later determined that if the hemp fiber is longer than about 6", it tends to clump together in the mixer). Each batch has to dry 28 days and the lab was busy, so this step ended up taking about four months.

d. Once we had acceptable testing results with the coveted engineer's stamp, we could finally submit our plans to the county building inspections for plan review. All this was happening in spring of 2020, so everyone was discombobulated from having to work at home due to the coronavirus pandemic. Some clarifications and changes were required, but after these changes the permit finally came through and construction could begin.

Improving cob's energy efficiency and why it's important to do so

There were two fundamental reasons to combine an insulation component on the exterior of our cob walls. The first was practical. We needed the numbers to work out according to the Rescheck energy efficiency evaluation to please the plans reviewer, to compensate for the cob walls low R-value. The insulation component was needed just to be able to legally build the cob home at all.

But the second reason is even more vital to promoting the embrace of earth and cob building on a broader level. And that is a fundamental fact about how high thermal mass objects behave on their own and then how they behave when they are wrapped in insulation. To start with a few examples, trees are probably my favorite. Trees use high thermal mass at their core (sap, basically sugar water) wrapped in insulation (bark). They use this impressive combination to fend off both extreme cold (think boreal forests or forested Rocky Mountains) and extreme heat (think fires that for some pines and other evergreens are actually need for strong growth and reproduction). By having a large reserve of a stable temperature (thermal mass) and a means of slowing the rate of temperature change (insulation), trees have naturally evolved a means of surviving what would otherwise kill them dead.

For the second example, think of some of the new breed of coolers such as Yeti that have created a super tight envelope with very little thermal bridging to wick away temperature, and that are filled with ice and cold beverages. It's not uncommon for ice to still be present 3 or 4 days after being added. Then think about one of these coolers with just air in it. Still an impressively insulated structure, but not likely to retain a cool temperature inside if it's sitting in the hot summer sun. This last example

Figure 3. Skid steer dumping cob on scaffolding.

of an air-filled cooler is basically what modern housing aspires to: a tight building envelope with no thermal mass. There's nothing to hold the temperature. So constant regulation is needed via mechanical heating and cooling equipment, and peak loads all occur at the same time.

An earth building without insulation is the ice and beverages sitting by themselves outside in the hot sun. It will take quite some time, but by late afternoon the ice will be melted and the beverages too hot to drink. It's the combination of the two that creates a viable thermal battery capable of impressively low energy use.

This concept has a name: **decrement delay**, basically the time it takes for heat to pass through an element of a building. From the designing buildings wiki: "the thermal behavior of buildings is dynamic, rather than static…thermal mass, as well as thermal insulation, has a significant effect on the energy efficiency of a building…a longer decrement delay is likely to reduce peak loads on building services systems."

Buildings with high thermal mass wrapped in insulation can provide remarkably stable temperatures. They are able to absorb heat or cool when it is more available and store it for later use. In effect, they are a thermal battery. So if large amounts of active or passive solar heating energy are available during the day, instead of producing overheating, the excess energy can be stored for later because of its decrement delay. Likewise, if excess cooling is available (from say cool night air or extra air conditioning when photovoltaics are at max capacity), it can be stored for later when it is still useful.

Because the task of creating enough battery storage for a grid based on renewable energy is such a daunting task, we need every kind of energy storage that is available, and earth buildings wrapped in insulation could offer a major component of that needed energy storage.

Hempcrete was a natural choice for providing exterior insulation. It can hold itself up, and retain a lime plaster. Because it's lime-based, and lime and clay are allies and both are breathable, hempcrete and cob make perfect companions like bark and sap or a cooler and cold beer. When finished, it is hidden from view and the finished product looks the same as a traditional cob home, albeit a few inches thicker.

Figures 4 & 5. Cob slipforms.

Improving the speed and accuracy of cob with forms and mechanical mixing

For making the volume of cob needed for our 1,200 ft2 house, some kind of mechanical mixing would be needed to hopefully complete the cob in one season (cob cannot freeze while drying) and to reduce labor costs. Over the last two decades of making cob, I've tried out four different methods for mixing cob: a portable cement mixer; a portable mortar mixer; a mini-excavator; and a skid steer with a cement mixer attachment. All are a great improvement in terms of speed compared with mixing cob by foot on a tarp as tradition dictates. A quick summary of their pros and cons follows.

Portable cement mixer: This is the most accessible and inexpensive. A wheelbarrow-type electric or gas cement mixer makes good quality cob in small batches and dumps them on the ground. It is the most lightweight option and workers with less experience are the most comfortable with it. The mixing action is fundamentally by gravity as the material cascades from the top onto the bottom of the barrel as it spins. The electric version reduces site noise and pollution.

Portable mortar mixer: These are heavy and are often moved by vehicle. They make more cob and do so in a more thorough manner because the paddles push against the material and break up the clay. Cob is again dumped on the ground and placed by hand or shovel.

Mini-excavator: A larger bucket attachment is needed to make cob in quantity. Cob is made by digging a hole in the ground and placing the clay, sand, water and straw in and repeatedly picking the material up and dropping it, similar to the cement mixer. The bucket can also be dragged across the material to help break it up. The wet cob can be placed directly on cob walls or nearby on scaffolding for placement by hand or shovel, but requires a difficult "flipping" motion that takes skill and practice to master, as the cob is dumped back towards the driver and can fall out in the wrong spot. Whether placing on the walls or on scaffolding, getting the cob up to the proper elevation saves a massive amount of work as walls get taller.

Skid steer with cement mixer attachment: Despite its name, the cement mixer attachment is more like a mortar mixer, using spiral paddles to push the mix against the sides of the bucket, and the action is reversible, which ensures an excellent mix. It does a good job of breaking up the clay clods, although large rocks need to be avoided. Placement can be directly onto the walls or nearby on scaffolding for hand or shovel placement. However, as the level of the walls gets taller (about 4'), the skid steer is not

Figures 6 & 7. Shoveling cob into forms.

reliably able to tilt its bucket forward enough to have the cob pour out, and it must be done by hand with a hoe or shovel.

Making good cob means making a consistently mixed batch with regularity. In my experience, the key to doing this is soaking the clay in buckets for as long as possible prior to mixing. The clay is mixed by itself first in a wet slurry for several minutes to form a batter prior to adding any sand. Sand is added gradually, then the straw and other fibers as needed, with additional water as needed throughout the process.

Formworks

Slipforms have been in common use for over a century, to make concrete and stone walls, so extending the idea to cob seems natural. For cob, they present many advantages:

- Hempcrete requires forms so they would need to be built anyways;
- A permanent roof could be constructed to keep the cob out of the rain;
- A taller “lift” of cob could be completed each time speeding construction;
- Since cob can mostly hold itself up, the forms would not need to be substantial, compared to rammed earth for example;
- The forms could produce a flat face for the cob and reduce or eliminate cutting and forming;
- The forms could help hold window and door bucks in place; etc.

After some experimentation, for the formworks we constructed vertical 2” x 6”s every 8’ on both sides of the wall, with doubled boards at the corners. We were building an octagon with roughly 16’ sides. For the forms themselves, we built 18” tall stud walls, with a thin veneer of primed plywood on the inside form and ½” hardware cloth on the exterior. We wanted the exterior to end up being rougher to bond to the hempcrete, and wanted the interior to be relatively smooth to facilitate finish plastering. Also, having the hardware cloth on the exterior would provide additional surface area for faster drying. The forms rested on the insides of the 2” x 6”s, so for our 16” wide walls, the 2” x 6”s were

Figure 8. Flattening last full layer of cob for bond beam.

Figure 9. Inside of wall is smooth for finish plaster.

spaced approximately 23” apart, resting on the 28” wide concrete footing. The foundation for the cob wall was one row of CMUs two wide to elevate it off the footing, and the bases of the vertical 2” x 6”s were pushed up against the CMUs with 2” x 4” spacers and braced to keep them in place. Cross-sections connecting the 2” x 6” were placed every 3’. 3” screws and some 6” ledger lag screws were used for fasteners.

Filling the forms was done at lower levels by a combination of directly depositing the cob into the forms from the skid steer’s cement mixer attachment, or by positioning the mixer attachment close enough where it could be hoed in or removed from the mixing bucket by hand or shovel and placed directly in the form. After about the third lift, we would place the cob from the skid steer onto scaffolding walkboards covered in a tarp and shovel it in. We tried to get the skid steer to do as much of the mixing, lifting, and placing work as possible in every situation without endangering the formworks and the existing cob walls by getting too close. Some sections we were able to complete the 9’ wall (six lifts) in two months, but we had relatively dry weather during this time (May-June). Higher humidity levels increase the drying time, and since the previous layer needs to be stiff enough to support the new cob, this slows down the process generally. After the bond beam was installed, we left the exterior formworks in place and used 8’ sheets of ¾” plywood ripped in half (2’ wide) to place our stone and hempcrete exterior in a similar manner, working from the bottom to the top. This hempcrete then took a finish plaster to protect the hempcrete and the cob from rain, along with generous roof overhangs.

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