Regrounding Rammed-Earth Energy Systems

Brian Poirier

May 2, 2018

Contents

1 INTRODUCTION

"The history of building construction can be construed as a narrative of the inertia and momentum of two divergent construction logistics. One mode[, discussed above,] has very minimal historical inertia coupled with great current industrial momentum (the muli-layered assemblies of modernity.) The other has great historical, physical, and thermodynamic inertia that is coupled with minimal industrial momentum in the contemporary building industry/building science industry (more monolithic assemblies and masses). The former follows the short history of the twentieth century "rationalization" of construction, air-conditioning, factory production, lightweight envelopes, and, more recently, mass customization. The latter is a several-thousand-year history of accumulative knowledge and performance all but forgotten in the interesting yet hubristically selective amnesia of twentieth century architecture."

— Kiel Moe.

Convergence. 2013.

"Rammed-earth" refers to an earthen building material formed by a particular mechanical process. Rammed-earth architecture has ancient archaeological, anonymous, and autochthonous roots in China, Africa, Europe, India, the Middle East, and other regions globally [1]. Observably, rammed-earth forms have been (re)appearing in the U.S. over the past half-century with a frequency and technical gain atypical of earthen construction, especially in the West. Contemporary rammed-earth forms are predominantly connected to academia, professional architectural design, and building science/industry.

Rammed-earth structures have appeared relatively recently on the campuses of M.I.T. (2005), Stanford (2015), and Princeton (2016)[1]. Rammed Earth Works (the designers of Stanford's Windhover Contemplative Center) is one of multiple professional architectural firms to be designing modernized rammed-earth buildings and installations valued in the multimillion-dollar range[2]. David Easton, the founder of Rammed Earth Works (1976), also invented PISE (Pneumatically Impacted

[1] `https://archive.is/5gPbZ` (M.I.T.); `https://archive.is/VhpW2` (Stanford); `https://archive.is/9SF6K` (Princeton)

[2] `https://archive.is/K853p`

Rammed Earth) and Watershed Blocks (under a $750k grant from the N.S.F.); a sprayed application of wet soil-cement and a mechanical system for mass-producing modular soil-cement blocks, respectively. SIREWALL (Structural Insulated Rammed-Earth, B.C., Canada) is a rammed-earth-based building product incorporating an intermediary layer of patented insulation[3]. Numerous technical papers concerning rammed-earth's structural and thermal properties have been published globally. A select few include: *Analysis of the hygrothermal functional properties of stabilised rammed-earth materials* by Hall and Allinson. (2009), *Modeling rammed earth wall using discrete element method* by Bui et al. (2015), and *Measured and simulated thermal behaviour in rammed earth houses in a hot-arid climate. Part B: Comfort* by Beckett et al. (2017).

Hypothesis: Along the decades of rammed-earth's previous resurgence in the U.S., at the eco-movements of the 60s and 70s, rammed-earth took on a greater socio-technical momentum while standards, practices, and policies of the building culture remained inert. The result was a form-based function of modern construction—a virtual image of sustainability—reducing, reusing, and recycling a historically function-based form of complexity, persistence, and adaptability. The rammed-earth material *and* method morphed more significantly in forty years than it had in four thousand.

If Doctor E. is right, and we can not solve problems by using the same kind of thinking we used when we created them, then it stands to reason that greater control of contemporary rammed-earth technology is not as much a determinant of sustainability as the model by which rammed-earth forms are conceptualized, codified, communicated, designed, logisticized, and constructed.

Objective: **Design a system** of design (a coalescing model of models) drawing from contemporary theories and technology, reaching towards the principles and heuristics of the traditional rammed-earth material and method. The model is directed towards a computational system (digital accumulator and distributor of information) capable of organizing two flows:

[3] `https://archive.is/Sf9fu` (PISE); `https://archive.is/x3iwg` (Watershed Materials); `https://archive.is/s0cHI` (SIREWALL)

1. The flow of soil types from deposit to building site (determinants of rammed-earth's embodied energy and building performance).

2. The flow of knowledge between builders (determinant of rammed-earth's standardization and design).

"[T]he culture that once was slow-moving, and allowed ample time for adaptation, now changes so rapidly that adaptation cannot keep up with it. No sooner is adjustment of one kind begun than the culture takes a further turn and forces the adjustment in a new direction. No adjustment is ever finished. And the essential condition on the process — that it should in fact have time to reach its equilibrium — is violated. This has all actually happened. In our own civilization, the process of adaptation and selection which we have seen at work in the unselfconscious cultures has plainly disappeared."

— Christopher Alexander.

Notes on the Synthesis of Form. 1964.

1.1 The Model is the Message

Marshall McLuhan noted (*Understanding Media*, 1964) that, with respect to media/technology, the medium is the message. The rammed-earth building medium *qua* pre-modern rammed-earth conveys a natural socio-technical desire for a functional, durable, and economical form of building. Without any positive rammed-earth heritage to draw from, the U.S. has nonetheless considered or adopted rammed-earth construction during energy-sensitive phrases of its history. For instance, in the late-eighteenth century, French architect/builder François Cointereaux presented Thomas Jefferson and America's burgeoning rural economy with a case for rammed-earth architecture. Encoded in a copy of *Ecole d'architecture rurale* (Paris, 1790-91), Cointereaux believed that if America adopted "the economical building art of the ancients, perfected and made more universal," She would incur a great physiocratic power. Jefferson reacted indifferently, in a letter to William Short, "how far it may offer benefit here superior to the methods of the country, founded in the actual circumstances of the country as to the combined costs of labour & materials, and the circumstances of durability comfort & appearance, must be the result of calculation."[4]

Rammed-earth later appeared in *Popular Mechanics (Vol. 41, No. 2, 1924)* and *The Farmers Bulletin (No. 1500, 1926)*, endorsed as a frugal, Do-It-Yourself building method. During the Great Depression, rammed-earth briefly held the attention of the New Deal-era Resettlement Administration as an economical building alternative fit for an over-abundance of available labor. Around the 1960s and 1970s, rammed-earth attracted marginal interest from the environmental movements, following the global recognition of troubling anthropogenic effects on the biosphere and building's major role aside this phenomenon [2]. Speculatively, following this last wave of rammed-earth building in the U.S., although the material would continue in some form, the D.I.Y.ness was lost to the momentum/inertia of building practices.

In a gross linearization of history, it would appear that a growing field around "ecodevelopment" in the 1960s/1970s effectively reintroduced rammed-earth building for the first time into a tech-

[4] `http://archive.is/yWexi` (Cointereaux to Jefferson); `http://archive.is/ozqQv` (Jefferson to Short)

nologically dependent world aware of the consequences of (in binary terms) developmentalist and zero-growth economic strategies[5]. Hypothetically, at this shearing of [simply] technological positivity and technological negativity, building societies retrofit rammed-earth into a model through which cake could be had and also eaten. On one hand, the tried method would remain a symbol of building sustainability. On the other, seemingly innocuous technical changes to rammed-earth's composition and construction would modernize the material-method, ensuring marketability, scalability, standardization, and security.

Rammed-earth v2.0 manifested as "soil-cement", also known as "cement stabilized rammed-earth." Over time, it was layered with modernizing assemblages of mechanization, pre-fabrication, insulation, transportation, seal-ification, svelte-ification and modularization. An early code of practice was *Soil-Cement: Its Use in Building*, distributed by the U.N. Department of Economic and Social Affairs in 1964.

> *"The use of simple compacted soil (natural earth) as a building material dates from time immemorial, and it can be said that ever since, and down to the present day, the method of building houses with earth has been used, because of its constructive qualities. Yet, despite its* good insulating and resistant properties [author's emphasis], *there are limitations to the use of earth owing to its lack of strength and its vulnerability to moisture and the erosive effects of external agents. Provided that natural soil possesses a combination of certain characteristics, however, it can be subjected to the process known as 'stabilization'. The effect of adding a stabilizing agent like Portland cement, for instance, is not only to enhance its best qualities but to impart to it other properties which soil alone does not possess."*
>
> — Augusto A. Enteiche
>
> *Soil-Cement: Its Use in Building.* 1964.

> *"Contemporary stabilized rammed earth (SRE) draws upon traditional rammed earth (RE) methods and materials, often incorporating reinforcing steel and rigid insulation, enhancing the structural and energy performance of the walls while satisfying building codes. SRE structures are typically engineered by licensed Structural Engineers using the Concrete Building Code or the Masonry Building Code."*

[5] `http://archive.is/sOf7w`

— Bly Windstorm and Arno Schmidt.

A Report of Contemporary Rammed-Earth Construction and Research in North America. 2013.

Generally, the above quotes represent modern/contemporary models concerning rammed-earth's function as a building material, physically and also with regard to their respective building cultures. Endemic to both rationalizations is [what is now seen to be [3]] a destructive reduction of vital qualities (or non-qualities) of rammed-earth building, e.g. "resistant properties" and questionably "[enhanced]" energy performance.

McLuhan's wisdom remains, the cement-stabilized rammed-earth medium conveys the message that, as Bruce Sterling noted (*Shaping Things*, 2005), the model is the message. Rammed-earth ceases to exist as an unselfconscious technology of sustenance and increasingly becomes defined by complicated logistics, stylistic preferences, and virtual references. This is to say that contemporary rammed-earth *in rem* does not necessarily possess the property of sustainability. Instead, the historical ability of rammed-earth to sustain itself, its settlers, its ecosystem, and the biosphere at large is a phenomenon emerging from the inanimate and animate collectives involved in rammed-earth building, i.e. its model.

2 BASIS IN ARCHITECTURE

Architect/builder/author/professor Kiel Moe has authored a number of texts and a number of buildings in and around the past decade that cogently embody novel theories about building(s) and energy. *Convergence* is one such textual work based around the notion that "matter is but captured energy" [3]. This realization, and associated theorems, is central to the model for contemporary rammed-earth building at hand.

As Professor Moe explains much more thoroughly and lucidly in *Insulating Modernism*, disparate fields related to building(s) have inevitably imparted their own characters onto modern building(s), leading to questionable building practices from a standpoint of "building energy". Industrial engineering, as a prime example, translated applications of nineteenth century thermodynamics (e.g. artificial refrigeration through systems closed by insulation) to building-scale, setting in motion a contra-rational model [if air is primarily an insulator, why temper spaces with convective heat transfer?] for H.V.A.C. systems still in effect today. Following from this professional paradigm is a cultural language fixated on "energy-efficiency" [transformations of energy always operate at 100% efficiency] and "energy-conservation" [equating exergy exclusively to The Grid], when nature (and rammed-earth building) offers a more nuanced potential for engaging energy/matter systems *MOEIM*.

Aside from the fact that rammed-earth building is primarily an architectural endeavor, a contemporary architectural theory motivates historically-oriented rammed-earth building because it presupposes a model learned from the iatrogenic effects of twentieth century modernism and anticipates twenty-first century non-equilibrium thermodynamics. Not accidentally, the theory mirrors incipient rammed-earth building principles manifesting before science or architecture were known as such.

Professor Moe explicitly references rammed-earth at least twice. Once, in the Building Lecture

Series at the University of Virginia[6], in the context of rammed-earth as a thermally massive building material. Capillary to this vein, the material quantities thermal effusivity (e) and thermal diffusivity (α) contribute to a more effective understanding of built environments as thermally transient, interactive, radiant, qualitative systems rather than scientifically ideal systems forever operating in the steady-state mode. Second, Professor Moe references rammed-earth as a case study in *Convergence*: the Granturismo Earth and Stone project in southern Portugal. Initially a reforestation initiative funded by the European Union, the project entailed ten rammed-earth and stone structures in the inner Algarve region suited for tourism and recreation. In this remote area, the locally-sourced property of rammed-earth proved to be critical for design, construction, economic, and ecological reasons. Furthermore, the Algarve does possess a positive heritage in rammed-earth building and Granturismo was an opportunity to "[make] the history of the Algarve material culture apparent while [the material selection reinvests] in the labor and skill connected to that material." [3]

The aforementioned objectives, organization of soil flow from deposit to site, and conceptual flow between builders, may be construed as a consequence of the convergence of matter and energy. The first flow is a matter of emergy, that rammed-earth does not materialize for free. The second flow is a matter of exergy, that knowledge is one of the most potent forms of exergy, and predicates the contemporary development of rammed-earth energy systems.

3 BASIS IN ENGINEERING

"Many historical and modernized systems of building with unstabilized earth exist around the globe, and comprise the housing for a large percentage of humanity. In many cases, multiple examples can be found of extant structures with many centuries of useful service life, none of which have been designed by engineers. The durability, utility, and appeal of earthen construction is thus established, and historical systems in particular express designs generally well adapted to local climate and conditions."

— ASTM International.

[6] `http://archive.is/u9TKf`

Standard Guide for Design of Earthen Wall Building Systems : Appendix X1 : Empirical Design and Minimum Detailing Requirements for Earthen Structures. 2010.

A side effect of rammed-earth's relative dormancy in the U.S. is a lack of centralized, homogenized research data (when compared to concrete or steel, for instance) or a unified science for guiding rammed-earth construction from wild soil to building performance and eventual deterioration. Historically, the rammed-earth building process has been guided by the immediate intuition and somatosensory judgements of experienced builders [4]. In contemporary rammed-earth building, the scientific viewport is of great importance. Essential considerations range from the seismic behavior of geographic regions to the chemical behavior of clay particles.

Both of these construction logistics are evidenced across an array of modern building guides, codes and standards. In the empirical sense, formal guides such as ASTM E2392/E2392M (Appendix X1) appear to be relatively liberal with the techniques and quantities involved in rammed-earth construction. Granted a single-story building in a seismically low-risk area, methods such as the "Ball Test" and the "Roll Test" provide approximate values for design and construction. In the modern scientio-industrial sense, codes such as the New Mexico Earthen Building Materials Code demand stabilization on the order of six percent by weight of Portland cement and laboratory testing on a set of samples prepared from the site[7]. Joe Dahmen (principal investigator/designer for the rammed-earth wall at M.I.T.) reported, in discussion with a Tuscon-based rammed-earth builder, "builders often increase the amount of Portland cement to double the amount specified to avoid a shortage of cement in the mix, which is measured by approximate means in the field.[8]"

The constitutional complexity of rammed-earth is a challenge and an opportunity. It is a challenge because the emergent performance of a rammed-earth is determined by an ensemble of microscopic particles and resultant pore structure, fuzzy pre-factors of construction such as water content, compaction energy, the configuration of the structure, local topology, hydrology, and weather/climate

[7] `https://archive.is/2wkiN`

[8] `https://archive.li/WP2Uf`

patters, to name only a few factors.

This complexity may also be one of rammed-earth's great assets. By keeping track of a finite representation of these parameters in a centralized, visible, and open format, an outward-facing standard may evolve not simply around ensuring an arbitrary value of mechanical strength, but also around the customization of performance per local geology and geography.

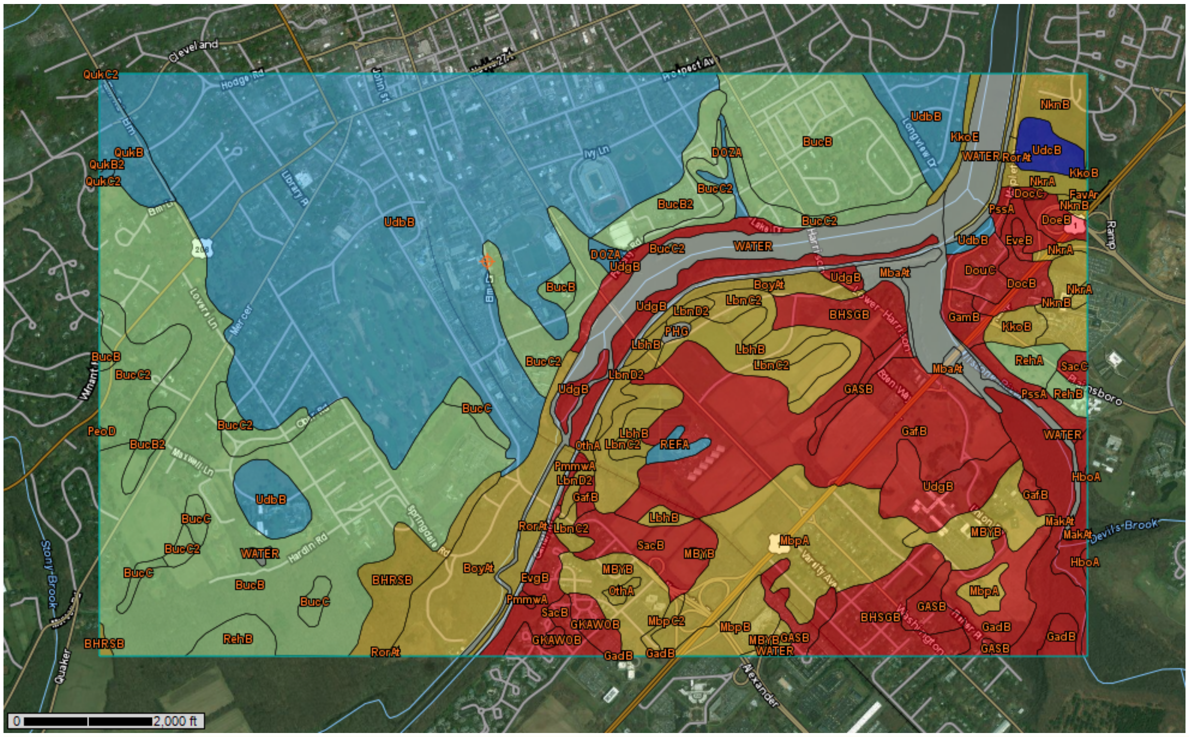
This is a case for empirical science in rammed-earth building and standardization, mainly but not exclusively opposed to analytical models and "top-down" standards which lack the capability to express this complexity without years of abstracting laboratory research and much mathematical rigidity. Whether empirical data is somehow integrated or plainly recorded and made accessible, it is a quick and transparent mode of science that has the potential to become more detailed and also adapting in time with new data. The artistic aspect of rammed-earth has not prohibited experimentation with tempers such as lime, straw, or chaff [4]. An empirically open standard is able to facilitate and propagate new practices, while a closed, prescribed standard prohibits timely adaptability.

A notable link between the geographic and the geological is the steady accumulation of pedological information over time. Saliently, the U.S. Soil Survey began in 1899 as an endeavor based in the utility of knowledge about soil for e.g. agricultural and constructional purposes. Since, the database has been digitized and covers more than ninety-five percent of the nation's counties [9]. Of note is SoilGrids[10], a machine learning-based pedological model drawing from several independent sources and projecting results at a spatial resolution of 250 meters.

Queryable soil properties of the Soil Survey include: percent clay, percent sand, percent silt, linear extensibility, plasticity index, AASHTO group classification, and Unified soil classification.

[9] http://archive.li/hD4CZ

[10] http://archive.is/l07N3



Tables — Percent Clay — Summary By Map Unit

Summary by Map Unit — Mercer County, New Jersey (NJ021)
Summary by Map Unit — Middlesex County, New Jersey (NJ023)

Summary by Map Unit — Mercer County, New Jersey (NJ021)

Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
BHRSB	Birdsboro sandy subsoil variant soils, 2 to 6 percent slopes	13.4	39.3	1.2%
BHSGB	Birdsboro gravelly solum variant soils, 0 to 6 percent slopes	7.0	80.8	2.5%
BoyAt	Bowmansville silt loam, 0 to 2 percent slopes, frequently flooded	16.2	96.6	3.0%
BucB	Bucks silt loam, 2 to 6 percent slopes	20.8	573.5	17.8%
BucB2	Bucks silt loam, 2 to 6 percent slopes, eroded	20.8	43.4	1.3%
BucC	Bucks silt loam, 6 to 12 percent slopes	21.1	22.3	0.7%
BucC2	Bucks silt loam, 6 to 12 percent slopes, eroded	18.9	135.6	4.2%
DOZA	Doylestown and Reaville variant silt loams, 0 to 2 percent slopes	27.0	8.8	0.3%
EvgB	Evesboro loamy sand, 0 to 5 percent slopes	4.3	22.1	0.7%
GadB	Galestown loamy sand, 0 to 5 percent slopes	5.6	40.5	1.3%
GafB	Galestown sandy loam, 0 to 5 percent slopes	5.7	216.0	6.7%
GASB	Galloway variant soils, 0 to 5 percent slopes	5.0	37.8	1.2%
GKAWOB	Glassboro and Woodstown sandy loams, 0 to 5 percent slopes	8.7	11.6	0.4%
KkoE	Klinesville channery loam, 18 to 35 percent slopes	15.6	5.7	0.2%
LbhB	Lansdale sandy loam, 2 to 6 percent slopes	12.3	55.1	1.7%
LbnC2	Lansdale channery loam, 6 to 12 percent slopes, eroded	12.6	54.7	1.7%
LbnD2	Lansdale channery loam, 12 to 18 percent slopes, eroded	12.6	16.6	0.5%
MakAt	Manahawkin muck, 0 to 2 percent slopes, frequently flooded	3.5	51.7	1.6%
MbaAt	Marsh, fresh water, 0 to 2 percent slopes, frequently flooded		13.2	0.4%
MbpA	Matapeake loam, 0 to 2 percent slopes	14.8	129.8	4.0%

"What holds for the pyramids and the ant hills holds for all our logistics and manufacturing operations."

"The pyramid and the quarry grow at the same time. If the pyramid is a positive architecture ($y < 0$), the quarry is its negative. Such positive-negative pairs are everywhere in history and geography, even though modern advances in transportation technology tend to obscure them"

— Adrian Bejan

Advanced Engineering Thermodynamics, Third Edition. 2006.

A main consequence of readily available geo-spatial information is the optimization of soil convergence as an area-to-point flow. Adrian Bejan describes this phenomenon in pyramid and ant hill construction, wherein the location and the shape of pyramids and ant hills around the world are predicted by applying a principle of least work [**FLOWFOSSIL**].

Saliently, this connection between ancient principle and modern technology stands to offer a previously unseen level of accountability for rammed-earth building. Designers are able to openly access (Web Soil Survey:SQL, SoilGrids:JSON) soil information local to their site, determine where and not where soil may be accessed, and predicate rammed-earth material composition around the local soilscape and climate. Emergy-oriented design decisions can be made between, for instance, adding two percent more cement, or transporting additional clay from twenty miles away.

4 BASIS IN COMPUTATION

"[V]ernacular architecture producing recipes for everyday buildings is another form of early lo-fi open-source culture, openly sharing and optimising technologies for building."

— Ratti et al.

Open-Source Architecture. 2011.

References

[1] Charles Augarde. “A chronological description of the spatial development of rammed earth techniques”. In: *International Jounral of Architectural Heritage* (2008).

[2] Jennifer Lynn Carpenter. *Dirt Cheap: The Gardendale Experiment and Rammed Earth Home Construction in the United States*. 2010.

[3] Kiel Moe. *Convergence. An Architectural Agenda for Energy*. Routledge, 2013.

[4] David Easton. *The Rammed Earth House*. Chelsea Green Publishing Company. White River Junction, Vermont, 2007.