The University of Texas at Austin
Civil, Architectural and Environmental Engineering
Cockrell School of Engineering

TEXAS
The University of Texas at Austin

Potential for Use of Earthen Materials in 3D Printing Applications

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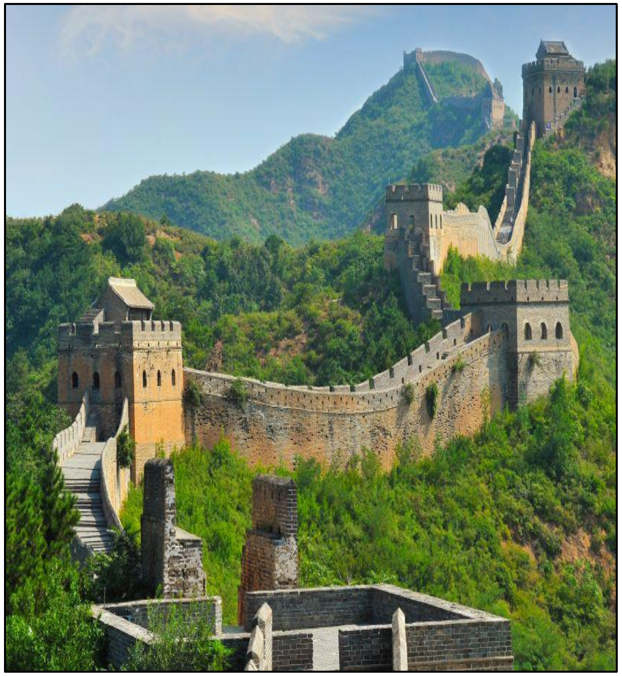
ACI Spring 2023 Convention ● Session on Advances in Sustainable and Bio-inspired Cementitious Materials for 3D printing applications Part 1 ● 2 April 2023 ● San Francisco, CA

Earth: The oldest infrastructure material



Great Wall of China
(China, 7th Century BCE)
Source: National Geographic

Walls of some watchtowers made using earth

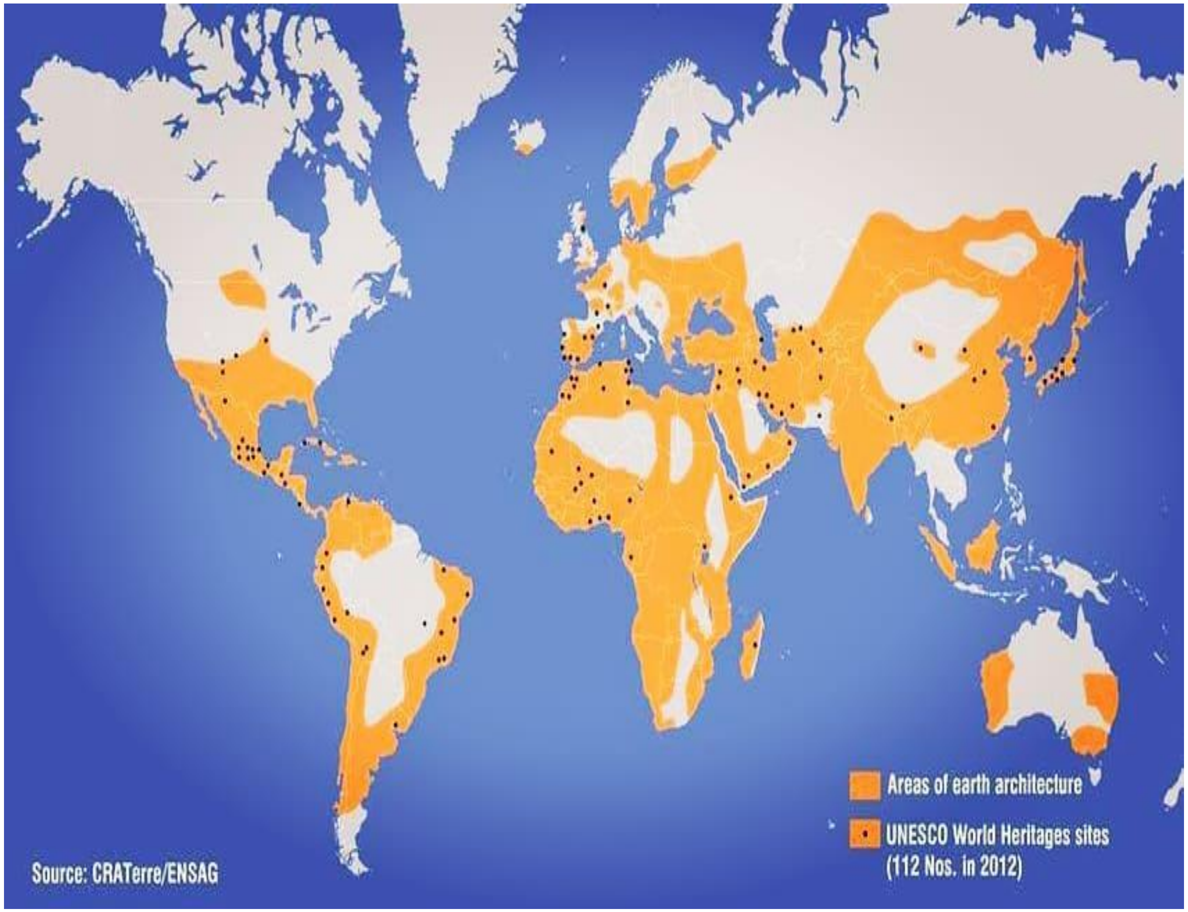
Great Mosque of Djenné
(Mali; 300 BCE)
Source: New York Times

Primarily made from earth

Taos Pueblo
(New Mexico; 1000 -1450)
Source: John Mackenzie Burke

Primarily made from earth
*

Earth architecture around the world



World map illustrating the worldwide use of earth construction
Source: CRATerre/ENSAG, 2012

Multi-family apartment building using rammed earth in Mücheln, Germany (1955)
Source: united4design

Traditional earthen building methods

Adobe

Cured adobe blocks in being used for historic restoration of San Miguel Chapel in Santa Fe, New Mexico

Source: André Fuqua

Cob

Close up view of insulating layer (left) and structural layer (right) of cob wall

Source: University of Plymouth Building Physics and Materials Lab

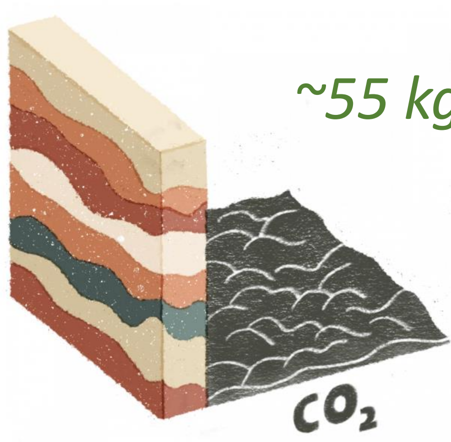
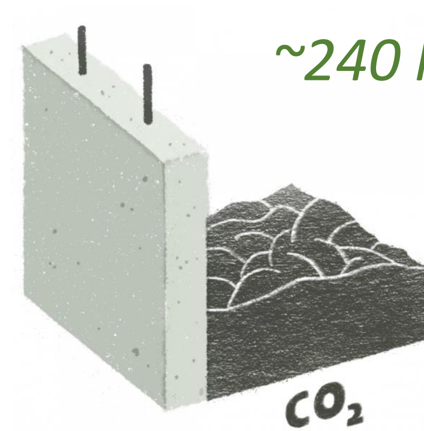
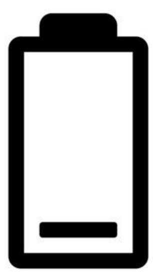
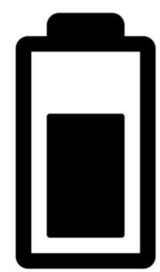
Rammed Earth

Close up of rammed earth wall texture

Source: Rise Design Studio

Renewed interest in earthen construction

Earthen materials have lower embodied energy and thus a lower carbon footprint than concrete

	<u>Rammed Earth</u>	<u>Concrete</u>
Carbon Footprint	 *~55 kg/m^3*	 *~240 kg/m^3*
Embodied Energy	 *~800 MJ/m^3*	 *~2700 MJ/m^3*

Source: Ashby, M. (2020) Materials and the Environment: Eco-informed Material Choice, 3rd edition

Advanced manufacturing

Compressed Earth Blocks

Source: André Fuqua

3D Earth Printing

Source: Ronald Rael

Unique challenges when building with earth

Housing Development in Niger ; constructed in 2016
Source: united4design

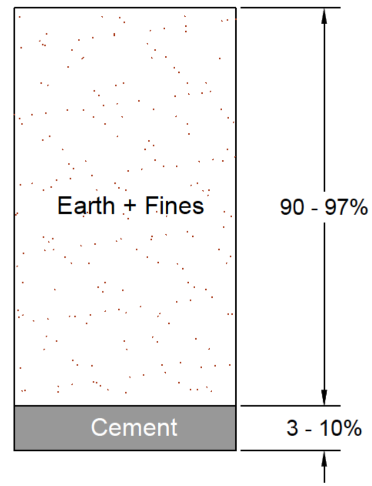
Concern: Moisture resistance

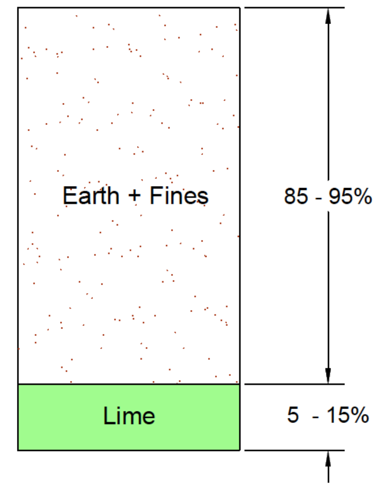
Stabilization of soils

Soil stabilization is an essential step in improving the durability of earthen materials.

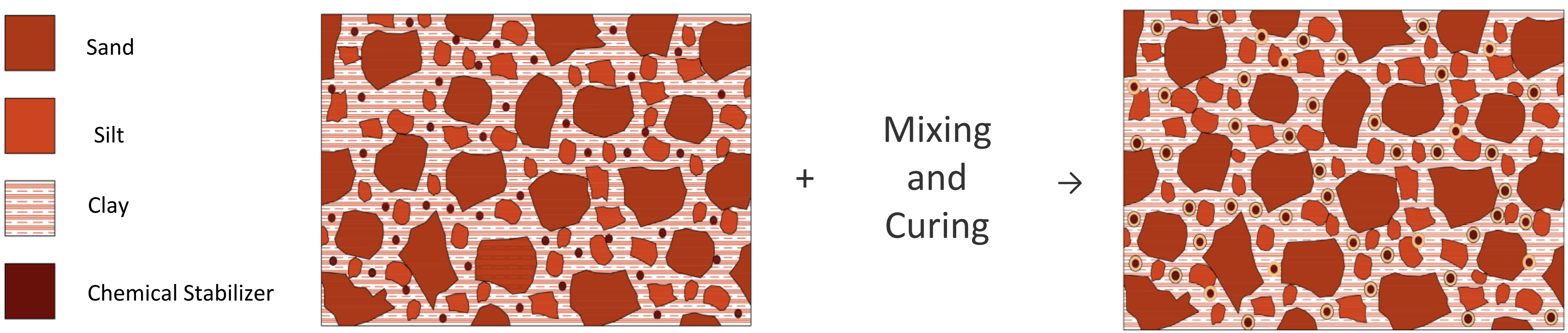
Cement

Lime





The Chemical Stabilization Process

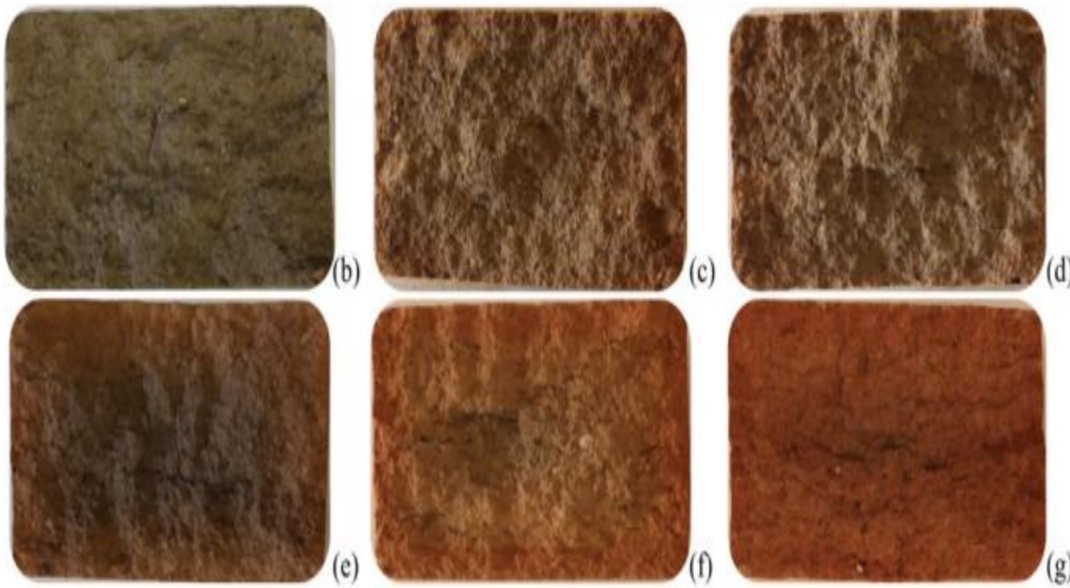


Initial state of soil particles

Soil matrix after formation of hydrates

Concern: Safety

Fire Resistance



(b-g) cross-sections of stabilized CEBs after exposure to 24 °C, 200 °C, 400 °C, 600 °C, 800 °C, and 1000 °C

Source: Earth USA 2022 Conference Proceedings, M. Barbato

Structural Integrity

Failure modes of full-size blocks of the same soil type. Molded adobe is shown on the left, and compressed earth block is shown on the right

Source: Lan G., Chao S., Wang Y. et al, 2021

TITLE 14 HOUSING AND CONSTRUCTION

CHAPTER 7 BUILDING CODES GENERAL

PART 4 2015 NEW MEXICO EARTHEN BUILDING MATERIALS CODE

14.7.4.1 ISSUING AGENCY: Construction Industries Division of the Regulation and Licensing Department.

[14.7.4.1 NMAC - Rp, 14.7.4.1 NMAC, 11/15/2016]

K. Qualified soil means any soil, or mixture of soils, that attains 300 psi compression strength and attains 50 psi. modulus of rupture.

before that date.

[14.7.4.2 NMAC - Rp, 14.7.4.2 NMAC, 11/15/2016]

14.7.4.3 STATUTORY AUTHORITY: Section 60-13-9 and 60-13-44 NMSA 1978.

[14.7.4.3 NMAC - Rp, 14.7.4.3 NMAC, 11/15/2016]

14.7.4.4 DURATION: Permanent.

[14.7.4.4 NMAC - Rp, 14.7.4.4 NMAC, 11/15/2016]

14.7.4.5 EFFECTIVE DATE: November 15, 2016, unless a later date is cited at

Challenge: Communication differences

Characterization language of contractors

Jar Test

Particle size distribution, clay content

Shrink Test Box

Shrinkage, plasticity, clay content

Cigar Test

Plasticity, cohesiveness, texture

Ball Test

Plasticity, clay content

Sniff Test

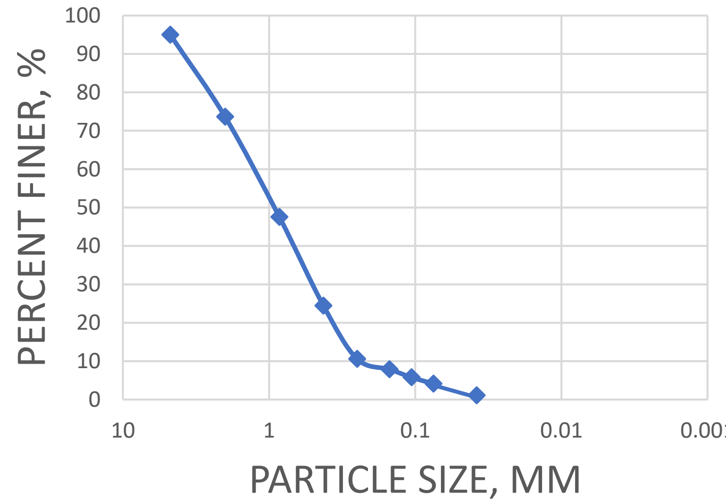
Soil texture

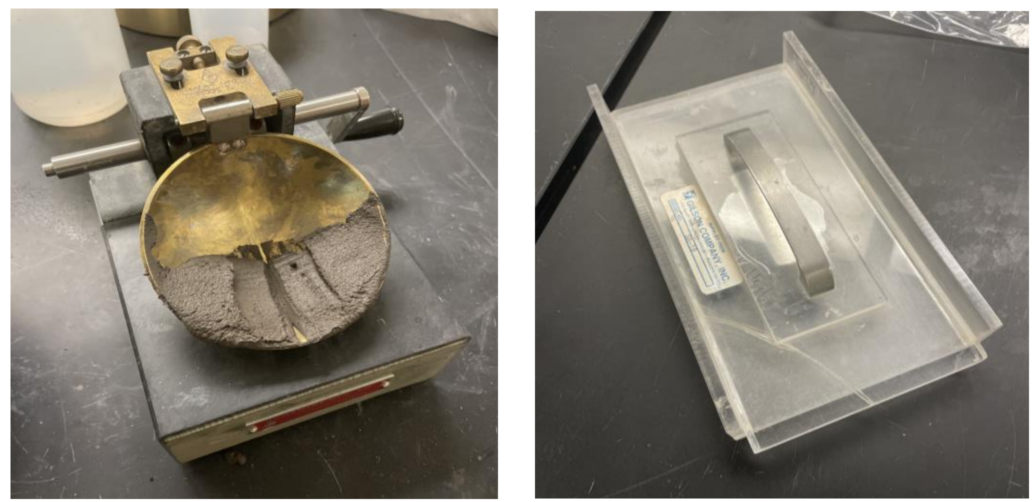
Characterization language of engineers

USCS Classification (ASTM D2487)	SW, well graded coarse grained borderline sand

Particle Size Distribution (ASTM D6913) **Note: 4.75mm was maximum particle size for mix**	
Gravel (>2 mm) (%)	26.4
Sand (2 – 0.075mm) (%)	68.31
Silt + Clay (0.075 and finer)	5.23

Atterberg Limits (ASTM D4318)	
Liquid Limit	29
Plastic Limit	14
Plasticity Index	15





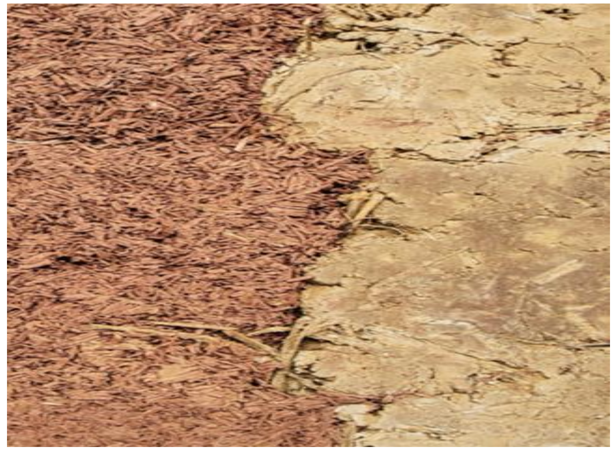
Casagrande (left) and plastic roller (right) used in Atterberg tests

Challenge: Link between engineering properties and earth performance for building applications

Opportunity:
Engineering of earthen mix for buildings

Understanding role of moisture content on earthen materials

Rammed Earth (~5%)



Cob (~10%)

Adobe (~15%)

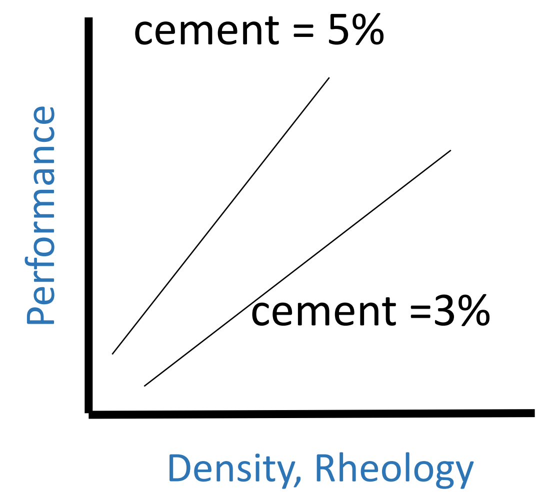
Compressed Earth Blocks (~15%)

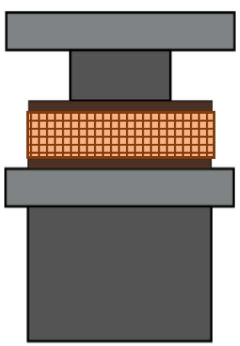
3D Printing (~25%)

Approach: Engineering of earthen mix for buildings

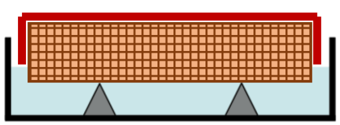
Characterize soils; Vary moisture content & stabilizer content

Determine density and rheology

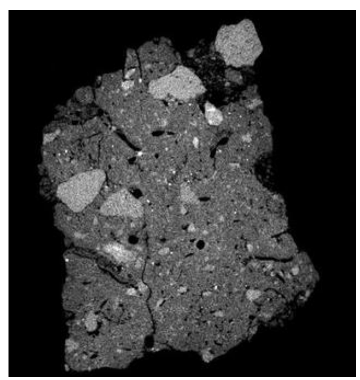




Compressive Strength

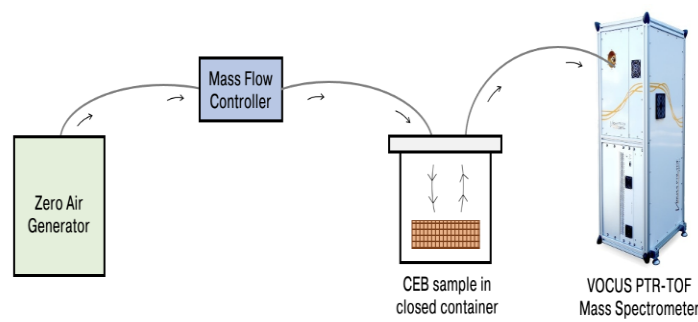


Capillary Test



Structure

Image from microphotonics.com



Indoor Air Quality analysis

Conclusions

- Renewed interest in earthen materials and advanced construction methods of these materials.
- Chemical stabilization is essential
- Understanding how to identify suitable soils and engineer the mixture design to achieve target performance is needed to advance the field from art to engineering

Earthen home in Fredericksburg TX (2020)

Source: Native Earth Block

Questions?

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