

The future and the common ground

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ABSTRACT: Marissa Mayer was the first female engineer at Google. She was responsible for the fun. When she left to become CEO at Yahoo, she put an end to the policy of working from home. In her words, “Some of the best decisions and insights come from hallway and cafeteria discussions, meeting new people, and impromptu team meetings” (Marks 2013). Scientists, academics, engineers, and practitioners, come from as far as it is possible to travel on this planet, finally, in the same room for the ICREC event. ICREC has put an end to working from home. For four days, lab-coated scientists can exchange ideas and experiences with dust-encrusted practitioners, every one committed to a common cause - advancing the credibility of rammed earth as a global solution to durable, healthy, ecological shelter. This paper gives a personal overview of the past and future of rammed earth, with a particular emphasis to the rammed earth activities in North America in the 40 years.

1 INTRODUCTION - THE BEGINNINGS AND THE FUTURE OF RAMMED EARTH

I've been obsessed with rammed earth for forty years, but never has an opportunity such as this presented itself.

I grew up in Southern California in the 1950's. One of my earliest memories was building earth dams to guide the irrigation water in my father's orange grove. The soils of Southern California are primarily sandy alluvium, eroded over millenia from the granite and sandstone of the San Bernardino Mountains. The alluvium was very easy to dig, even for a six year old. I had a shovel put in my hands at a very young age. One of my second early memories was watching bulldozers and steam shovels push over the orange trees and build dams from that same sandy alluvium to encircle the playground that became Disneyland. That's right, my father sold the family farm to a crazy cartoonist from Los Angeles who made his money on a talking mouse. As a show of gratitude for giving up the farm, Walt gave us lifetime free passes to Disneyland. All those impressionable years of my developing youth, spent in the magic kingdom, the happiest place on earth. This very likely molded my adult personality. I spent far too many days in a land where the impossible is made easy and where dreams come true.

When did rammed earth begin? 10,000 years ago in China? 5000 in Mesopotamia? 3000 in Asia Minor? And when did modern rammed earth begin? In 1200 AD in Spain when the Moors constructed the Alhambra? In 1820 in France with Francois Cointeraux (Lee 2008)? 1840 in the US with Samuel Johnson (John-

son 1806)? 1930 in the US with Tom Hibben and Ralph Patty (Hibben 1941)? In the 1950s in Australia with George F. Middleton (Middleton and Schneider 1992)? Johnson built the Church of the Holy Cross in South Carolina. It's still one of the most significant old rammed earth buildings in the US.

To be sure, the Chinese, the Moors, and other civilizations have kept rammed earth continuously alive - alive but not thriving. Cointeraux, Johnson, Patty, Middleton - they were enthusiasts in their time, but when they died or retired, rammed earth slipped into a sort of architectural dormancy.

I'm going to stick my neck out here and say modern rammed earth began in 1976, when Stephen Dobson built his first rammed earth house in Darwin and I built mine in the California foothills. Quentin Branch was in Arizona, and Patrice Doat and Hugo Houben were in graduate school discovering the widespread effects of Cointeraux's passion for rammed earth.

In 1975, I bought a hundred acres of river-crossed woodland at the end of a paved road in the foothills of eastern California, far enough off the beaten path that I could hide out from building inspectors. Little did I know when I bought that land that the red clay soil under the pine needles would produce beautiful rammed earth walls. One river valley north, and one hundred years earlier, Chinese gold miners found that same red clay soil and built structures that are still standing to this day.

Two little books provided my introduction to rammed earth: *Farmer's Bulletin 1500* (Betts and Miller 1937), published by the US Farm Bureau, and *Build Your House of Earth* by George F. Middleton

(Middleton 1980). We bolted some heavy wooden forms together and tried our hands at pounding earth - sheds, barns, and small houses for me and my neighbors, each one a little better than the one before it, the forms a little less cumbersome, the mix a little more uniform. We discovered the versatility of the pipe clamp and the wide wooden waler, bought a used rammer, an old air compressor and a front loading tractor. We were in business.

In 1981, we came out of the foothills and had the audacity to build the Haywood Winery in Sonoma (shown in Figure 1). Stephen Dobson and Giles Hohnen built the St. Thomas Church in Margaret River (Figure 2) - both surprisingly large undertakings considering how little we knew back then.



Figure 1: Haywood winery in California, USA.



Figure 2: St. Thomas Church in Western Australia.

But back to the 1970's: What in the world were Stephen, Giles, Quentin, and I thinking? Who in his right mind would believe that you could simply pound dirt into durable shelter - that walls built this way could stand up to wind, weather, and gravity? Who in his right mind would think you could make a business out of such a thing, that people would actually pay for it? What were we thinking? That here was an opportunity to support our families and put our kids through college? That we would get rich and successful and launch a global renaissance? Mark Twain once

said, "it takes two things to be successful in life - ignorance and confidence." Look at us old timers today. What in the world made us stick with the idea of rammed earth? Was it ignorance, or confidence?

The year was 1979, I was applying for a building permit in a new county in California. I brought my plans and engineering to the office of the chief plan checker, explained that the walls were to be rammed earth, stabilized with cement and incorporated within a concrete post and beam frame, and that he needn't worry because I was a graduate of the Stanford school of engineering. His reaction: "Rammed earth? I never heard of it, but I can tell you right now I don't like it". He wasn't alone. Forty years ago almost no one had heard of rammed earth. And yet here we all are today to celebrate the past successes and to lay out the future of rammed earth.

And what is that future? Many people believe we are on the brink of a global environmental crisis, consuming resources at a lightning pace. During the Carboniferous Period, between the Devonian and the Permian, roughly 350 million years ago, the earth was a vast sweltering swampland. For 60 million years the bodies of billions of dead organisms, buried in mud, and under intense pressure and heat were lithified into hydrocarbons. It has taken 350 million years to build up the hydrocarbon reserves that we industrialized humans have burned up in a mere two hundred. The construction industry is responsible for a large share of this resource consumption. Cement in particular can be held accountable for 5% of all CO_2 emissions. To make cement we incinerate hydrocarbons in order to calcine limestone, which is mostly lithified coral. In the process we release the carbon dioxide that was stored in both the limestone and the hydrocarbons. One ton of CO_2 is released to the atmosphere for every ton of cement produced - not a particularly efficient rate of conversion.

Rammed earth practitioners and researchers should seek out a common ground among them and ask each other this question: *how can we retain the quality of our rammed earth and at the same time reduce our use of cement?* Scientists can guide to improve mix designs and seek out alternative stabilizers. Engineers can develop new protocols that recognize the improvements. Architects can adjust their designs to accommodate the means and the methods established by the practitioners. By doing so, the high visibility projects in Europe, Australia, and North America can be leveraged into expanding rammed earth technology to the places where it can do the most good - building healthy, affordable, durable housing for the rest of the world.

2 IT IS NOT EASY TO DO WELL

When I was in my mid twenties, two people provided me with inspiration to walk the rammed earth path. One was David Miller, a country lawyer from Col-

orado who when he wasn't arguing water rights cases between the wheat farmers and the sheep ranchers, was a globe trotting rammed earth historian and an owner builder. The other person was Wayne Dunlap, a geologist from Texas A & M who wrote a milestone manual, Handbook for Building Homes of Earth (Wolfskill et al. 1963). I met them both at the first national conference on Earth Building in Albuquerque New Mexico in 1980. David was one of the very few who kept the rammed earth dream alive between the depression era years and the mid 1970's when it was "re-discovered".

Wayne Dunlap was one of the most inspirational college professors I ever listened too. I wish I could have taken a full course from him rather than the one short lecture. In his will, David bequeathed me his library of photos and rammed earth research. You could put the little handbook Wayne wrote in your coat pocket, travel anywhere in the world, and feel confident selecting the best soil to build rammed earth. The handbook made it seem so simple.

Simple was the operative word at the start. Let me tell you those were the days. Simple forms, simple buildings. Grab a bucketful of soil from the footing excavation and beat it so hard it stands up on its own. I remember the first time I did this - set a form, filled it with pounded earth, and stripped the form - I could hardly believe my eyes. Could this be real? Why doesn't everyone build this way? This is so simple! I was mesmerized, transfixed, I was as smitten as Francois Cointreaux. My life's work was laid out in front of me as clearly as Dorothy's yellow brick road leading to Oz.

But Wayne's handbook contained a warning: Number one on his list of the disadvantages of building with rammed earth: "it is not easy to do well". He was right. It is not easy to do well. The yellow brick road to Oz wasn't as well-paved or as clearly visible as I first thought.

The Myth of Sisyphus is a philosophical essay written by Albert Camus in 1942 (Camus 2000). The original Greek myth tells us that Sisyphus was condemned to repeat forever the same meaningless task of pushing a boulder up a mountain, only to see it roll down again. Camus maintains, however, that "the struggle itself is enough to fill a man's heart. One must imagine Sisyphus happy". Have I been happy pushing a rammed earth block up a hill for forty years? Absolutely. Remember, I spent my youth in a land where the impossible is made easy and where dreams come true.

There is a road in California, the original road, as a matter of fact, but back then it was more like a dirt path. It runs from the southern border with Mexico for six hundred miles, all the way to Sonoma, an hour north of San Francisco. The road is called El Camino Real - the King's Highway. In the 1940's it was paved with macadam, a type of rammed earth in which layers of small broken stones are compressed.

Sometimes macadam is mixed with a bitumen, but not always. That macadam has mostly been replaced with concrete by now, but along this road are scattered twenty-one two hundred and fifty year old adobe missions. My father took us to every one of those missions (one of those presented in Figure 3). Fourth graders in California public schools make models of them. The missions are part of California's heritage. You might say adobe was the original California building material.



Figure 3: Mission of San Francisco Solano, California, USA.

The adobe missions have provided a valuable field laboratory over the years. Every one of the bell towers and tall gable end walls has tumbled down in one earthquake or another - 1812, 1827, 1857, 1923 - but the low walls survived. Forensic engineers were able to look at the slenderness ratios and extrapolate safety standards. The important information garnered is that slenderness ratios under 4.5 can survive earthquakes, even with unit compressive strengths of 0.25 MPa (30 psi).

I would have thought building rammed earth with slenderness ratios below 4.5 and compressive strengths well above 0.25 MPa would have satisfied the building department. "Just look at all of those field tests verifying the numbers, each of them over two hundred years old". No luck. Sometimes it feels like trying to convince a building official is like being stuck in geologic time.

Another quote from Mark Twain. "Whenever you find yourself on the side of the majority it is time to pause and reflect". You had to be on the opposite side of the majority to be a rammed earth builder in the 1970's, certainly in California where earthquakes put the shakes in the heart of every structural engineer and code official. I could not have picked a worse place to revive rammed earth than California if I had tried. Think of Sisyphus pushing the stone up a cliff - in geologic time. The County of Los Angeles is so obstinate we still haven't been able to crack the code there in forty years.

3 WHAT IS RAMMED EARTH?

Perhaps even before we start building our macadam highway, we should agree on one important common definition. What is rammed earth? Is it a method of building structural walls on site in which soil, aggregates, sometimes with a binder are beaten down in layers until each is hard? Or is it no longer considered rammed earth if the mix design is not pure earth, but crushed aggregate mined in a quarry?

Is rammed earth only pure compacted soil or is it any aggregate pounded into a monolithic wall, whether or not blended with stabilizer? Is it the act of ramming, or the composition of the earth? Is a poured earth wall rammed earth? Is a shot earth wall rammed earth? Is a wall of compressed earth blocks rammed earth? What defines rammed earth? The material, the method, or its monolithic character? Does cement stabilization change the character of the wall so much that we can no longer call it rammed earth?

To many people, rammed earth must be made of pure earth. As soon as cement is added, the product becomes something different - it loses its hygroscopic properties, its clay properties are gone forever, and most importantly it is only marginally sustainable: remember using 10% cement stabilization in a 400 mm wall releases more CO_2 than a cast in place concrete wall.

I believe there are some builders and researchers who would argue that those adding cement are not building true rammed earth at all, but an ugly sister relegated to a sort of marriage of convenience. A marriage of convenience, is *a marriage contracted for social, political, or economic advantage rather than for mutual affection*; broadly: a union or cooperation formed solely for pragmatic reasons. Was the union of earth and cement contracted solely for pragmatic reasons: to ease the pathway, to build a wide paved road, an El Camino Real, leading to building department approvals and public acceptance? Or was the marriage of earth and cement contracted with an expectation of mutual affection in order to improve the strength and performance of rammed earth in general and to allow for the use of otherwise marginal soils?

4 CEMENT-STABILIZED RAMMED EARTH

Cement was being used as a stabilizer for rammed earth as early as the 1940's. Earlier builders had tried urea, manure, fiber, lime, bitumen and other admixtures. Portland cement was the best of them all, and this was long before the environmental effects of calcining limestone and releasing CO_2 were an issue. Cement, after all, was a very effective and affordable glue, capable of improving the strength and durability of raw rammed earth by a factor of five.

The question now might be: since we have worked together for forty years to create acceptance for rammed earth as a modern building medium, can we

begin to retrace our steps? To go backwards, as illogical as that sounds. Can we remove the cement from our mix designs or at least cut back, from 10% to 5% or 2.5%? Can we find an alternative to Portland cement that will give us strength, durability, resistance to erosion and still maintain the credibility we have so patiently acquired? Can we find common ground?

The researchers at Watershed Materials, working with the support of the National Science Foundation (\$740,000 Phase II Small Business Innovation Research grant from the National Science Foundation), are in the second phase of a testing program and now obtaining strengths up to 41 MPa (6000 psi) using geopolymers to replace Portland cement.

In my opinion, the battle around the reduction of elimination of the use of cement is as much public policy as it is structural safety. In the US, we are compelled to achieve compressive strengths higher than actual design calculations would require. There are layers of safety imposed on structural design that force us in this direction, some by structural engineers others by policy makers, some by the fear of lawsuit. Variations in how to interpret the code, safety factors, and design guidelines, especially in California, can lead one engineer to require a compressive strength of 5.5 MPa (800 psi) where another engineer will only feel confident with two times those strengths; 11 MPa (1600 psi) and higher. Some builders and engineers try to achieve strengths of 17 MPa (2500 psi), equal to that of cast in place concrete, as a pathway around the code.

Why do the world's codes differ so radically on the perception of what is safe rammed earth - 0.25 MPa (30psi) in some countries, 17 MPa in others? In soils, it takes a minimum of 10% Portland cement to achieve strengths of 17 MPa, less cement in crushed aggregate. What this means, distressingly, is that there is nearly twice the cement in a 400 mm stabilized earth wall than there is in a typical concrete wall, and every pound of cement calcined generates nearly a pound of CO_2 .

This is the dirty little secret we are not sharing about rammed earth. It's akin to the myth of Pandora. Today the phrase to "open Pandora's box (it was actually a jar)" means "to perform an action that may seem small or innocent, but that turns out to have severely detrimental and far-reaching consequences". Pandora removed the lid and all manner of evil escaped and spread over the earth.

In the instance of stabilized rammed earth, it isn't that evil will spread over the earth, but what will happen is that our claims that rammed earth is an environmentally benign, even beneficial wall assembly will be seriously challenged. Yes it saves on lumber, drywall, and paint; it outlasts other wall assemblies and requires far less maintenance, but cement, ordinary Portland cement is, after all, responsible for 5% of all the world's CO_2 emissions.

Let me share with you how I got addicted to ce-

ment. I confess I am one of the worst offenders. I confess I fell under the spell that stronger is always better. Cement made me feel invincible. I look back on my past and I can see when this addiction started. I began building in the 1970's, taking earth from the site and pounding it into simple, not very elegant walls - fast, inexpensive, but somewhat crude. Very little energy input other than human carbohydrates.

As opportunities grew for our struggling company, the marketplace - architects and clients - wanted the magic and the muscle of rammed earth, but wished it were not so crude. Building officials and engineers wanted it not so unrefined and difficult to specify. Here came our first big price jump - quarry materials, steel reinforcing, better forming methods, slower more careful work, higher wages, diesel fuel, and the demon cement. Only a little at first, but gradually we became heavy users, lured by the vision of code approval.

4.1 *Pneumatically impacted stabilized earth*

In the 1980's we invented PISE - high pressure air delivery. PISE for pneumatically impacted stabilized earth (Figure 4). No shovels, no ramming, half the formwork. We were working on a very large construction site for a wild animal theme park. We were building rammed earth termite mounds, and next to us was a gunite crew shooting concrete against a dirt bank, then carving it and painting it to look like earth. I studied their equipment for a few hours and got to thinking maybe we could shoot rammed earth that way.

The early attempts were troubling. I'd say 90% discouraging, but there was 10% hope, the same hope left in the bottom of Pandora's box. To continue working to perfect PISE called once again on that unique combination Mark Twain identified: ignorance and confidence. We persevered to bring PISE to the marketplace.

PISE was fast. We shot thousands of cubic yards of PISE throughout the wine country of northern California in the 80's and 90's. Wine makers especially liked it because it was an inexpensive way to get great thermal storage. But pise needs even more cement than rammed earth due to the higher water contents. Over the years, as cement and diesel prices went up and concerns over global warming grew, my passion for PISE waned. I could no longer justify burning 100 gallons of diesel fuel to power the big air compressor to get 1000 square feet of finished wall. It didn't pencil out, financially or ecologically. I had to kick the habit.

The good news, I'm proud to say, is that I am on the road to recovery. Our testing programs are verifying that we can attain the necessary strengths at reduced cement ratios, and for our most recent two rammed earth installations we dropped our cement use by 30%.



(a) work in progress



(b) final construction

Figure 4: Examples of Pise - Pneumatically impacted stabilized earth.

5 RAMMED EARTH AND BIOPHILIA

This raises a question: What is it that makes rammed earth so attractive, so alluring, so captivating? What exactly is the magic? Is it simply the hygroscopic ability of raw earth to maintain optimum humidity levels within a space? Or is it the way thick earth walls can soften sounds and provoke a sense of calm? Perhaps they capture the essence of biophilic design, that the earth walls provide a source and sense of connection to the natural world, distilling natural materials to their elegant simplicity and rightness of fit.

The recent interest in biophilia - architecture to connect people with nature - could not find a better mascot, a better poster child than rammed earth. A thick, strong earth wall acts like a filter, excluding the noise and the stress that is outside, creating a positive, beneficial environment within. It's pure and simple.

I have my own idea of what makes rammed earth so endearing and mesmerizing. It links us to geologic time. The first law of thermodynamics states that energy can be transformed from one form to another, but cannot be created or destroyed.

I believe this construct can be applied to raw earth. 4.6 billion years ago, when the magma that would become planet earth was cooling for the first time, rock

began to form. We call this first generation rock precambrian - a period in the earth's history that began 4.6 billion years ago and extended to the beginning of the Cambrian era 540 million years ago. Geologists have been forced to lump 80% of all the world's geologic metamorphosis into this one vast period of time because there was no life, no fossil record prior to 546 million years ago, and hence no accurate way to date the origin of the rock. In a sense rock goes through a life cycle. It grows, either from heat or pressure, and it dies, from weather, grinding, or leaching, only to form again.

The individual grains of gravel, sand, silt and clay used to build rammed earth walls are as old as the earth itself, the product of the big bang, the molecules that from nothingness fused to become the planet we call home, and which we rammed earth builders transform into shelter, into home.

Yes, we rammed earth builders have mastered a technology, and we've done so in such a way as to capture the nature of rock, the natural, made-by hand character, the wabi sabi, of the material itself, it's incredible age and it's tenacity - its endearing quality. After experiencing a building with thick earth walls, there is no going back.

This is what keeps us pushing that mammoth stone of rammed earth up the hill, but is it the ancient precambrian rock composition or is it purely biophilic determinism? Is it tenacity or obstinate contrarianism?

6 CONCLUSIONS

I think we're all big wave riders, on the crest of a green building revolution, and it's either confidence or ignorance that keeps us here. Will rammed earth prove to be the most ecologically responsible of all wall systems - bringing safe, healthy, affordable housing to people in need, while at the same time giving modern architects a massive new materials pallet?

Wayne Dunlap warned me, and we all know, it is not easy to do well. But let's all stand committed, from this point on, to doing it right.

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