Potential for Use of Earthen Materials in 3D Printing Applications

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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.

**Carbon Footprint**

- **Rammed Earth**: ~55 kg/m³
- **Concrete**: ~240 kg/m³

**Embodied Energy**

- **Rammed Earth**: ~800 MJ/m³
- **Concrete**: ~2700 MJ/m³

Advanced manufacturing

Compressed Earth Blocks
Source: André Fuqua

3D Earth Printing
Source: Ronald Rael
Unique challenges when building with earth
Concern: Moisture resistance
Stabilization of soils

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

The Chemical Stabilization Process

- **Initial state of soil particles**
- **Mixing and Curing**
- **Soil matrix after formation of hydrates**

**Chemical Stabilization Process**

- **Cement**
- **Lime**
- **Sand**
- **Silt**
- **Clay**
- **Chemical Stabilizer**
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
K. **Qualified soil** means any soil, or mixture of soils, that attains 300 psi compression strength and attains 50 psi. modulus of rupture.

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

14.7.4.4 **DURATION**: Permanent.

14.7.4.5 **EFFECTIVE DATE**: November 15, 2016, unless a later date is cited at
Challenge: Communication differences

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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

### Atterberg Limits (ASTM D4318)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Limit</td>
<td>29</td>
</tr>
<tr>
<td>Plastic Limit</td>
<td>14</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>15</td>
</tr>
</tbody>
</table>

### Particle Size Distribution (ASTM D6913)

Note: 4.75mm was maximum particle size for mix

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel (&gt;2 mm)</td>
<td>26.4</td>
</tr>
<tr>
<td>Sand (2 – 0.075mm)</td>
<td>68.31</td>
</tr>
<tr>
<td>Silt + Clay (0.075 and finer)</td>
<td>5.23</td>
</tr>
</tbody>
</table>

**USCS Classification (ASTM D2487)**

SW, well graded coarse grained borderline sand

**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

Indoor Air Quality analysis

cement = 5%
cement = 3%
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
Questions?

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