Permitting a load-bearing cob studio in Berkeley: a white paper.

Massey Burke, with Anthony Dente and the Ecological Building Network.

Introduction and purpose

This paper describes the process of taking a load-bearing cob structure through the permit process in the city of Berkeley. The intention of the design team was to generate a useful technical precedent for cob construction in an urban context. For this purpose Berkeley is a paticularly useful jurisdiction to engage with, since it is culturally disposed to forward-thinking, ecological design, yet fairly conservative and detail-oriented when it comes to the permit review process. In this sense, the city of Berkeley was likely to be a good collaborator in creating a precedent that would be useful in other situations and jursidictions.

Describing a cob structure technically necessitated a "translation" process from the vernacular, grassroots, primarily hands-on information that exists about cob into the technical, enforcible language used by building officials. The conversation with the city of Berkeley took place over the better part of two years, and required a fair amount of research and strategy along the way. This paper includes the initial application to the city of Berkeley, the evolution of the conversation, and the final form of the permit. The primary design team for the project was Jessica Tong, Anthony Dente, P.E., and Massey Burke, with indispensable feedback and support from Kevin Donahue, S.E., Bruce King, P.E., David Mar, P.E, and many others.

What is cob?

Cob, also known as monolithic adobe, is a vernacular earthen building technique with many variations worldwide. The word "cob" derives from the British tradition of earthen construction, and means a "lump" or "loaf." Cob is mixed from clay subsoil, sand, and straw; and is built by hand-shaping layers of wall in layers or "lifts" which are formed on top of and integrated into the previous layer. Most cob construction is of typical residential proportions, one or two stories tall. However, there are historic cob "skyscrapers" in Yemen that are several stories in height.

Variations on cob were rediscovered and/or reinvented in the US, UK, Europe, New Zealand, and other places as a part of the ecological building, DIY, and permaculture movements. The Cob Cottage Company in Oregon studied the mixes traditionally used in the UK, and redeveloped the approach to suit more modern approaches.

Cob has recently gained considerable momentum as a grassroots construction technique, partly because it is fairly accessible for non-professional builders, and partly because it is, in some sense, the diametric opposite of conventional construction. To date most cob construction has been unpermitted, in rural areas;

but there is increasing interest in permitted uses and construction in urban areas and more prominent contexts.

Because there is no code for cob construction, any cob project seeking a permit will typically apply through the Alternative Means and Methods clause, which can be found in the International Building Code, section 104.11. Evaluation and approval of an alternate method depends upon the discretion of the building official in a given jurisdiction. This method requires the applicant to demonstrate that the requested alternate method performs in a manner equivalent to the requirements for structure, durabilty, and safety as described in the building code. The building department may accept a range of information to demonstrate equivalency, ranging from other codes that exist internationally, to structural testing results, to historical precedent. We used all of the above.

History and intention of the project: why permit cob?

The Berkeley cob studio originated as a portfolio project for Jessica Tong, a recent architecture graduate who grew up in Berkeley, and whose parents still live there. I met Jess through a hands-on natural construction course that I taught in the summer of 2012. Jess was attending the course because she was exploring how to use her architectural degree to ecological ends. Her parents were already interested in building a backyard studio for themselves; and they saw in this a good opportunity to support Jess to create a portfolio project that would express her values as a developing ecological designer. Jess was, and continues to be, interested in experiencing construction directly, and feels that hands-on, personal experience of construction—particularly unusual, cutting-edge green construction—is essential to designing well for those techniques. This project offered her a way to explore all of these aspects of design and ecological experience.

My work for the last ten years has been in implementing natural building techniques in many contexts, as well as in advocating for their use and in assembling technical information that supports their implementation. My interest in this project was primarily the opportunity to demostrate tangibly that low-tech earthen construction can meet modern technical expectations.

The building.

The Berkeley cob studio is a secondary structure in the backyard of the Tong residence in North Berkeley. It is small—130 sq. ft.—and has an earthen floor with radiant heat, interior lime and earth and exterior earthen plasters, and a conventional roof. It is in Seismic Zone E, so is designed very conservatively, with thick walls and few openings. In an early conversation with the Berkeley building department, it was agreed that for a project as ambitious as a load-bearing earthen structure in a seismic zone a small building would be preferable. The size of the structure was also constrained by the size of the Tongs' lot and by zoning requirements.

What the permit was required to address.

The permit application was required to address three primary categories, according to how the buildng envelope is described in the California Building Code: structural performance of cob, exterior wall performance of cob (moisture/weather resistance), and the earthen floor. An Alternative Means and Methods Application was written and submitted for each of the above categories. Each category required both research and time spent understanding how to translate our information into the right form. We needed to communicate vernacular, historical, or empirically observed data to an audience (the building department) that is accustomed to the more formal, enforcible language of the building code.

This project gained visibility in other jurisdictions during the course of our process, which both helped and hindered our progress. It emphasized for the building department that we would be setting a useful precedent, and one that would be leveraged by other jurisdictions. However, it caused the department to be even more cautious than they would otherwise have been, in response to the scrutiny of colleagues.

The summaries of the information below are organized by the AMMR (Alternative Means and Methods) categories.

Structural

Our goal with the structural design of this project was to keep it as simple and elegant as possible, minimizing the use of industrial materials. This was for two reasons: 1. Industrial materials tend to have several times the environmental impact of less-refined natural materials, and the clients wished to create a building that was as ecological as possible. 2. Because we intended to set a technical precedent, we wanted to keep the structural design as streamlined as possible. Because the closest analog to cob in the building code is masonry, it would be easy to end up with the worst of both worlds—a massive cob wall with a lot of steel reinforcing. Since the project is in Seismic Design Category E, and since adobe, a much better-known relative of cob, has a miserable seismic reputation, we knew that this would be a challenge. We also decided to pick our battles, and did not attempt to use an alternative foundation system as well.

Our structural design, as originally submitted, included 18-inch-thick cob walls with one inch of plaster on each side, for a total wall thickness of 20 inches. Loads are transferred from the cob to the foundation through 1” thick anchor bolts, staggered at 7” intervals; and from the wood double top plate to the cob by 1” anchor bolts at 6” intervals. All headers and sills for openings in the cob were designed according to specifications in the New Zealand Standard 4297, Table 5.1.

Structural calculations were based upon a series of tests conducted through the University of San Francisco, using the specific clay soil that will be used in the construction of this project, which yielded compression, bending, and modulus of rupture values for the wall mix. Combined with these values, we used the New Zealand Standards' strength design loads and formulae to confirm structural adequacy and redundancy in the design. We made the case that cob is not actually masonry, because it is monolithically constructed and reinforced throughout with straw. The structural performance of the straw in the wall mix is demonstrated in the USF tests, and longevity of straw in the wall is illustrated by many examples of straw-reinforced earthen building in wet climates. Thus, our original submittal included no reinforcing steel aside from the anchor bolts at top and bottom, and a continuous piece of all-thread at each corner to counteract overturn forces specifically.

The consulting engineers assigned to the project by the building department responded that " The unreinforced wall system is considered plain masonry (see CBC 2109) , and is not permitted in Seismic Design Category E per ASCE Table 12.1-1. Item A10. The request must demonstrate CBC-equivalent strength, effectiveness, durability, and safety. Unreinforced earthen walls will not be permitted, and any straw added to the mix will not be considered reinforcement. The alternate request must propose a reinforced system."

CBC 2109 includes the adobe section of the California Building Code, in which adobe is described as plain (unreinforced) masonry. Because adobe is the only existing earthen material in the code, this section is the closest analog. After considering our options, we decided to try again to convince the building department that cob without a more conventional reinforcing system is not "unreinforced."

To do this we took a two-pronged approach. We researched the history of the adobe portion of the California Building Code, and found that it became part of the International Building Code in 2000, by way of the Southern Building Code, a regional code that was partially included in, and superseded by, the IBC. The adobe code was originally proposed by Jim Hunt, the chief building official of El Paso, Texas, in 1980 and again in 1982, when it was accepted. The code was not the product of a more general professional conversation, thus contains several oddities and is not really representative of best adobe practice. According to the Historic Codes Division of the International Code Council in Birmingham, AL, the code has changed a negligible amount since the original draft in 1982 (phone call, Feb. 6, 2013.) We therefore suggested to the plan check engineer that the adobe code is not a particularly useful analog for our project, and requested not to be bound by all of its requirements.

To address in more detail the question of reinforcement, we turned to the definition of reinforcement in the CBC. As it turns out, "reinforcement" without qualifiers is not defined in CBC 202, definitions. Therefore, the term falls into the category of CBC 201.4, Terms not defined. This section states that "where terms are not defined through the methods authorized by this section, such terms shall have ordinarily accepted meanings such as the context implies. Both cement-based code requirement texts, ACI 318-08 Building Code Requirements for Structural Concrete and TMS 402-08/ACI 530-08/ASCE 6-08 Building Code Requirements and Specifications for Masonry Structures define "reinforcement" as "steel reinforcement." This is appropriate for cement-based materials for many reasons, but is not necessarily a good analog for clay-based wall systems, because of the differences in bonding and moisture relationships between Portland cement and clay.

Our case for straw reinforcement addressed three major aspects of straw as a reinforcing material: the durability of straw in a clay matrix, structural viability of straw as a reinforcing material, and the use of straw-reinforced walls in seismic regions.

To support the fact that straw remains structurally intact in a cob wall over time, we cited the molecular tendency of clay to wick water away from biodegradeable materials, which has a preservative effect on straw, wood, and other biodegradeable materials that are in contact with the clay matrix. Documentation of this tendency is quoted from The Design of Straw Bale Buildings, p. 33; Building with Earth, p 15, and Cob Building in Cob, Pise, Chalk, and Clay, p 41. We also cited an example given to us by Feile Butler, an architect and builder in Ireland, who supplied us with a photo of straw in a cob wall from a cottage that first appears on the Irish ordnance survey map of 1838. "As you can see," she commented, "the straw is still golden." This structure is in County Kildare, Ireland, a rainy climate.

To support our claim that straw is able to reinforce cob adequately without the need for other structural reinforcement, we referred primarily to the tests performed through the University of San Francisco, which compared the behavior of test samples with different proportions of straw. Although additional testing is needed for greater redundancy, these tests suggest that straw adds significant tensile strength to cob mixes. We also cited two other groups of cob tests, one at Oregon State University, and one at the University of Plymouth, UK, that underscore the findings of the USF tests.

To support our claim that straw-reinforced cob is suitable for seismic zones, we cited the cob shake table test performed by the University of British Columbia. A total of 3 shake tests were performed on a simple half-size cob structure. The first test was incomplete due to hydraulic failure, but the two subsequent tests simulated a 7.2 Richter test, and a destructive test to failure. The 7.2 test lasted 18 seconds and produced minor, centralized, visible cracks with no significant framentation of the material and exhibiting no life safety hazards. The second test lasted 12 seconds before small fragmentation began to occur and 18 seconds until large fragmentation resulted in failure. The structure was shaken at 2g (significantly above the 1.34g required for our project) without complete collapse.

In summary, we argued that straw fits the "ordinary accepted meaning" of reinforcement for the following reasons:

- It adds tensile capacity to a compression-based material
- It will not biodegrade in the cob mix
- Its quality, length and bent orientations allows for engagement/development in the base material regardless of shrinkage or expansion
- It adds containment to a mass material with potential to fracture
- It adds tensile continuity to allow a mass material to fracture and dissipate energy in a ductile manner without resulting in catastrophic failure.

After we sent this response to the plan check engineers, we met with them in person to clarify any questions, as well as to underscore the care that we have taken with our research. We did this well knowing that a request to build a straw-reinforced structure in a seismic zone would sound outlandish to any structural engineer not familiar with natural construction methods (as well as to many that are!)

As a result of our response and this meeting, the consulting engineers sent a memo to the City of Berkeley building department, stating the following:

"We have carefully studied the New Zealand Standards relating to seismic hazards and earthen construction, and have reached the opinion that the NZS earthen building standards could be used for the subject project, but with certain limitations and restrictions. During our meeting on Sept. 10, 2014, the design team indicated that NZS 4297 (Engineering Design of Earth Buildings) and NZS 4298 (Materials and Workmanship of Earth Buildings) were undergoing revision. We contacted the Earth Building Association of New Zealand to get a sense of what the revisions would entail, and received the following response:

> *"Bill ,*
> *there won't be any radical changes in the design methodology of NZS 4297*
> *What we found in the Christchurch earthquakes reconnaissance expeditions is that earth houses built to the standards (or on principles aligned with the standards) performed well. W[e] have never had a report of a problem with an earth building that was designed to the NZ Earth Building Standards*
>
> *I would just go ahead and do your design as per the current NZS 4297 (the NZ standards revision is mainly a tweaking to align the standards with other building standards that have "leapfrogged" the earth standards over the last 16 years (such as the NZ-Australia Structural Loadings Code)*
>
> *Regards*
>
> *Thijs ("Tase") Drupsteen*

Indeed, our review of the New Zealand earth building standards indicates that some of the references to other standards are outdated, but are nevertheless still easily followed and implemented.

Further, the seismic hazards in New Zealand are very similar to those we face in Northern California.

ASTM E2392-10, "Standard Guide for Design of Earthen Wall Building Systems", identifies New Zealand Standards 4297, 4298 and 4299 as appropriate for the design of earthen wall system. NZS 4299 is a prescriptive, non-engineered standard that will not apply in California as it conflicts with California Business & Professions Code provisions.

Surveys of earthen building construction in New Zealand following the Sept. 2010 M7.1 (MMI VIII and greater) earthquake in Canterbury revealed reinforced earthen structures that were designed and constructed in conformance with New Zealand Standards performed well:

> *http://www.standards.co.nz/touchstone/building/2010/dec/earth-buildings-surveyed-following-canterbury-earthquake/*

A similar survey performed after the 2011 Christchurch earthquake (M6.3, MMI up to VIII) again revealed that properly-designed, reinforced earthen construction performed well:

> *http://www.nzsee.org.nz/db/SpecialIssue/44(4)0358.pdf*

An additional report describing earthen building performance in both earthquakes is found at this link:

> *http://www.civil.mrt.ac.lk/conference/ICSECM_2011/SEC-11-89.pdf*

As noted above, we have carefully reviewed New Zealand's standards as they relate to earthen construction, and believe these standards can be applied to the subject project and satisfy the provisions of CBC 104.11. The subject AMMR can only be recommended for approval if based on the New Zealand standards.

The following limitations on the cob earthen wall system, however, should be clearly outlined in the AMMR document from the design team:

1. *The AMMR should clearly indicate that the system is applicable to a single-story U-Occupancy with an area not exceeding 500 s.f.*

2. *The reinforced earthen wall height : thickness (h/t) ratio shall be limited to 10, and the walls shall be 10"-thick, minimum.*

3. *Unreinforced earthen wall systems will not be permitted.*

   Straw added to the soil mixture will not be considered as reinforcement. Reinforcement shall be steel, as defined by NZS 4297, Section 2.1; NZS 4298, Sections 1.3 and 2.6.1; and TMS 602, Section 2.4.

We have made reasonable efforts to ensure this report is accurate given the information made available by the design team and found by us during research. Our recommendations are based upon our experience and observations of a wide range of structural systems in the Western United States, and upon the reported performance of reinforced earthen structures in recent New Zealand earthquakes. We do not, however, have direct design or construction experience with this particular building system. As experience with this system develops in California, it is possible to envision a future adoption of formal standards - via legislative action as with straw bale construction or otherwise - with equally-conservative or less-conservative provisions than those recommended above.

As a result, our final structural submission consisted of a 12" cob wall, with 1" of plaster on interior and exterior, with the addition of steel reinforcement. The wall is reinforced with a grid of #5 rebar running horizontally and 5/8" threaded rod running vertically down the center of the wall, 1' 2" spacing each way, in addition to half of the original anchor bolts (the reinforcing grid replaces the other half.)

Exterior walls

The exterior walls of the cob studio are designed with 1" of earthen plaster directly over the cob surface. The city required evidence that these materials will stand up to weather and will prevent the accumulation of moisture within the walls of the building.

When we initially applied for our permit, we did not have a clear idea of which specific sections of the building code the city of Berkeley wished us to address. Our original application was in the form of a short essay describing the building science of clay and clay soil mixes relating to water and moisture, broken down into the following categories: clay plaster as a water-resistive barrier, vapor-permeability of finish, eaves and erosion protection, cob as "mass" moisture storage (the building science of clay-based walls and water penetration), and cob in contact with wood.

Organizing the information this way gave the building department more guidance for how to decide which sections of the California Building Code were most relevant for proving equivalency. They responded with a request to write a separate AMMR for Exterior Walls, addressing the sections of code that are referenced below.

Deciding which sections of the code for which we should prove equivalency was an interesting process: it became clear that the building department wasn't sure what to ask us for either. After a couple of conversations with the building department, we narrowed it to the following:

R104.11. Alternative materials, design, and methods of construction.
CBC 1403. Exterior Wall Performance Requirements, and specifically:
CBC 1403.2. Weather protection

CBC 1403.2 provided the specific text and concepts for us to use in demonstrating equivalency. It requires a weather-resistant exterior wall envelope, to be accomplished by a water-resistive barrier, a means for draining water that enters the assembly to the exterior, and protection against condensation in the exterior wall assembly. Accordingly, we discussed the clay plaster on a cob wall in terms of each of these requirements separately, using the plaster testing requirements set forth in the New Zealand earthen building code 4299 as our primary justification.

The Exterior Walls AMMR states that clay plaster over a cob wall accomplishes these performance objectives as follows:

1. Clay-based exterior plaster, combined with conventional flashing and detailing around openings, provides the water-resistive barrier. Clay molecules, when wetted, bond at the molecular level with water molecules to prevent further movement of liquid water into the wall assembly.
2. Roof overhangs combined with the plaster mix design protect the plaster from erosion. The appropriate relationship between overhang length, wall height, and erosion resistance of plaster is expressed in table 2.2, NZS 4299.
3. Condensation within the wall is prevented by the use of vapor permeable finishes, and by avoiding the use of any material that is not vapor-permeable, allowing the wall to release moisture in the form of water vapor.

The ability of the clay plaster to provide a water-resistive barrier shall be demonstrated by the erosion test (pressure spray method) described in Appendix D, NZS 4298, and with reference to table 2.1 and table 2.2 in NZS 4299. This test shall demonstrate both the plaster's resistance to water penetration and its resistance to physical erosion. The cob walls average 8' in height with 2' eaves in a sheltered urban zone, thus requiring an erodibility index of 2, according to table 2.2 in NZS 4299.

To support our description of clay plaster/cob weather performance, we provided the following additional supporting material:

NZS 4299, C 2.10.2. "The improved waterproofing properties of clay surfaces, which are free to swell to form a waterproof layer, are recognized. When these materials get wet, they have superior waterproofing properties compared to the more porous matrices formed by cement and lime stabilizers. "

Design of Straw Bale Buildings, on clay plasters, p.32. "Because of its chemical structure, clay is very hydrophilic, literally attracting and adsorbing water between its silicate sheets. As these spaces fill with water molecules, the clay expands and forms a water-resistant barrier. Both cement and lime plasters wick water by capillary action. The actual structure of the material does not change when wet, so the rate is the same whether lime and cement plasters are wet or dry. Because clay expands when wet (as the spaces between the silicate sheets fill with water molecules), earth plasters act like "smart membranes"-- the wetter they are, the more they resist the passage of liquid moisture. Because of the electrical charges between silicate plates, earth plasters tend to store moisture rather than just wicking it through. "

Using Natural Finishes, p. 29. "Clay's most prized characteristic is its ability to readily attract and take up moisture from the atmosphere and retain this moisture within its pore structure…as it incorporates this moisture into its structure, it causes the clay molecules to expand, blocking the further passage of moisture through its structure. This forms a water-resistant barrier. This self-sealing ability can prevent moisture from wicking into the wall substrate beneath, whilst still allowing moisture to move back out."

NZS 4298, 2.13, "A surface finish exposed to the exterior environment and which tends to trap or hold water so that it affects the durability of the material, is not permitted."

The Devon Earth Building Association, http://www.devonearthbuilding.com/. FAQs "The fundamental principle is to achieve vapor permeability in finishes on earth buildings to avoid saturation. DEBA for this reason advises strongly against the use of renders and plasters which incorporate Portland cement as this heavily reduces or prevents such permeability."

In response to the information above, the city requested that we show documentation that the clay plaster can meet the New Zealand Standards cited. We responded as follows:

"The referenced erosion test is designed to mimic heavy rain and wind conditions present for this site. The test require that for this project's wall height to eave length ratio--wind zone L, 2400 mm (8') average wall height and 600mm (2') eave length--the plaster shall resist erosion to a depth of 50 mm (1.9 inches) for one hour of erosion testing.

An earthen plaster of the same materials, formulation and thickness was used in a remodel in a building in the East Bay hills, in the same wind zone category, and with greater weather exposure (eaves 2', average wall height 10'.) This exterior plaster was installed previous to the framing insulation inspection (Contra Costa county permit #418682) on September 23, 2010. To date this plaster exhibits no erosion: the attached photo was taken March 25, 2015. This existing precedent therefore demonstrates performance that is superior to the requirements described in the New Zealand Standards."

The city considered this response sufficient, provided that we insert a clause including preconstruction testing of plaster durability according to the New Zealand tests.

Because the building is four feet from the property line, the walls are required to meet a one-hour fire resistance rating according to CBC Table 602. This is addressed by NZS 4297, 5.5.1, which states that the fire resistance of 6" thick earth construction is given as 120/120/120. This means that for 120 minutes the material maintains its structural adequacy, integrity, and insulation.

Earthen floor

Our original AMMR did not include information about the earthen floor. The city requested in response to our initial application that we fill out a separate AMMR or the floor system. The earthen floor includes a subfloor of compacted gravel, a layer of rigid foam insulation, and a total of 3.5" of earthen floor, poured in three layers and sealed with linseed oil. The second layer contains hydronic heat.

As with the Exterior Wall AMMR, deciding which sections of the code for which we should prove equivalency required some conversation with the building department, with the following result.

R104.11. Alternative materials, design, and methods of construction.
CRC 501.2. Floor requirements.
CRC 301.1 Application (of design critera.)
CRC 301.4. Dead load
CRC 301.5. Live load
CBC 804. Interior floor finishes

CRC 501.2 simply states that floor construction shall be capable of accommodating all loads according to Section R301 and of transmitting the resulting loads to the supporting structural elements. CRC 301.1 lists generally all of the load categories that structures must support. Requirements for live and dead loads are described in CRC 301.4 and 301.5. We described performance equivalency of an earthen floor as follows:

"An earthen floor weighs 130 lbs/cu.ft, as stated in Claylin technical specifications.) At 3.5" thick, an earthen floor therefore has a dead load of 38.3 lbs/square foot. The total design load is therefore 38.3 pounds per square foot plus 40 pounds per square foot, yielding 78.3 psf of total load.

According to the testing report completed by Oregon State University, the compressive strength of earthen floors ranges from 87 psi to 113 psi . The earthen floor is continuously supported by the compacted gravel substrate, thus will easily support loads of 78.3 psf."

CBC 804 addresses interior floor finishes, and requires that anything which is not a "traditional finish" meet specific flame spread tests. We approached this requirement by describing the oil and wax as a "traditional finish," as follows:

"The floor is finished by application of Claylin floor oil and wax. This contains the following traditional ingredients: tung oil, linseed oil, gum rosin, beeswax, D-limonene (citrus terpenes), food grade essential oil of orange, extracted by distillation from orange peels, no added chemicals, Dipentene (natural citrus and pine terpenes)- no added chemicals. "

The city accepted this with the addition of technical specs for the subfloor foam and cut sheets for the oil mix, which are available on the Claylin website.

Implications and next steps for permitting cob.

Our original purpose was to establish a technical precedent demonstrating that cob, in its simplest, most ecological form, can meet modern expectations for modern building performance in the most exacting context (a high seismic zone.) Even though we were not able to convince the building department fully of this, the process of the conversation, and what we have learned about how to express the technical aspects of cob in terms of language and code that has been developed for what is essentially the opposite of cob—for refined, industrial, uniform materials—has been invaluable, and has created a good foundation for further efforts to legitimize cob . The combination of our research and the city consulting engineer's efforts to talk with the authors of the New Zealand code has yielded a project that is a good representation of the international conversation about seismic earthen design: as forward-thinking as it can be, while still expressing conservatism until we have more complete information about wall-scale behavior of cob in seismic conditions.

It also helps clarify what information we need to assemble to better support subsequent efforts to permit cob structurally. What is primarily needed is more wall-scale tests. These do not need to be full-scale shake table tests necessarily, which are extremely expensive, as well as more difficult to extrapolate specific structural information from—information that is not specific to the geometry and proportions of the structure that was tested. Other wall tests, such as the Reverse Cyclic In-Plane Loading test, would yield useful information about how fiber reinforcement behaves over the wall as a whole.

Another important field of information to clarify is the relationship of clay, and cob, to metal. It would be useful to know more about both the chemical (oxidation or corrosion) and physical (development or withdrawal) relationships between the clay matrix and rebar in particular; but for other types of metal as well, since the more we know about corrosion rates of metal in clay, the easier it becomes to use the most minimal amount of metal possible, in situations when metal reinforcement is unavoidable. In addition, it would be helpful to drill down into the specifics of the structural relationship between straw and clay, and why smaller, more distributed, biodegradeable fibers complement a clay matrix in ways that metal cannot.

The design team hopes that this paper will be helpful to others wishing to permit cob in the future. We also wish to thank the many people who have supported our process, technically, morally, and financially: Kevin Donahue, Bruce King, Sandy Wiggins, Sallie Calhoun, David Mar, and last and most importantly, Linda and Roger Tong.

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