PEDAGOGICAL AND RESEARCH FRAMEWORKS FOR EARTH ARCHITECTURE

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Abstract

Research and pedagogy that focuses on low-carbon and low extractive building practices are critically needed to address urgent global climatic, societal, and economic challenges. As a result, studies on earthen material performance and pedagogical programs have been increasing their focus on characterizing, demonstrating, and fabricating new modes of earth technologies. And yet, earth materials still require a more consistent representation within conventional architectural programs – both in research and education. Earth materials are yet to be integrated within architecture technology curriculum worldwide, and training on a range of earth techniques is still missing for building professionals. To address this need, the Natural Materials Lab at the Graduate School of Architecture Planning and Preservation at Columbia University aims to catalyze ecological knowledge – both traditional and futuristic- on earth materials throughout their design, construction, fabrication, and policy arenas in the architectural technology field. Focusing on natural, raw, and un-stabilized earth practices, the research and teaching conducted at the lab is geared towards expanding various earth building techniques: adobe, cob, rammed earth, compressed earth blocks, light straw clay, and wattle and daub. The work at the lab aims to develop opportunities for reimaging earth materials – through novel mix designs, fabrication techniques, and construction operations. This paper details the research projects, experimental workflows, and pedagogical activities developed as part of the lab, while outlining the workflows in each project, to be used by researchers and educators.

Keywords: Earth Materials, Building Technology, Architectural Education

1 Introduction

Inaugurated in 2020, the Natural Materials Lab is a research and pedagogical center with a mission to study earth building materials and methods. The lab's activities investigate the following lines of inquiry:

- Study earth material mixtures using traditional recipes while employing material science advancements with a focus on bio-based additives and vegetable fibers.
- Develop advanced fabrication using 3D printing and additive manufacturing, while delving into highly manual craft techniques.

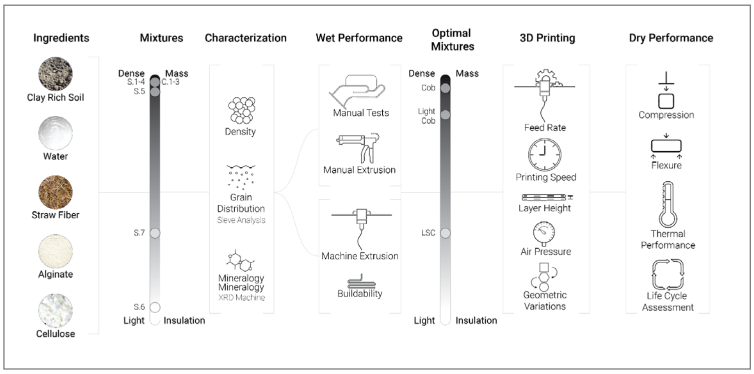

Figure 1. Research procedure: mixture design with various fiber content, 3D printing processing parameter development, and characterization of wet and dry performance. Research Student: Zackary Bryson.

- Investigate earth materials and characterize performance using energy simulations, thermal and hygrothermal mechanism, structural possibilities, and geometrical limits.
- Develop environmental and social LCA (ELCA & SLCA) for various earth materials and methods, addressing global urgencies and enumerating impacts such as carbon and energy, health and well-being, local employment, circular economy, community engagement, and access to resources.

2 Fabrication processes

2.1 3D printed elements and assemblies

This line of research at the Natural Materials Lab catalyzes digital explorations of earth-based materials using a range of fiber and bio-based additives. Current 3D printing fabrication focuses on cob earth materials to offer critical responses to environmental impacts posed for 3D printed concrete, which results in even higher carbon intensities than conventional concrete because it typically contains much more cement given its paste constituency (Le et al. 2012). To date, however, 3D printed earth mixture design research has been limited to cob mixtures with relatively lower fiber content. One limitation to using cob for 3D printing is the heavy mass and low thermal resistivity that results in thick walls to comply with building codes (IRC, 2021). Existing 3D printed cob advancements are shown to require water content of 23-25% and 2% straw to be applied in a 3D printer (Gomaa et al. 2021; Fratello and Rael 2020).

To address these challenges, this project aims to maximize fiber content to provide greater thermal resistivity, while increasing carbon storage due to the use of fast-growing bio-additives. Characterizing a range of mix designs, a series of mixtures from cob to light straw clay were 3D printed into building elements and small-scale assemblies, while classifying their wet- and dry-state properties. Shown in Figure 1, the procedure developed for this research is initiated with constituent materials characterization for densities, grain distribution, and mineralogical content, while obtaining mix designs for a range of fiber types and contents. Each mixture is then tested for its printability – its ability to be extruded through a nozzle and withstand the weight of subsequent layers - using a manual and robotic extruder. Finally, mixtures are characterized for their dry thermal and compressive performance.

The results of this work provide a framework and prototype demonstrations for a range of mixtures,

Figure 2. 3D printed prototypes of cob, light cob, and light straw clay. Research Student: Zackary Bryson.

Figure 3. The process of designing and constructing Jandug, using a layered skeleton building, a light straw clay infill, and a cob finish sealed with flaxseed oil. Research Students: Bisher Tabbaa and Sarah Hejazin.

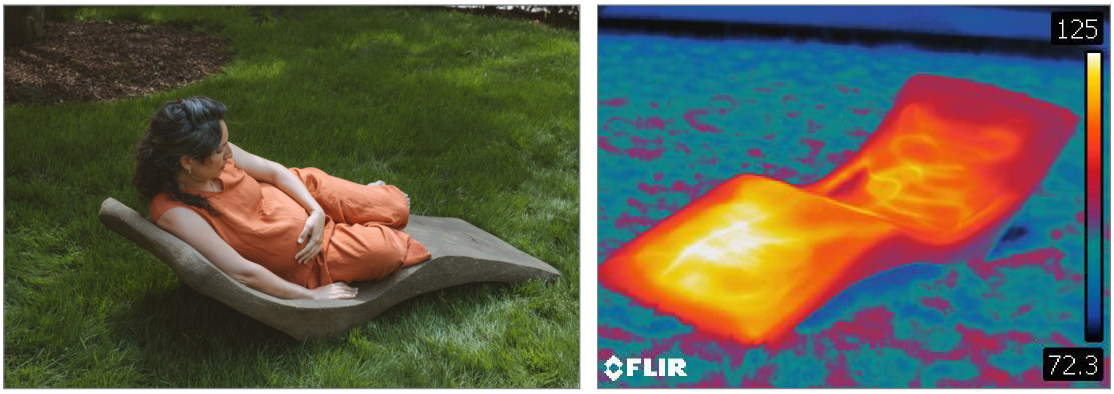

Figure 4. The final chaise prototype and a thermal imaging showing the radiant heating system embedded within the earthen mass. Research Students: Bisher Tabbaa and Sarah Hejazin.

Figure 5. The Earthen Mud Skins prototypes: the raw pure soil prototype, earth-fiber porotypes, and the final earth-fiber-bio porotype. Research Student: Penmai Chongtoua.

as shown in Figure 2. By looking at the implementation of clay-based earthen materiality in a post-industrial context, this study navigates the unique challenges of working with a material that has been moved, mixed, and contaminated for centuries, and proposed how the everyday person can add to the lexicon of earthen construction.

2.2 Skeletons and skins

In parallel to the digital explorations of 3D printed earth, this project aims to trace back manual practices that speculate various combinations of of clays and fibers. As part of this inquiry, the project termed *Grounded Chairs* was emerged, where we used earth materials to provide a new interpretation of seating sculptures. The first experimental iteration, Jandug ("body" in Aramaic), includes a bamboo skeleton, integrated with a light straw clay infill, cob plaster, and flaxseed oil finish. The flaxseed oil was used as a sealant, very similar to adobe floors, so that Jandug can be used outdoors and its surface is water-resistant.

As a special feature, Jandug was equipped with a radiant heating system that elaborates the thermal advantages of the clay mass assembly that can store heat and absorb moisture to provide optimal thermal comfort.

2.3 Fabrics and wearables

The use of earth-based materials has been historically focused on clays for pigments and coloration. However, research-based design is still missing for using earth in everyday common fabrics. To address this potential, this project, termed Earthen Mud Skins, integrates earth as a wearable substance, built directly onto one's body. Earthen Mud Skins explores a range of technologies to create earth lightweight and flexible, to be worn as an element that can bring back sacred connectedness between the human body and the Earth. This project was initiated with a set of garments made of raw soils. Preliminary crude and heavy-duty prototypes were then refined by using straw fibers in various chopping constituencies. Lastly, the earth-fiber mixture was introduced with bio-additives to introduce flexibility, elasticity, and additional lightweightness.

Earthen Mud Skins aims to open up the possibilities of improving circular systems within garment construction and calls into question what types of garments are constructed to shape our day-to-day

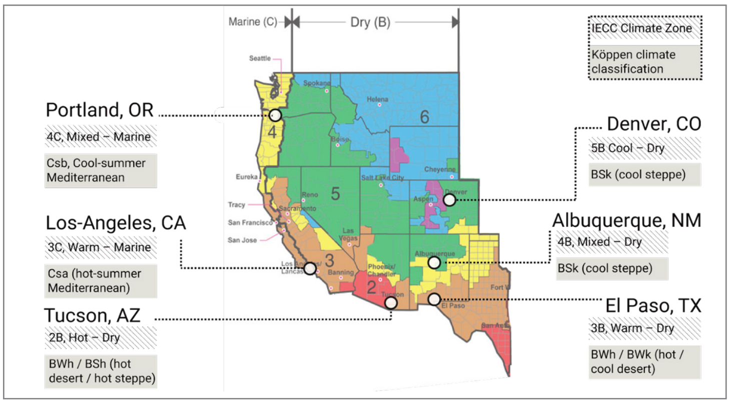

Figure 6. Cities chosen for simulations shown on the western portion of the International Energy Conservation Code (IECC) map (adapted from ref), including IECC (hatched) and Köppen (shaded; Beck et al., 2018) climate classifications.

experiences of productivity, mindfulness and meditation. Wearing earth materials is envisioned in this project as an action that bridges our intimate connection to all that is alive, including the soil itself and its vivacious microbiomes and bacteria that live within the uniquely differentiated soil composites.

3 Simulation processes

3.1 Survivability in the face of climate change

Despite the advantages of earth materials for hot-arid climates with high diurnal changes, earth has been used as a building material in a range of climates, both hot and cold. Shown in Figure 6, this line of research investigates the thermal and hygrothermal performance of unconditioned (passive) earth dwellings in six climates in the US, both warm and temperate, following evidence for earth construction that can be found in temperate and humid climates such England (Devon cob), China (rammed earth) and South America (adobe), to list a few.

The results of the operational impacts for a full year energy balance shows that the light straw clay outperforms other earth-based assemblies in the majority of instances. Insulated rammed earth is shown to result in similar energy requirements as conventional assemblies, with fewer heating energy required in arid and temperate climates

3.2 Thermal pleasure, not comfort

In recent decades, international standards that define energy requirements are based on the notion that thermal comfort is achieved in uniform and steady-state environments, increasingly created within sealed building envelopes that lack any connection to outdoor thermal variability, a necessity for human well-being. These excessively sealed, mechanically ventilated, and energy consuming environments feed our addiction to air-conditioning and excessive over-cooling, while transitioning carbon from the operational phase of the building to the embodied extraction stages of the building materials.

However, there is a different path that can reduce energy while improving comfort; Recent research suggests that thermal perception and comfort are more than a deterministic heat balance and that positive thermal experiences can be created from more energy-conserving and dynamic fluctuations

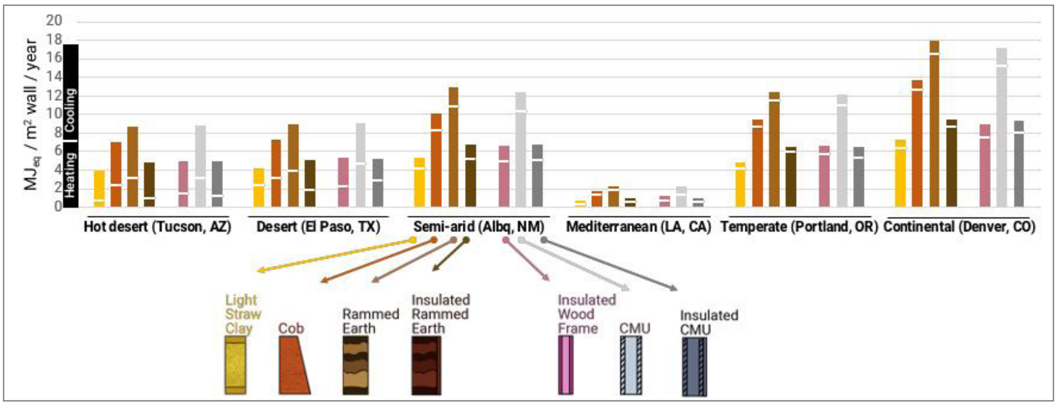

Figure 7. Operational energy results following the thermal simulations for each assembly in each of the 6 tested locations. Divided by a white line, the lower bars signify heating energy and the upper bars signify cooling energy.

in temperatures, air flow, radiant, and humidity conditions. This physiological phenomenon is called thermal alliesthesia: the sensory pleasure arising from transient or contrasting thermal experiences. As part of this understanding, earth materials can employ a range of radiant and localized thermal responses, addressing thermal alliesthesia (pleasure) concepts that were shown to inspire a more coherent understanding of occupant comfort requirements. As an emerging paradigm, thermal alliesthesia research challenges the thermal monotony that has become the status quo in the built environment by promoting non-uniform and dynamic thermal strategies such as personal environmental control systems and transient thermal environments.

4 Artistic processes

4.1 Laminating and preserving earth

In order to push the boundaries of earth materials, artistic process can provide with architectural representations while drawing from land art practices of raw soils. Using this perspective, Laminated Earth is a project that carefully looks at preservation techniques for soils using plastics. As a solo exhibition by artists Sharon Yavo Ayalon, and curated by the author, this project aimed to mediate between the personal and collective homes while engaging in the preservation of raw soils as an increasingly eliminated resource. The surreal environment created in this installation was composed of mud paintings and structural forms.

4.2 Parallel between buildable and edible earth-based practices

The use of earth-based materials appears in two practices throughout history: in the construction of buildings and —far less commonly known or conclusively understood— in certain dietary consumption patterns as an edible substance. Both historical practices – of using earth as a buildable and edible substance – have experienced negative interpretations. As part of this scholarly inquiry, the Eat Me Build Me project speculates the contemporary and futuristic possibilities of using earth as a nutritional resource for the built environment. While it literally maps raw soils for their buildable and

Figure 8. The Laminated Earth Exhibition, at the ZAZ10TS Gallery, NYC. In collaboration with Sharon Yavo Aylon.

edible potencies, this experimental work also produces a periodic table of the various minerals and substances that make the soil a potent material for the reformulation of our being in the world.

5 Educational processes

5.1 Merging into a common ground

Across the land, across all sites, soil varies significantly. One soil extracted on a construction site will differ from the soil at a neighboring site. This variability is what makes soil such a standardization challenge, making soil an inherently non-commodified building material. Indeed, the emergence of standard materials from soils is hindered by their high variability and their reliance on local additives and traditional construction methods. The degree to which end-use construction products are engineered from soil varies although the soil remains the 'feedstock'.

This workshop was developed while asking the following questions: How do we find the common ground, the prescribed and characterized soil optimal for buildings? What is the mineralogical classification of clays most suitable, the grain distribution, and optimal mix design?

As part of these inquiries, students who participated in this workshop engaged in collaborative design/build of a rammed earth wall, comprised of the collection of soils of participants - who vary in diversity very much like their soils - to create a "common ground".

Acknowledgment

This body of work could not have been manifested without the assistance of my collaborators, peers, and students. The research students at the Natural Materials Lab whose work is shown in the paper include Penmai Chongtoua, Zackary Bryson, Bisher Tabbaa, and Sarah Hejazin. And other assistants who contributed to the processes and workflow at the GSAPP Natural Materials Lab. Further acknowledgement should be extended to Joshua Jordan, Mark Taylor, and Yonah Elorza for their assistance with the fabrication and facilities processes at the lab. Lastly, I would like to thank my collaborators across and outside Columbia University, including Sharon Yavo Ayalon, Shiho Kawashima, Wil Srubar, and Alexandra Rempel.

Figure 9. The Eat Me Build Me project in the making. In collaboration with Sharon Yavo Aylon.

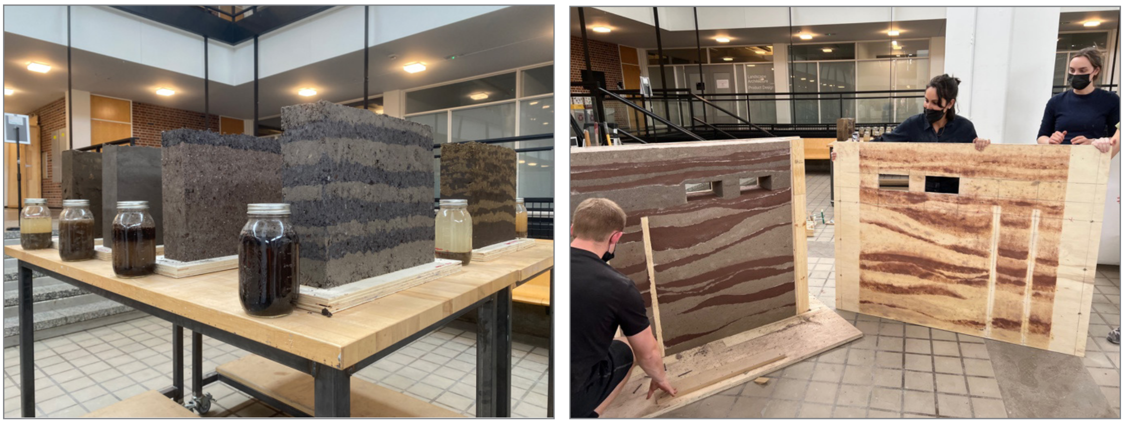

Figure 10. The small wall samples with their shake tests, and the final collaborative wall. In collaboration with the University of Minnesota - College of Design.

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