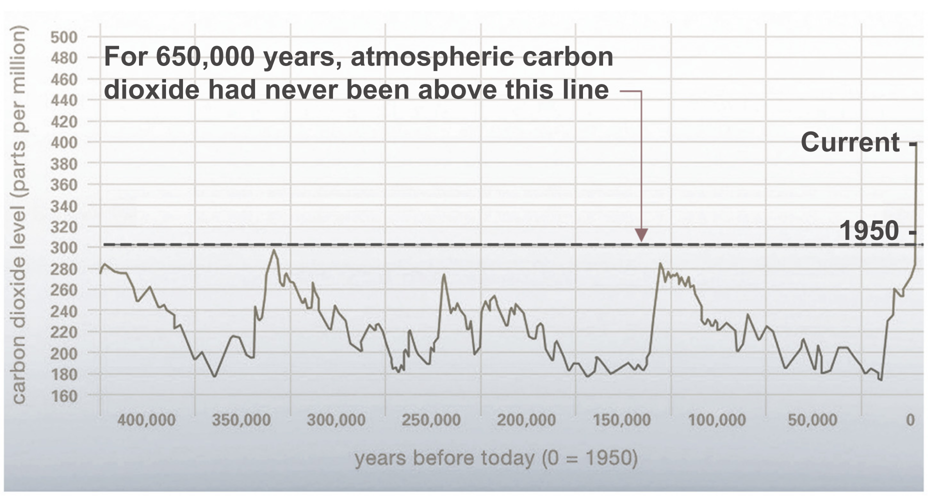
ENGINEERED CAST EARTH

"The poetry of the earth is never dead." ~John Keats

CONDITIONS

"97 % or more of actively published climate scientists agree climate-warming trends over the past century are very likely due to human activities"
(NASA Earth Science Communication Team, Cal Tech).

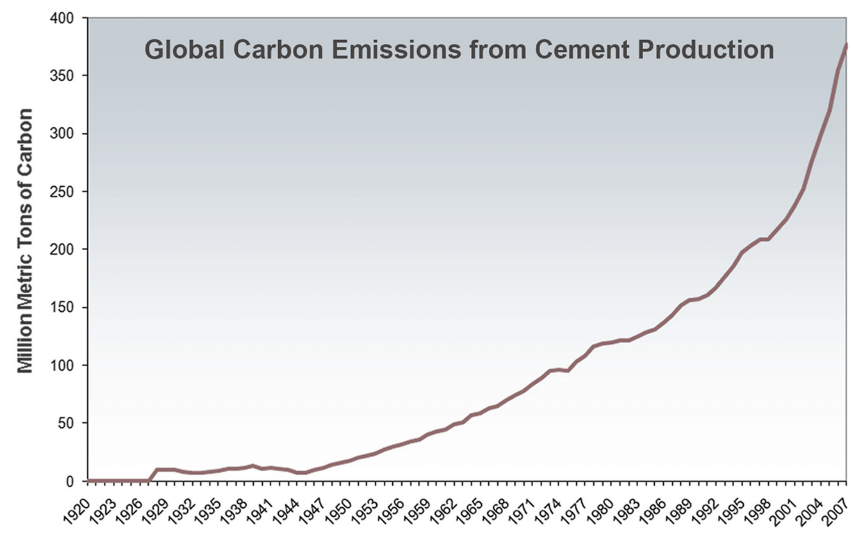


Credit: Vostok ice data/J.R. Petit at al.; NOAA Mauna Loa CO2 record. NASA

All three major global surface temperature reconstructions show that Earth has warmed since 1880. Most of this warming has occurred since the 1970s, with the 20 warmest years occurring in the past 1200 years. (NASA).

According to the World Carfree Network (WCN), cars and trucks account for about 14 percent of global carbon emissions, while most analysts attribute upwards of 15 percent to deforestation. (EarthTalk).

Portland cement is the second most used material on Earth after water, and responsible for almost 5% of the world's anthropogenic CO2 emissions. (USGBC).



Source: Boden, T.A, G Marland, and R.J. Andres 2010. Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S Department of Energy.

Buildings account for 39% of CO2 emissions in the United States per year, more than any other sector. U.S. buildings alone are responsible for more CO2 emissions annually than those of any other country except China. Most of these emissions come from the combustion of fossil fuels to provide heating, cooling and lighting (USGBC).

WHY EARTH?

Currently, earth architecture is being explored as either a low-tech building material in developing countries or as a highly exclusive boutique application in more developed nations. Despite its economical and material advantages, earth building has not experienced popularity in the modern construction industry. This is due in part because the initial set up costs associated with earth building are absorbed only if the development unit numbers are sufficiently significant for any given project. However, systematic prejudices associated with earthen architecture also contribute to its devalued status.

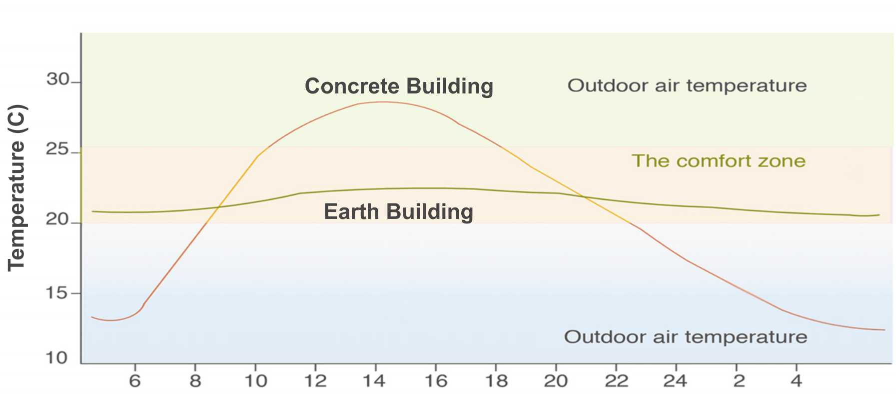
As contemporary architectural designers we should be designing in increasingly intelligent, sustainable and accessible ways. Our aim is to explore earth as a building material so that we may learn ways in which to make earth architecture a more attractive alternative for architects, builders, developers and the general public both in terms of economy and sustainability.

Earth as a building material has many advantages including:

Abundantly available
Locally Sourced
Recyclable
Potential for low carbon footprint
Breathable and mold resistant
Low in toxicity and VOC emissions
Fire-proof, Sound-proof, Bullet-proof
Hurricane and Tornado resistant
Structurally sound, durable and low-maintenance
Able to regulate temperature and moisture levels, for example:

Earthen building components are able to absorb and desorb humidity faster and to a higher extend than all other building materials, giving hem the ability to balance indoor comfort levels.

Thick earthen walls can store heat as thermal mass. As a result, in climatic zones where the differential temperature are high, earth walls can help regulate the indoor climate.



Because earth is ubiquitous, readily available, and can be locally sourced, earth-based construction has the potential for being the most economical and sustainable building technology available on Earth. Furthermore, if earth based construction were to become a valued and accessible building technology it could potentially revolutionize the building industry by mitigating carbon emissions and saving oxygen-producing forests.

THE QUESTION

How can we leverage computational technology to create an engineered cast earth that allows maximum performance of the building envelope; including thermal, structural and aesthetic expressions?

THE HYPOTHESIS

By leveraging the flexibility of Engineered Cast Earth (ECE) we can:

1. Engineer an earth based formula that meets industry standards while also remaining environmentally friendly.

2. Use computational methods to enhance performance both through structure and surface geometry while also providing aesthetic qualities.

"*we do not inherit the earth from our ancestors, we borrow it from our children*." Native American

ELIZABETH HURTADO, JOSEPH BORING, IKRAM ELOUALID, CAPPA- SP 2016

PRECEDENTS

Old Walled City of Shibam in Yeman, 15th century. 1700 years old. 11Stories High "the Manhattan of the Desert"

Earth is often seen as a building material only used in rural environments; however, a wealth of architecture can often be found in urban environments. Called the Manhattan of the Desert. The city of Shibam, Yemen, has about 7,000 inhabitants and a population density of thirty-two people per acre.

Shigeru Ban Architects in Kirinda, Sri Lanka 2007

This project provides 100 houses in a Muslim fishing village, in the region of Tissamaharama, on the southeast coast of Sri Lanka, following the destruction caused by the 2004 tsunami. Shigeru Ban's aim was to adapt the houses to their climate, to use local labour and materials to bring profit to the region, and to respond to the villagers' own requirements through direct consultation.

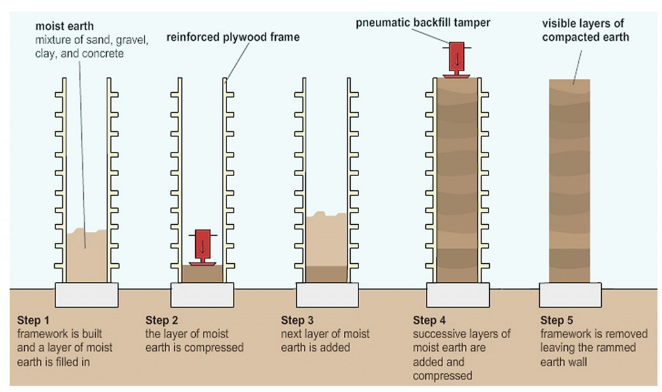
Rick Joy Architects in Tucson, Arizona 1998

The 2800 square foot private residence comprises two rectangular rammed earth columns that define the public and private spaces.

METHODOLOGY

Rammed Earth

The material specified for this project comes from local quarries and a mixture of clay, soil, and marl (an unconsolidated soil composed of clay and lime). In the Ricola building, Herzog& de Meuron chose to prefabricate panels of rammed earth in a nearby factory and have them hoisted into place by crane. The architects also chose to incorporate lime mortar and volcanic tuff into every eighth layer of the material to prevent erosion.



Herzog & de Meuron Ricola building 2014

Poured Earth

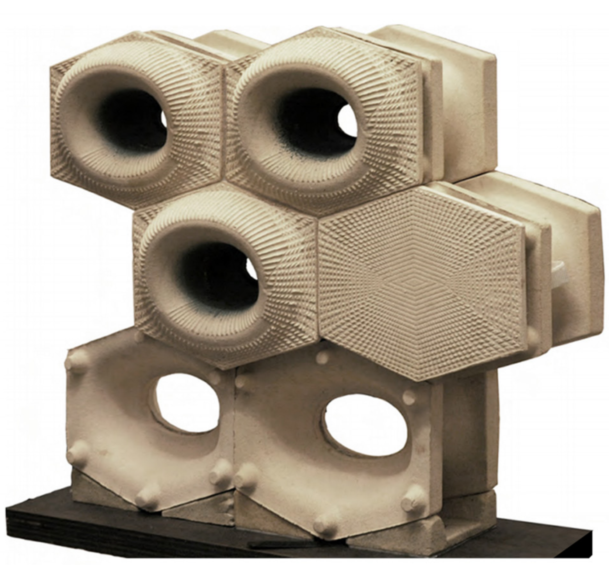
Cast earth is a proprietary natural building material developed since the mid-1990s by Harris Lowenhaupt and Michael Frerking. Poured Earth is a concrete like composite with soil of a suitable composition as its bulk component stabilized with about 15% calcined gypsum instead of Portland cement. Cast earth is poured in forms similar to concrete construction.

Michael Frerking 2014

RESEARCH

EcoCeramic

Jason Vallon, October 2008.



EcoCeramis wall systems prototype exhibited at ACADIA Silicon and Skin.

Geometry as a thermal regulator.
The research involves development, testing and prototyping of reinforced ceramic composite building units..." Emerging Building Technologies in Ceramics Performance Masonry System.
"Based on the passive strategies of the termite mound and the barrel cactus, in combination with local solar incidence. A preliminary profile was established. The profile was further developed through simulations". *Jason Vallon, Pourous Boundaries 161.*

Compressed Earth Blocks

Omar Rabie, MIT 2006-2007

Tactility; Single Curve and Three Walls

From Omar Rabie's research thesis:
"All over India, the villagers burn mud brick, which is made of topsoil that is rich in organic substance for three continuous days in the open. The waste of brick is huge (around 15%). The CO_2 emission and energy consumption are extremely high. Using topsoil means waste of soil suitable for agriculture. This is clearly an extremely harmful practice to our continuously degraded environment. What would happen if all the adobe villages in India and many other developing countries were rebuilt with village fired brick? Compressed Earth Blocks pollution emission is 2.4 times less than kin fired bricks. A 7.8 times less than country fired bricks. Moreover, its energy consumption is 5 times less than kiln-fired bricks, and 15 times less than country fired bricks (according to a study from development alternative in New Delhi)". Omar Rabie, Rabie Mockups .P1

ENGINEERED CAST EARTH RESEARCH AGENDA

Restating the question:

How can we leverage computational technology to create an engineered cast earth that allows maximum performance of the building envelope; including thermal, structural and aesthetic expressions?

CRITICAL PATH

UNIVERSITY OF TEXAS ARLINGTON | CAPPA COLLEGE OF ARCHITECTURE, PLANNING AND PUBLIC AFFAIRS | COLLEGE OF ENGINEERING

Engineered Cast Earth reasearch involves working with various industry experts including interdepartmental collaborations.

PRODUCTION SCHEDULE

Engineered Cast Earth (ECE)

January 20 - May 11

	DESCRIPTION	LEAD	WEEK 1 1/20	WEEK 2 1/29	WEEK 3 2/5	WEEK 4 2/12	WEEK 5 2/19	WEEK 6 2/26	WEEK 7 3/4	WEEK 8 3/11	WEEK 9 3/18	WEEK 10 3/25	WEEK 11 4/1	WEEK 12 4/8	WEEK 13 4/15	WEEK 14 4/22	WEEK 15 4/29	WEEK 16 5/6
I-Material Research	Preliminary Discussion	Team + BB																
	Material Consultation	Team+Dr.Mehta																
	Material Research	Team																
	Testing: Chemical compositon + particle size	Team+ Geotechnical Lab																
II-Geometry	Geometry Consultation	Team + BB																
	Formwork & Casting Consultation	Team + BB																
	Formwork Casting	Team+ ZAHNER																
	Testing: R-Value	Team+Dr.Mehta																
	Compression	Team+ Civil E Lab																
	Thermal	Team+Geotechnical Lab																
III-Outcome	Logistics	Team																
	Final PrototypeCasting	Team																
	Research Compillation	Team																

TESTING & SPECIFICATIONS

SYNOPSIS

The various research components relate and intertwine forming a non-linear procedural net:

Compliance to ASTM standards:

Sieve Analysis

Atterberg Limits

Compaction Test

PH Test

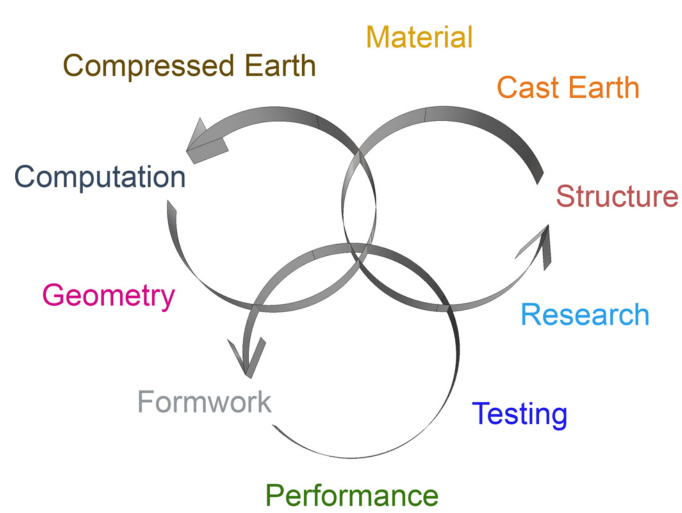
Dry Compressivie Strength

Erosion / Scratch Tests

Seismic

Thermal Performance

Acoustic Reduction



I. Material Research:
- Heterogeneous mixtures
- Strength
- Performance
- Life Cycle Assessment LCA

II. Geometry:
- Digitally Crafted Formwork
- Structural Performance
- Thermal Mass
- Load Bearing
- Digital Energy Simulation

III. Outcomes:
- Logistics and Costs
- Performance Tests
- Evaluation

IV. Phase II
- Project Application

RAMMED EARTH

Rammed Material -

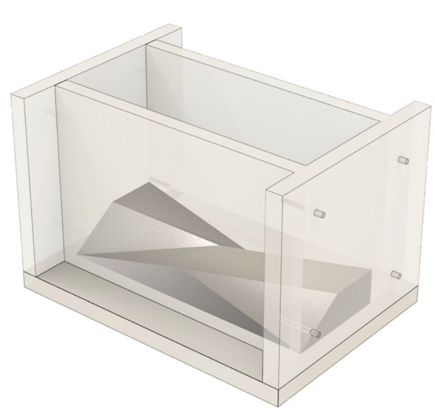
Rammed earth using a semi-dry mix

Pros:

Minimal admixtures for adequate strength
Hygroscopic properties (regulates humidity)
Phase change properties
Thermal Mass
Low to nil toxicity
Available data / research

Cons:

Less Flowability / Flexibility
Labor / assembly intensve



POURED EARTH

Poured Material -

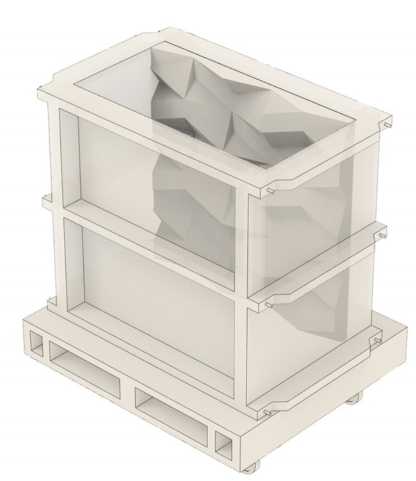
Poured earth using a slurry mix

Pros:

Flowability (similare to concrete)
Adequate strength
Application of existing concrete accessories
Thermal Mass
Erosion resistant

Cons:

Greater amount of admixures
to achieve adequate strength
Lack of available data / research



Modular Units -

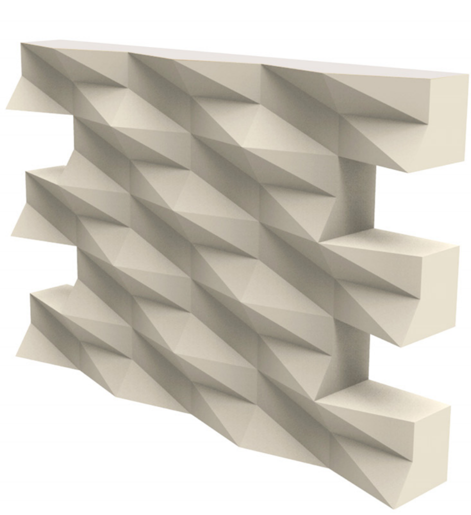
Tessellating blocks

Pros:

Reusable steel form work
Modular units easily transportable
Potential for mass produciton

Cons:

Thermal breaks
Transportation Costs



Monolithic Wall -

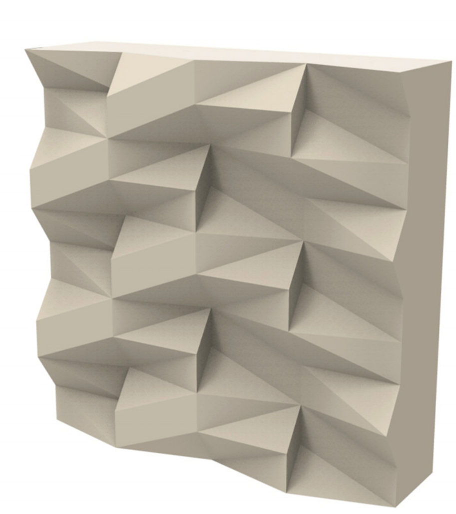
Structural sandwich wall system 18” thick

Pros:

Milled foam form work facing
On site production
No thermal breaks

Cons:

Need for heavy equipment such as crane
Form work costs



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RAMMED EARTH

Heterogeneous Mixtures:

Our goal is to ammend an existing soil conditon using appropriate percentages of admixtures and stabilizers. In choosing percentages, sustainability and other health factors took precedence over strength.

MATERIAL MATRIX

3 cubic yards of select fill soil were locally sourced and tested for particle size, plastic limit, liquid limit, plasticity index, PH, compaction and compression. Based on the sieve analysis and Atterberg Limits, our soil sample was classified as well-graded SAND with silt.

According to the 2009 New Mexico Earthen Building Materials Code: The ultimate compressive strength of all rammed earth soil, stabilized or non-stabilized, shall be a minimum three-hundred (300) psi.

Three formulas (soil + admixtures) were tested:

Formula 1 stabilizers: Lime, Fly Ash, Glass Fiber
Formula 2 stabilizers: Lime, Magnesium Oxide, Glass Fiber
Formula 3 stabilizers: Portland Cement, Glass Fiber

Test I: Rammed			Compression Test (Psi) for 12"X6" Cylinders				PH	$ Cost/LB	Cost/Material	Supplier
Materials	Mass (LB)	% of Total	Sample I	Sample II	Sample III	Average				
Soil (Select Fill)	81.2	58.5					9.23	0.008	0.65	Silver Creek Material Ft. Worth, TX (817)246-2426
EPK Kaolin Clay	11.4	8.9						0.36	4.1	Trinity Ceramics Supply Dallas, TX (214)631-0540
Decomposed Granite	28	20.2						0.09	2.52	Home Depot
Type S Lime	5	3.6						0.17	0.85	Home Depot
Fly Ash	5	3.6						0.03	0.15	Larfarge Holcim - Earth, TX Amy Audrey (806)729-4156
Glass Fiber	0.24	0.17						3.39	0.8	Fibre Glast Developments
Water	8	5.76						N	N	
Total	138.84	100						N	9.92	

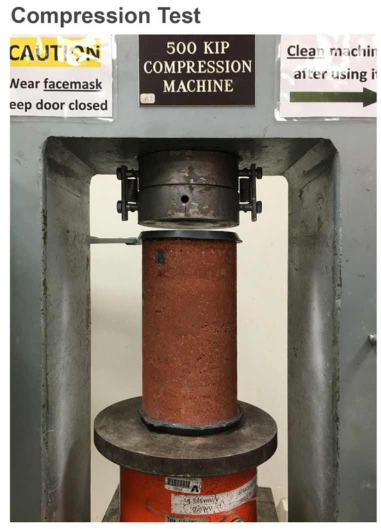
Test II : Rammed			Compression Test (Psi) for 12"X6" Cylinders				PH	$ Cost/LB	Cost/Material	Supplier
Materials	Mass (LB)	% of Total	Sample I	Sample II	Sample III	Average				
Soil (Select Fill)	81.2	58.5					12.15	0.008	0.65	Silver Creek Material Ft. Worth, TX (817)246-2426
EPK Kaolin Clay	11.4	8.9						0.36	4.1	Trinity Ceramics Supply Dallas, TX (214)631-0540
Decomposed Granite	28	20.2						0.09	1.5	Home Depot
Type S Lime	5	3.6						0.17	0.85	Home Depot
Magnesium Oxide	5	3.6						0.6	3	Premier Magnesia W.Consh, PA Jim Preskenis (302)218-4987
Glass Fiber	0.24	0.17						3.39	0.8	Fibre Glast Developments
Water	8	5.76						N	N	
Total	138.84	100						N	10.9	

Test III : Rammed			Compression Test (Psi) for 12"X6" Cylinders				PH	$ Cost/LB	Cost/Material	Supplier
Materials	Mass (LB)	% of Total	Sample I	Sample II	Sample III	Average				
Soil (Select Fill)	80	70	560 psi ultimate stress				11.95	0.008	0.65	Silver Creek Material Ft. Worth, TX (817)246-2426
Decomposed Granite	21.5	18.8						0.09	1.9	Home Depot
Portland Cement	6.5	5.7						0.1	0.65	Home Depot
Glass Fiber	0.16	0.14						3.39	0.5	Fibre Glast Developments
Water	6	5.2						N	N	
Total	138.84	100						N	3.7	

Compaction Test

PH Test

Compression Test



Results:

Formula 3 using cement as stabilizer is most economical; Formula 3 is also most resistant to erosion.

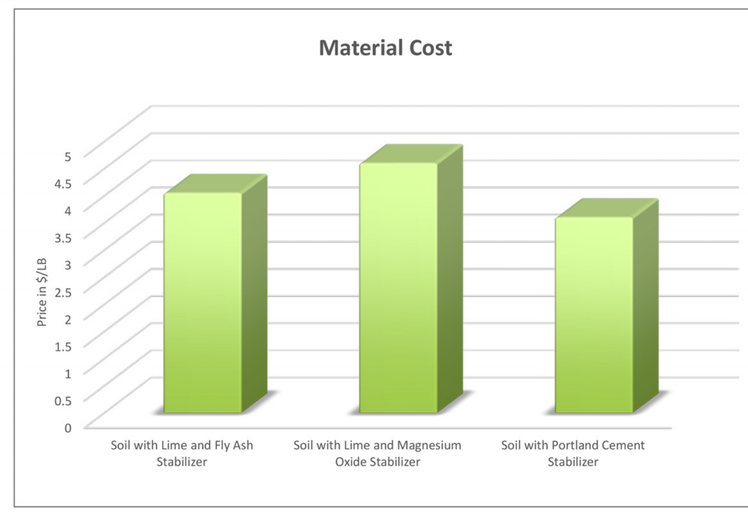
Shear forces applied by process to prepare for compaction damaged various cylinders, therefore only one formula was tested for compression. Furthermore, due to unforseen circumstances only one cylinder of Formula 3 was tested, reaching an ultimate stress of 560 psi.

Moving forward, the formulas, methodoligies and testing methods will be revised to meet adequate standards.
For testing compression strengths, compressed earth blocks, instead of cylinders, may be tested.*2009 New Mexico Earthen Building Materials Code.*

General guidelines for selecting stabilizers for different soils:

Type of Soil/ conditions	Stabilizer
For nearly all types of soil	Portland cement
Medium, moderately fine and fine-grained soils	Hydrated lime
Coarse-grained soil with little if any fine grains	Fly ash
Cold climate applications	Calcium chloride
For increasing resistance to water and frost	Bitumen

Rinker School of building Construction, University of Florida, November 2010



Erosion Test:

Preliminary empirical tests found Formula 3 (with cement as stabilizer) to be the most resistant to erosion. Further testing meeting ASTM standards should be run with the supervision of the Geotechnical lab.

Formula 1 (lime, fly ash)

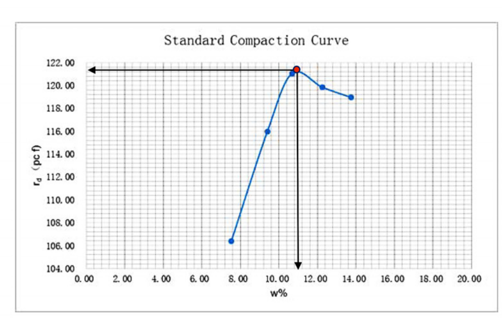
Formula 2 (lime, MGO)

Formula 3 (cement)

Testing blocks were allowed to cure for 21 days, submerged in water for 5 minutes and scraped with a wire brush an equal number of times.

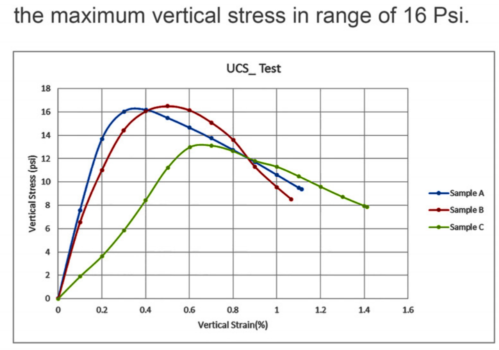
Standard Compaction Test:

According to the standard compaction, the well-graded Sand has the 12% of optimum water content and 121 Pcf maximum dry unit weight.



Unconfined Compressive Strength Test:

The test was conducted for 3 different samples, which were prepared based on 95% of optimum water content. The results indicate the soil has the maximum vertical stress in range of 16 Psi.



Sample A- ω=10.14%
Maximum stress=16.3 psi

Liquid Limit	Plastic Limit	plasticity Index	Standard Compaction	PH	UCS	
21%	15%	6%	ω=11% Ɣ=121pcf	8.66	A	Load Peak=16.3psi ω=10.14%
					B	Load Peak=16.8psi ω=10.15%
					C	Load Peak=13.4psi ω=10.41%

Patrons: Geotechnical Lab, Civil Engineering Lab, Zahner.

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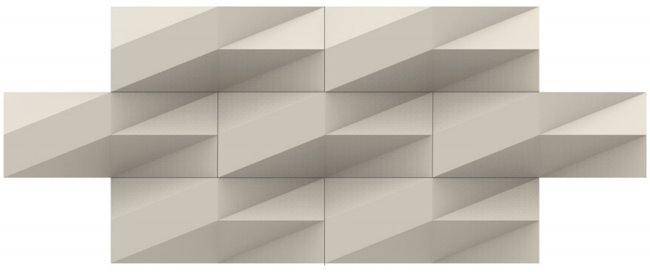
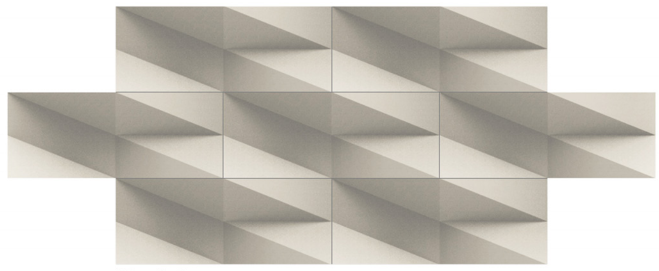
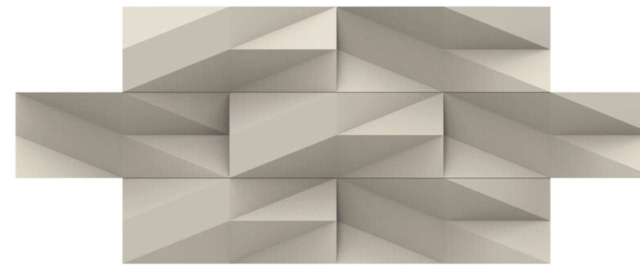
RAMMED EARTH BLOCK / GEOMETRY


Block A


Block B

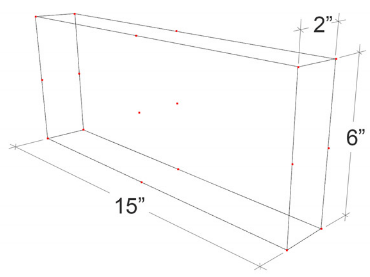

Block A + B

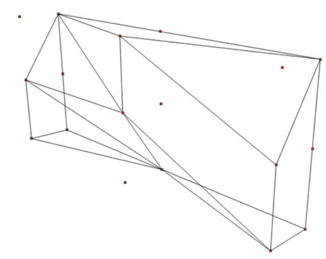
Surface geomtery to act two-fold:

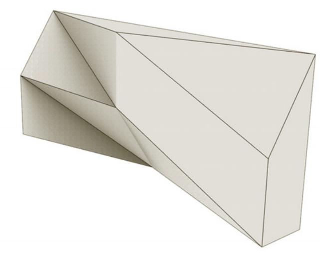
Potentially enhancing the thermal performance of the building envelope by increasing the distance that heat must travel from exterior to interior wall surfaces.

Iterative design and aesthetic expression.

Articulation for the rammed earth block is digitally designed to tesselate in a running bond. The geometry is fashioned such that the course below will fully support the course above, thus avoiding horizontal ledges or over-hangs once assembled.

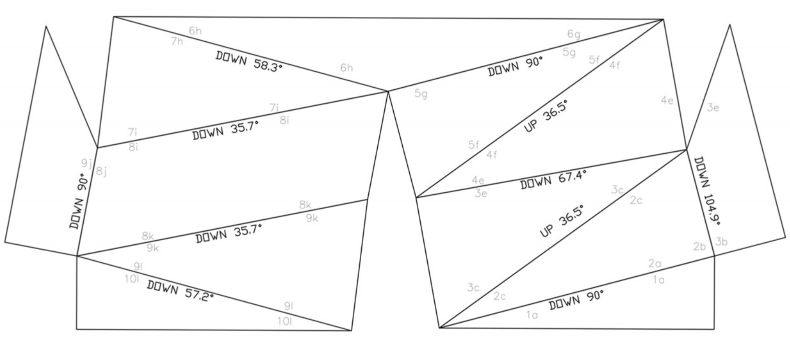


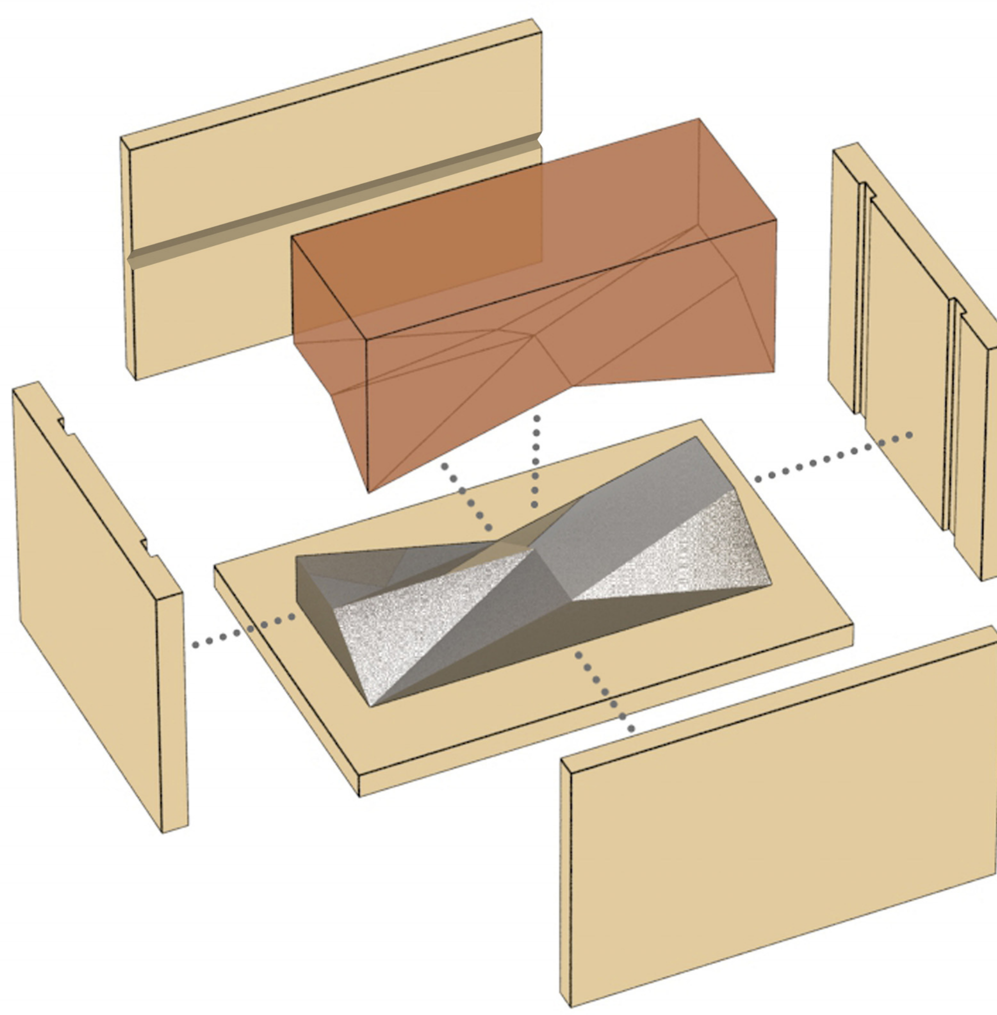



Block B negative

FORMWORK

The steel form, fabricated by Zahner, was laser cut and tack welded from 14-guage steel. 1-1/4 inch Lauan plywood surrounds the steel form to complete the form work.



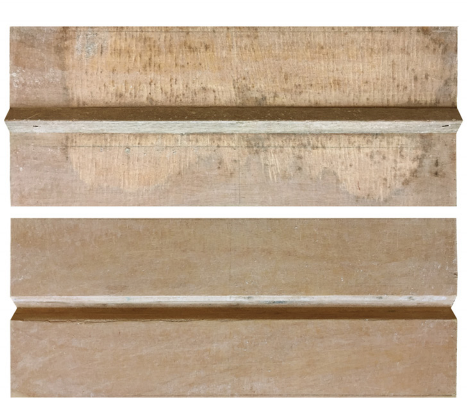


Postive / negative keys were added the plywood form at both top and bottom of blocks to create an interlocking component.

Half-blocks were made by fitting and splitting the form work with a plexi-glass divider.

Small gaps between the steel form and plywood box were filled in with insulation.

The steel and plywood forms held up to repeated use, thus confirming the potential cost savings afforded by a modular block system.

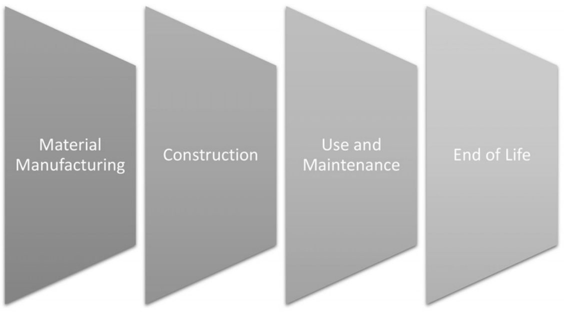


Patrons: Geotechnical Lab, Civil Engineering Lab, Zahner.

Environmental Targets:

Environmental impact was an essential consideration when deciding on material and assembly components. In order to better understand such impacts, we adopted the Life Cycle Assessment using Athena Impact Estimator tool

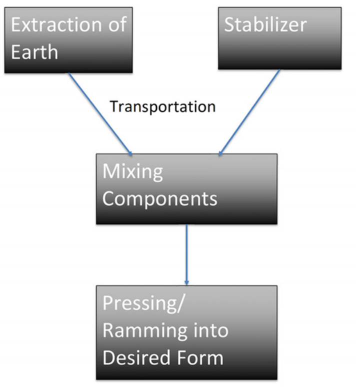
Every product or process goes through various phases or stages in its life. Each stage is composed of a number of activities. For industrial products, these stages can be broadly defined as material acquisition, manufacturing, use and maintenance, and end-of-life. In case of buildings, these stages are more specifically delineated as: materials manufacturing, construction, use and maintenance, and end of life.



Life- Cycle Stages of buildings (AIA Guide to Building LCA in Practice).

ATHENA IMPACT ESTIMATOR

Life Cycle Assessment is a tool for evaluating environmental impact of an object from its beginning as raw material through its use and eventual disposal. Taking a 'cradle-to-grave' approach gives a thorough understanding of the environmental impact at all stages of a product's existence.



In this analysis, only the initial phase of a rammed earth block's life time, from excavation of the materials through production, is considered. The disposal phase of the block is also not considered in this analysis. "Because the lifetime of a block is typically greater than 100 years and is often longer than the lifetime of the overall structure" (Illston & Domone, 2001). It is also essential to note that Athena Impact Estimator does not take in account the energy required by manual labour.

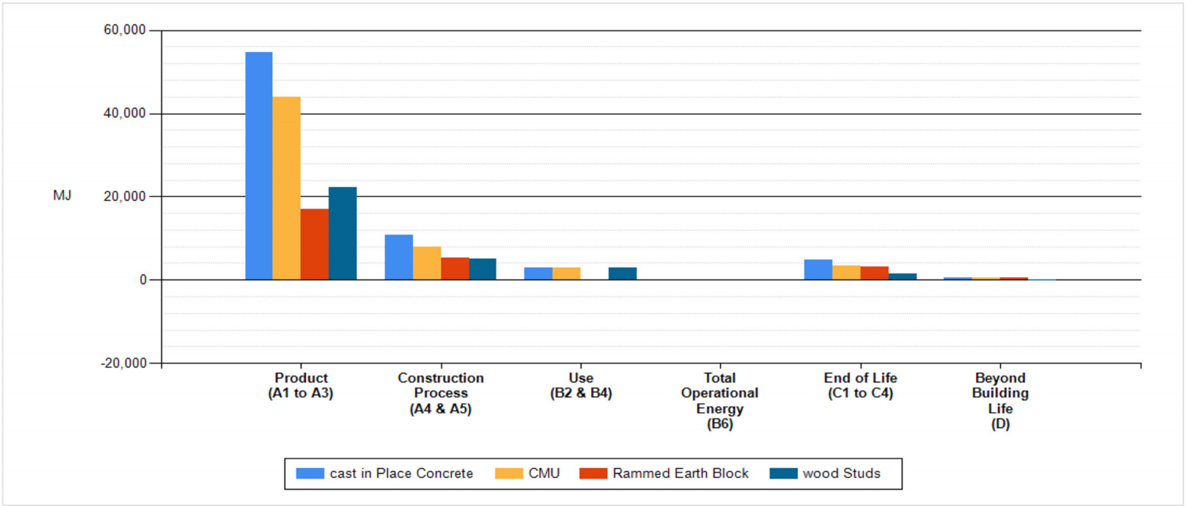
Carbon dioxide is the primary emission of interest for global climate change. Other greenhouse gases, such as methane, also contribute to climate change and air pollution; Athena Impact Estimator allow a calculation of the equivalent global warming potential in terms of amount of carbon dioxide. Reporting carbon dioxide equivalent emissions enables comparisons with CMU and other construction materials as carbon dioxide emissions are the most widely reported measure of climate change contribution.
The analysis is very sensitive to the processing technology choices and assumptions made when building the model. Therefore, it was essential for our research to consider real life scenario and add the cost of transportation and energy required in such methodology.

Because cement is both energy intensive to produce and emits a substantial amount of carbon dioxide during production, both from the chemical reaction and from the burning of fuels, the amount of cement included has the potential to dramatically affect the environmental impact. The analysis of the effect of the cement percentage assumes the same processing technology and extraction depth assumptions. The composition uses the same amount of Portland cement which does not exceed 6% by mass.

The environmental impact of rammed earth blocks depends on composition, processing, and policies. Using such block in building construction requires significantly less energy and emits far fewer air pollutants and greenhouse gases than other materials, but it is also necessary to note that there are many code restrictions in building regulations which limits its usability.

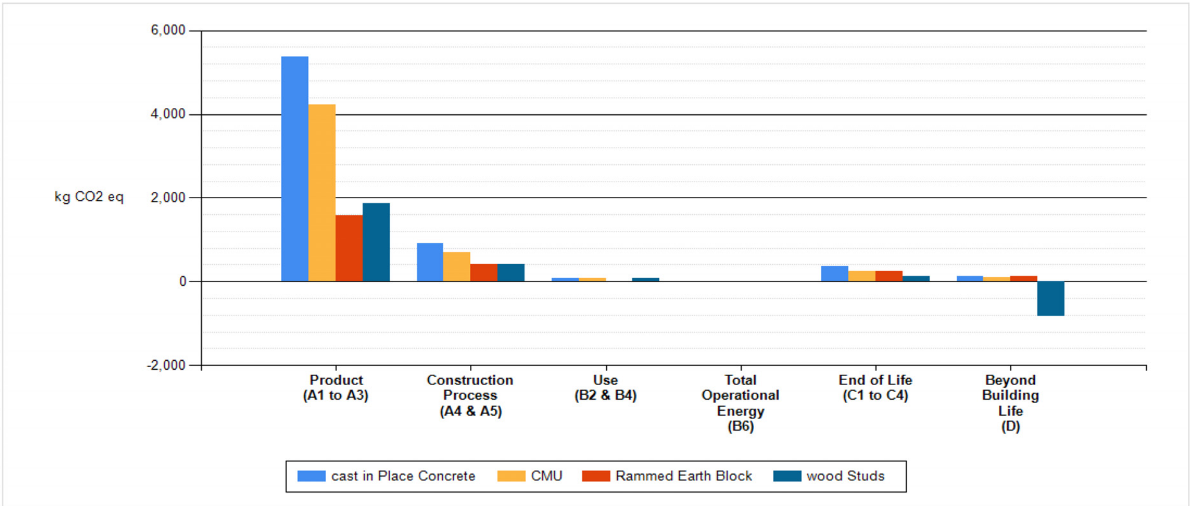
Finally, considering the tradeoffs between environmental impact, performance and cost, stabilized earthen blocks seem to be an option which most effectively balances these tradeoffs. The important key will be continuing to improve its performance to be comparable to fired bricks, CMU, and other building materials while reducing the environmental impact and improving sustainability.

Comparison of Non-Renewable Energy By Life Cycle Stage



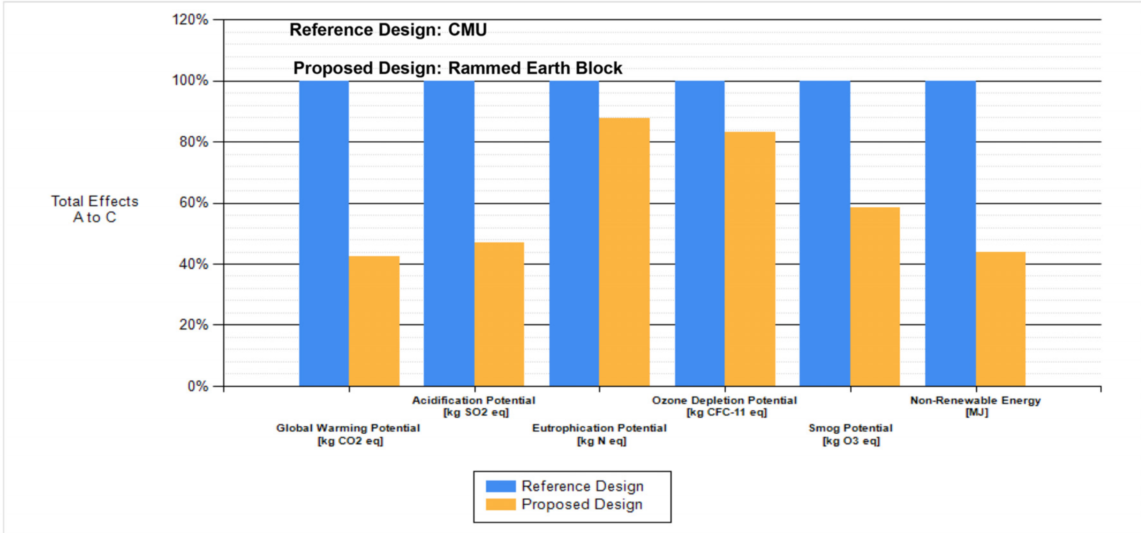
Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
cast in Place Concrete	MJ	5.46E+04	1.08E+04	2.85E+03	0.00E+00	4.88E+03	5.24E+02	**7.37E+04**
CMU	MJ	4.40E+04	7.95E+03	2.85E+03	0.00E+00	3.35E+03	4.60E+02	**5.86E+04**
Rammed Earth Block	MJ	1.69E+04	5.27E+03	0.00E+00	0.00E+00	3.24E+03	5.69E+02	**2.60E+04**
wood Studs	MJ	2.23E+04	5.03E+03	2.85E+03	0.00E+00	1.53E+03	-3.48E+01	**3.17E+04**
Total	**MJ**	**1.38E+05**	**2.91E+04**	**8.56E+03**	**0.00E+00**	**1.30E+04**	**1.52E+03**	**1.90E+05**

Comparison of Global Warming Potential By Life Cycle Stage



Project Name	Unit	Product (A1 to A3)	Construction Process (A4 & A5)	Use (B2 & B4)	Total Operational Energy (B6)	End of Life (C1 to C4)	Beyond Building Life (D)	Total
cast in Place Concrete	kg CO2 eq	5.38E+03	9.07E+02	7.00E+01	0.00E+00	3.61E+02	1.15E+02	**6.83E+03**
CMU	kg CO2 eq	4.23E+03	7.07E+02	7.00E+01	0.00E+00	2.52E+02	1.01E+02	**5.36E+03**
Rammed Earth Block	kg CO2 eq	1.59E+03	4.11E+02	0.00E+00	0.00E+00	2.32E+02	1.25E+02	**2.35E+03**
wood Studs	kg CO2 eq	1.87E+03	4.19E+02	7.00E+01	0.00E+00	1.21E+02	-8.33E+02	**1.65E+03**
Total	**kg CO2 eq**	**1.31E+04**	**2.44E+03**	**2.10E+02**	**0.00E+00**	**9.67E+02**	**-4.91E+02**	**1.62E+04**

LEED Summary Measure Comparison Report (A to C)



Summary Measure	Unit	Reference Design Total Effects A to C	Proposed Design Total Effects A to C	% Difference
Global Warming Potential	kg CO2 eq	5.26E+03	2.23E+03	-57.64%
Acidification Potential	kg SO2 eq	2.71E+01	1.28E+01	-52.94%
Eutrophication Potential	kg N eq	1.09E+00	9.52E-01	-12.39%
Ozone Depletion Potential	kg CFC-11 eq	2.40E-05	2.00E-05	-16.68%
Smog Potential	kg O3 eq	4.93E+02	2.88E+02	-41.50%
Non-Renewable Energy	MJ	5.81E+04	2.55E+04	-56.21%

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RAMMED EARTH BLOCK / PROCESS

Formula 3 containing cement as stabilizer was chosen due to a quicker curing time as compared with lime. Materials were weighed, mixed and wetted by hand. The water content was determined by performing a “ball test” in which the soil mix will form a cohesive ball which shatters when dropped from waist height (roughly 7% water content).**Earthdwell Ltd*. The material was then compacted by hand using manual tampers.

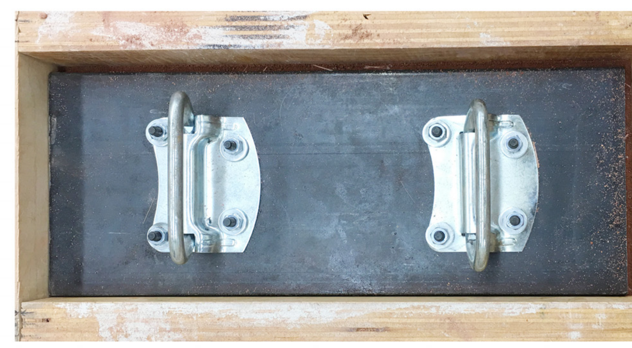

Weighing

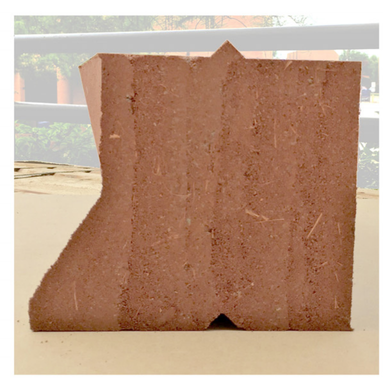

Mixing


Ball drop test (Earthdwell Ltd.)


Ramming

MAKING BLOCKS





Approximately 3” of soil / admixtures were tamped down by almost 50% original volume in successive layers. Erosion along the edges was mitigated by adding extra clay to the formula. Based on research as well as previous experience it is our expectation that the blocks will harden as they cure.

OUTCOME