Can we eat Earth Buildings?

The mineralogical common of earth building and edible earth practices

בנייה באדמה
אדמה אכילה
גיאופגיה
מינרלוגיה
מיצב אמנות
earth building
earth eating
geophagia
mineralogy
art installation

Ben-Alon, Lola[1]; Yavo-Ayalon, Sharon[2]

[1]Columbia University, GSAPP, USA.
rlb2211@columbia.edu

[2]Cornell Tech, USA.
sharon.ayalon@cornell.edu

Citation: Ben-Alon, L; Yavo-Ayalon, S. (2022). "Can we eat Earth Buildings?" UOU scientific journal #04, 58-71.

ISSN: 2697-1518. https://doi.org/10.14198/UOU.2022.4.07

Date of reception: 19/10/2022
Date of acceptance: 20/12/2022

Earth-based materials (namely, mud or dirt architecture) have been used for over millennia and are still sheltering approximately a third of the world population. These materials are currently experiencing a new Renaissance with construction methods and digital fabrication technologies that are highly focused on the mineralogical and particle characterization of optimal mixtures. Similarly, clay-based materials have been traditionally used as edible substances in almost every region globally: from the Middle East to India, and from Western Europe to the Caribbeans and Africa. Traditional recipes such as bonbon tè (Haitian mud cookies) and the Calabash Chalk (West Africa) have been used as part of human diet for religious beliefs, traditional local medicine, or as part of a regular supplement, a custom that has been interpreted by Western investigators as a pathology named Geophagia. This article presents a theoretical and experimental research-by-design investigation into the mineralogical content within earth materials and its role in building and human metabolism. A critical literature review on earth materials and their particle mineral content is presented, while analysing, comparing, and contrasting the ingredients that make a good buildable and edible earth artifact. The analysis reveals that both buildable and edible soil compositions share a common mineralogical base: the microstructure and water absorption capacity of clay minerals. The research-by-design process included creating buildable and edible artifacts based on traditional and current practices following the literature review. The project culminated in an architectural installation that maps earth artifacts for their compositions, critically contributing to the architectural field by provoking questions regarding the mutual dependencies between humans and their surrounding natural resources, while testing ideas and beliefs regarding the nature-culture divide that governs existing environmental paradigms.

חומרים מבוססי אדמה (כלומר, ארכיטקטורת בוץ או עפר) שימשו במשך אלפי שנים ועדיין משמשים, מחסה עבור כשליש מאוכלוסיית העולם. חומרים אלה חווים כעת רנסנס בעזרת שיטות בנייה משוכללות וטכנולוגיות ייצור דיגיטליות, תוך אפיון מדעי ומינרולוגי של תערובות אופטימליות. באופן דומה, חומרים מבוססי אדמה שימשו כבסיס למאכלים במסורות שונות ובאזורים שונים בעולם: מהמזרח התיכון ועד הודו, וממערב אירופה לאיים הקריביים ואפריקה. מתכונים מסורתיים מעפר, כמו עוגיות הבונבון בהאיטי, או מקלות קלאבש במערב אפריקה היוו חלק מהתזונה המסורתית מתוך אמונה דתית, כתרופה מסורתית או כחלק מהתפריט היומיומי. מחקרים עדכניים על אכילת אדמה הראו שחשק לאדמה, הבולט למשל אצל נשים בהריון, נובע לרוב מחוסר במינרלים. עם זאת, מנהג זה התפרש על ידי חוקרים מערביים כהפרעה נפשית ואף כפתולוגיה בשם "גיאופגיה". המאמר מציג סקירה תיאורטי וניסיונית של התוכן המינרולוגי של חומרי אדמה ותפקידם בבנייה ובחילוף החומרים האנושי. המחקר משלב בין סקירת ספרות ביקורתית, ניסוי חומרי ומחקר-על-ידי-עיצוב. בסקירת הספרות חיברנו את ההיסטוריות המקבילות של בניה באדמה ואכילת אדמה. בניסוי השוונו בין חומרי אדמה המשמשים לבניה ולאכילה ותכולת המינרלים החלקיקים שלהם ובחנו מה הם המרכיבים האידיאליים לכל אחד מהתחומים. סקירת הספרות והניסוי הראו בסיס מינרלוגי משותף הן לבניה באדמה והן לאכילת אדמה: מבנה המיקרו ויכולת ספיגת המים של מינרלים חרסית. בעקבות גילוי זה באמצעות מחקר-על-ידי-עיצוב, התחקנו אחרי הפרקטיקות המסורתיות והעדכניות ויצרנו חפצים הניתנים לבנייה ואכילה. המחקר הגיע לשיאו במיצב אדריכלי שקיבץ את כל התוצרים מבוססי חרסית שיצרנו במחקר-על-ידי-עיצוב, הממפה חפצי אדמה לבניה ולאכילה. מאמר זה תורם לתחום האדריכלי המדעי בכך שהוא מעורר שאלות בנוגע לתלות ההדדית בין בני האדם למשאבי הטבע הסובבים אותם, תוך בדיקת רעיונות ואמונות לגבי הפער בין טבע לתרבות השולט בפרדיגמות סביבתיות עכשוויות

Fig. 1 - Traditional practices of using clay-rich soila as an edible substance, and as a building material. Image source: AP Photo/Ariana Cubillos, Science Photo Library/David R. Frazier.

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. To put it simply; soil, the most important nutrient collector on earth, can be used for both building and for eating. This article presents a theoretical and experimental research-by-design investigation into the mineralogical content of earthen materials and their role in building and human metabolism. By converging the parallel histories of earth building and earth eating it suggests a first-of-its-kind attempt to expose the similarities and ask – could (and should) readily available soils be used as both buildable and edible substances?

For building practices, earth materials are among the oldest known to mankind, comprising structures that date over millennia and are still sheltering approximately a third of the world population (Niroumand, Zain, Jamil 2013). In contrast to the prevailing perception of earth as a vernacular material mainly in the Global South, vernacular earth architecture can also be found in Western countries, with more than 500,000 dwellings found in Germany, France, and the UK alone (Pacheco-Torgal, Jalali 2012). Meanwhile, with regards to earth eating, both cultural practices and individual behavior involving the ingestion of earth materials have been recorded for centuries across the world: in the Middle East, Ancient China, India, South Africa, the Caribbeans, and Europe. “Recipes”, so to speak, such as the Calabash Chalk, use clay-rich soils, whether for religious rites, as medicine, or to satiate a regular craving (Young et al. 2011). As opposed to buildable earth materials, no specific legislation exists for edible or healing clays, and these products are most often included within the concept of ethnopharmaceutics (Gomes 2018) (Fig. 1).

Despite many similarities and almost parallel historic and geographic routes - to the best of the authors’ knowledge - the two phenomena have never been compared or combined. This article aims to fill this lacuna by examining the parallel histories and converging them through an investigation into the mineralogical structure of clay-rich soils and its role in building construction –and human– metabolism.

Building materials affect human health and wellbeing, both physically and perceptually, via direct or unintended absorption such as touch, sight, thermal sensation, inhalation, and ingestion. Beyond the inhalation of material particles volatilized into indoor air, and dermal intake via gaseous and physical contact with building materials, a major exposure to substances in the built and interior environment is caused by ingestion intake through hand-to-mouth or object-to-mouth activities (Huang et al. 2019).

Therefore, just as “you are what you eat” rings true, so do the spaces we live and work in affect our lives and health. With more than 90% of human lives spent indoors, it is imperative to investigate healthier substances in building materials - beyond non-toxic - to substances that are nutritious and beneficial for ingestion in small quantities. Global nutrient deficiency has been an integral outcome of environmental degradation processes such as soil erosion and mass agriculture. Today’s eroded soils result in crops that tend to be of a lower quality: misshapen, smaller, and less nutritious to human health. As part of a critical pathway, this study suggests new interpretations to using, preserving, and consuming one of the most important nutrient collectors on earth: soil. Clay-rich soils are often combined with vegetable fibers and other additives that can be enacted as superfoods. By adapting superfoods within a clay-based environment, earth building components can introduce nutrients from soil to buildings, and from buildings to their occupants.

The article begins with a critical literature review that explores the histories, geographies, and traditions of using earth as

Fig. 2 - Colonialism material shifts led to replacement – or erroneously imitations of native practices. (Image sources: The G. Eric and Edith Matson Photograph Collection at the Library of the Congress, 364-LC-M32-A; A wood engraving by unknown artist, 1889, Alamy Stock Photo; Nebraska State Historical Society, RG2608-1190).

buildable and edible substances. It than delves into the particle mineral content of both material practices while analyzing, comparing, and contrasting the ingredients that make a good buildable and edible earth artifact. Discovering clay mineralogy as the common performance metric for both buildable and edible soil compositions, the Results section focusses on the research-by-design process of creating buildable and edible earth artifacts and presenting them in a public installation as part of the 2022 Tallin Architectural Biennale. As a speculative experimental demonstration, this research offers a unique perspective on human metabolism and nutritional intake by investigating earth-based matter as natural, healthy, nontoxic, and - presumably – edible building mass.

BACKGROUND
THE WESTERN BIAS

To investigate the extent to which soils can be adapted to mainstream building and consumption implementation, an overview of the perceptual barrier to using soil substances is much required. Both historical practices – of using earth as a buildable and edible substance – have experienced negative, and often, mistaken interpretations. Earth building has been pushed aside during the colonizing processes of industrial modernization due to the introduction of industrialized materials such as Portland Cement (Martinez 2017). As the dictates of architectural modernism and developmentalism (postwar international development) took root around the world, the desire to replace earth––a labor-intensive, highly variable and difficult to standardize material–– with mass-produced parts cohering with global economies of scale relegated earth-building to the sidelines.

Traditional practices of using earth as an edible substance, and as a building material have gained a negative perception as "dirty" and the poor people's choice for housing. Fig. 2 depicts how material shifts due to colonialism have led to the replacement of native practices. The left image shows traditional Palestinian stone with clay mortar that was replaced by Portland concrete brought during the British Mandate. The middle image shows Indigenous Peoples in Tanzania processing earth to be used into bricks, a technique that has been mostly displaced by Portland-cement stabilized earth blocks. Lastly, the right image is an example of Sod construction as imitated by settlers on the prairie, as seen in imitation of Native technology.

Fig. 3 shows a global perception survey by the author identifying the extent of the negative perception of earth materiality worldwide. As part of this survey's questionnaire, earth building experts repeatedly mentioned that, to their experience, there is a "poor public perception" and "peoples' aversion to dirt" that creates a strong barrier to implementing earth materials in mainstream construction.

The survey showed that selected excerpts from 25% of earth building experts, including architects, engineers, and builders, from 12 different countries, mentioned the perceptual gap for integrating earth materials in construction projects, due to cultural prejudice and negative social perception. Experts also elaborated on the relation between poor perception and socioeconomic prejudice; for instance, an architect of rammed earth and adobe from a seismically active region mentioned that "unfortunately, most people feel unsafe and poor in earth buildings"; an architect making use of adobe, earthbags, and clay plaster from South East Asia added that "people do not treat earthen building as a permanent and standard building, they think only poor [people] use earth as a building material." Lastly, some experts mentioned that another barrier is the lack of available technical data, and "lack of information on new developments and recent good examples".

In the case of eating earth, perplexity – both from outsiders to a cultural community and sometimes from members within

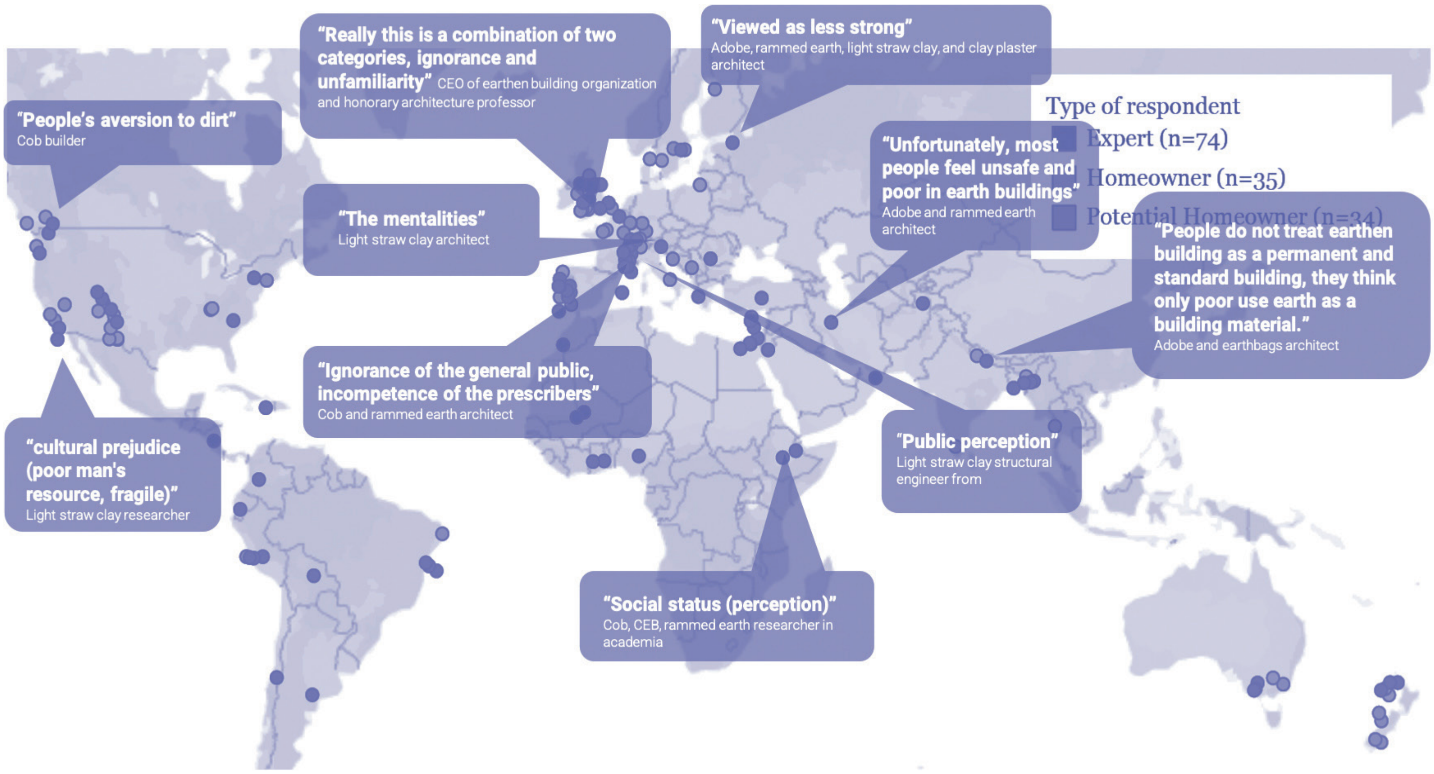

Fig. 3: Results from a global perception survey (Ben-alon et al. 2020), showing a perceptual barrier for integrating earth materials in construction projects, due to cultural prejudice and negative social perception.

the same society – has long led to associating it with the practice of Geophagia: a pathology or a psychiatric disorder involving unconstrained urge to consume earth, mud or dirt. Not only was it considered harmful to the consumer's health and digestion system, but the interchangeable use of "earth," "ground," and "dirt" also invoked notions of excrement, filth, and the dangers of decay. In that context, contemporary biases against the idea of earth-eating can also be traced to the perceived causal link between poverty and the practice – in short, the bias that eating earth can only be a desperate last resort in the face of food scarcity.

Eating earth was further assimilated as an eating disorder – Geophagia – during the 19th-century pre-colonial period when European explorers traveled to Africa on Christian missionary expeditions. Iconic, yet controversial British explorer, David Livingstone, described a local disease of clay eating at Zanzibar in his writing. He highlights that the phenomenon is not confined to enslaved people, "rich men who have plenty to eat are often subject to it."

The influence of colonialism was so deeply imprinted on the cultural prejudice of earth eating that it took several decades of civil and international warfare to begin to free the Western bias from its grasp. Consequently, in his book on Geophagia in China, Berthold Laufer, a German-American Sinologist, describes "a white, soap-like earth" eaten "with rice, because it melts like butter", and that "it is also used for white-washing their houses."

Where traditional practices of earth-eating exist, the earth eaten is specific and well-defined. This fact contradicts the assumption that eating earth is driven by hunger; only earth with particular qualities, such as color, odor, flavor, softness, and plasticity, that have been tested for generations are recommended for eating. From the standpoint of edibility, what is termed diatomaceous earth or kieselguhr, popularly known as mountain meal or fossil meal (in Chinese, stone meal or earth-rice), is a very light, porous earth resembling chalk that consists of the siliceous remains of very minute aquatic organisms or diatoms in several thousand varieties (hence, also styled infusorial earth).

However, more recently, attitudes have shifted regarding these phenomena. In the case of building with earth, the catalyst has been the urgent wake-up call due to the climate crisis and the need for more sustainable building practices and materials. In the case of earth-eating, a growing body of scientific evidence shows that eating earth can be traced to evolutionary advantages and can, in specific ways, provide certain benefits to its practitioners.

WHY EAT EARTH AND CAN IT BE CONSUMED?

Like the history of earth building's waning status throughout the 20th century, attitudes toward Geophagia were affected by modernity's standardization of hygiene and its emphasis on sanitation. Today, scientists have arrived at a more nuanced understanding of microbiomes, including those inside the human body and their vital contribution to an individual's overall health. The critical role that gut bacteria and other micro-organisms play in metabolic processes and the immune system have proven to be of particular relevance for the reframing of Geophagy (Schnitzler 2022).

Unexpectedly, eating clay has also emerged in the last decade as a lifestyle fad, in the health and beauty sector. An ABC News piece in 2005 by Lallanilla, titled "Eating dirt might be good for you" (Lallanilla 2005), exemplifies Geophagia's contemporary reincarnation as an ancient health practice worth giving a try. Bloggers sharing their experiments with eating clay often cite a statement from actress Shailene Woodley in an interview with David Letterman in 2014 as a major catalyst for the practice's commodification (Wong-Shing 2020). Woodley's statement was covered by The Guardian, by Elan and used by the BBC as the lead in their article "Who, What, Why?: Why do people eat clay?" (BBC News 2014), which sparked a trend of purchasing bentonite clay for its purported detoxification benefits

In the scientific and anthropological literature, there are three hypotheses around eating earth: first, that earth is food, and Geophagists are simply people who are hungry; second, that earth provides micro-nutrients and serves as a dietary supplement, i.e., Geophagists respond instinctively to particular nutritional shortages; and third, that clay's micro-chemical structure allows for removal of toxins from the body. Each of these hypotheses emerge in relation to a number of cultural, religious, and individual Geophagic practices that have been observed across the world throughout time, as detailed by (Young et al. 2011) and summarized in the following subsections.

THE FOOD HYPOTHESIS: PEOPLE EAT EARTH BECAUSE THEY ARE HUNGRY

The Food Hypothesis is based on historical observations in which people eat (or crave) earth because they are hungry and as a substitute for food. For instance, during the Thirty Years' War (1618–1648), Germany faced increased food shortages such that that people began to mix white earth with flour and baked bread out of this mixture (Strose, Suhle 1891). In another example, during a famine in Lapland, Scandinavia, earth was mixed with flour and tree bark and baked into bread (Dahms 1897). Hunger has been a favored explanation of Geophagia by colonial explorers in Oceania, the Americas, and Africa.

The food/hunger hypothesis in itself does not arrive from scientific deduction so much as induction from surface facts; as such, the trajectory of this hypothesis reflects and tends to perpetuate the assumption of all Geophagia as a pathological relationship to food: a nonsense choice that individuals make, given its lack of nutritional value, or to which individuals are reduced to making during times of crisis, in countless disaster zones. This history is reflected in the term "dirt-poor", accounts of slaves in the Southeastern US, to reports in the 20th Century of inner-city children in Detroit eating dirt in the 1940s and 50s (Vermeer, Frate 1975). More recently, in 2008, for example, due to a food crisis in Haiti, media reporters published that Haitians could only afford bonbons terres, or earth cakes.

However, although consuming earth might provide some sense of fullness, there are many Geophagists who frequently have other food to eat, and earth cravings occur also when more typical food is available. Additionally, earth substances are extremely carefully selected, and while hunger necessitates a small fraction of non-food consumption around the world, it is safe to say that it does not explain the bulk of Geophagia.

THE MICRO-NUTRIENT HYPOTHESIS: PEOPLE EAT EARTH DUE TO NUTRIENT DEFICIENCY

Other observations provide support to the hypothesis that people are eating earth as an instinctive way to supplement their diets where nutrients are missing. These observations converge around the practices of pregnant women, as integrated into and supported by various religious rituals. Here, properties of fertility are attributed to the earth, and consequently, pregnant women comprise the main consumers: in these instances, Geophagia is said to cure barrenness, protect pregnancies, ensure safe deliveries, and counteract morning sickness. Scientists, with the knowledge of the nutritional needs of pregnant women, reason that the ingested clay might be serving as a supplement to meet these requirements. Studies on the relationship between Geophagia and calcium deficiency seem promising: Wiley and Katz, (1998), have found that dairy farming was inversely related to Geophagia during pregnancy, i.e., pregnant women were less likely to engage in Geophagia in societies in which calcium-rich foods were available. They thus concluded that Geophagia during pregnancy could be motivated as an intuitive means to increase calcium intake (Wiley, Katz 1998).

However, in her book, Sarah Young (2012) reports that Geophagia does not track micronutrient metabolism cycles and in fact, the opposite of supplementation may be happening; in some instances, earth materials may be causing micronutrient deficiencies. Experimental evidence supports the idea that some earth substances interfere with the absorption of micro-nutrients and can thus contribute to deficiencies. The question then becomes, what might be going on for pregnant women (and the rest of the Geophagia population), if clay is not serving the purpose of micro-nutrient supplementation.

THE PROTECTION-DETOX HYPOTHESIS: PEOPLE EAT EARTH TO ABSORB TOXINS

Another hypothesis is that clay is extremely effective at removing toxins from the body. This hypothesis represents a synthesis of lateral scientific observations of animal behavior, a long transnational historical record of clays being used for medicinal purposes, and knowledge of clay's molecular structure and properties. Behavioral observations of animals support an emerging hypothesis of eating earth to absorb toxins. As plants are a major source of toxins - such as alkaloids, tannins, saponins, phenolics, and terpenes - animals seem to be aware of the benefits of adding clay to a plant-based diet (Young et al. 2011).

Earth has traditionally been used both internally and topically to heal a range of ailments. Clay soils have been described by historians as the "Medicine You Can Walk On" and types of clays such as the Terra sigillata were so valued for their healing properties that harvested pieces required the stamp of royal signets, as it was frequently counterfeited. Medicinal scriptures such as the Pliny's Naturalis Historia from the Roman Empire, and Dioscorides' De Materia Medica from Ancient Greece describe earth as an important medicinal practice; as an antidote to swallowed poisons and snakebites, as well as a treatment for dysentery, and a potent treatment for reducing inflammation around the eyes. Historical records also show medicinal use of clay soils by physicians, healers, and midwives throughout Europe to treat smallpox, dysentery, and pestilential (epidemic-causing) disease. Lastly, instances of Geophagia increase in parallel with tropical climate communities, where pathogen densities are higher (Young et al. 2011).

The Protection-Detox Hypothesis has been therefore the most widely accepted interpretation of Geophagia in the scientific community to date, and, in its basis is the mineralogical structure of earth-based materials.

WHY BUILD WITH EARTH AND CAN IT IMPROVE OCCUPANTS' HEALTH?

In contrast with other natural building materials, earth materials exhibit a number of advantages: a) they have high thermal inertia and structural capacity in compression; b) a better resistance to fungi, insects, and rodents, compared to exposed cellulose-based materials; c) potential abundance in and around the construction site; and d) a diversity of building forms and construction techniques, from sculptural monolithic assemblies to modular components (Racusin, McArleton 2012). Due to their high thermal inertia, earthen materials are particularly advantageous in warmer climates, especially when diurnal changes make for warm days and cool nights. When combined with bio-based fibers, earthen assemblies can provide both thermal inertia and thermal resistance to the building envelope. Additionally, the advantages of earthen assemblies as a thermal mass can be used in cold climates by placing it within an insulated envelope or by using Trombe walls; the assembly can store and retain heat from passive solar or active indoor sources and release this heat slowly over a period of time (e.g., over a cold night). Recent research has focused on the broader implementation of earth-based materials in the construction industry, by advancing building policy through a technical synthesis of structural, thermal, and environmental data on a range of earth-based construction technologies.

Earth assemblies were shown act as passive removal materials for internal environment quality against harmful volatile organic compounds (VOCs) (Darling et al. 2012). They also exhibit excellent moisture buffering capacities,

Term	Definition*	Used in traditional earth building?	Used in traditional earth eating?
Dirt	Dust, soil, or any substance that makes a surface not clean	No	No
Mud	Earth that has been mixed with water	Yes	Yes
Ground	The surface of the earth	No	No
Earth	The usually brown, heavy and loose substance of which a large part of the surface of the ground is made, and in which plants can grow	Yes	Yes
Soil	The material on the surface of the ground in which plants grow	No	Perhaps, on unwashed plants
Topsoil	(The soil which forms) the top layer of ground in which plants grow	No	Perhaps, on unwashed plants
Subsoil	The layer of soil that is under the surface level	Yes	Yes
Clay	Thick, heavy soil that is soft when wet, and hard when dry or baked, used for making bricks and containers.	Yes	Yes

Table 1:Earth terminology of interchangeable terms. *According to Cambridge Dictionary

Clay Mineral	Composition	Color	Relevance to Earth Building	Relevance to Earth Eating
Kaolinite	$Al_2(OH)_4Si_2O_5$	White to cream	Kaolinite consists of a strong hydrogen bond that makes it extremely difficult to separate the clay platelayers, and as a result, kaolinite is relatively stable for earth construction – water is less able to penetrate between the layers; thus, it exhibits relatively little swell on wetting (Yanguatin, Tobón, Ramírez 2017).	Kaolinites have a high specific area and sorptive capacity, low or null toxicity for users. They adhere to the gastric and intestinal mucous membrane and protect them; they can absorb toxins, bacteria and even viruses. However, they do eliminate enzymes and other necessary nutri-tive elements, and their prolonged use is not advised (Carretero 2002).
Illite	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$	Grey-white to silvery-white	Ilite is characterized by a rigid structure, which is due to the presence of K+ cati-ons in the spaces between the packets. These cations connect negatively charged surfaces, causing the illites to swell a little in contact with water, thus illites are clas-sified as non-swelling minerals (Karpiński, Szkodo 2015).	Illite clay minerals are used in spas – they are mixed with water (geotherapy), mixed with sea or salt lake water, or minero-medicinal water, and then ma-tured (pelothera-py) or mixed with paraf-fin (paramuds) (Carretero 2002).
Pyrophyl lite/Talc	$Al_2Si_4O_{10}(OH)_2$	Brown and brownish yellow	Pyrophyllite is both fire- and acid-resist-ant. it exfoliates when water is driven off upon heating, leaving a flaky mass. Calcined pyrophyllite has been studied as a cement replacement and it was shown to increase the compressive, tensile, and flexural strength of self-compacted con-cretes (Mansour 2020).	Pyrophyllite exhibits a unique ion-exchange and ad-sorption properties, which makes it an excellent soil condi-tioner for crop production, used instead mineral fertilizers (Murtić et al. 2020).
Montmor illonite	$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2\cdot nH_2O$	Red, yellow, pink	Montmorillonite, as a hydrophilic min-er-al, has a greater influence on the mois-ture balance between the earth assembly and the environment - buffering relative humidity and balancing moisture content (though resulting in lower strength, causing swellings, and correlated with the occurrence of a large number of microc-racks) (Narloch et al. 2020).	Montmorillonites are characterized by their high water absorption, which results mainly from their structure and from the existence of interlayer cations. As opposed to Illite, it has a labile structure, i.e., interlayer spaces may expand (Kaczyński, Grabowska-Olszewska 1997). This mineral was demonstrated to be able to fortify the intestinal barrier by cross-linking with molecules in mu-cus. It has even been shown to cause increased mucus production (González et al. 2004). Montmorillonite was shown to be beneficial when added to amphetamines and antibiotics, since it slows the release and absorption of active components, thus allow-ing slow and controlled desorption of the drug (Carretero 2002).

Table 2: Clay mineralogical composition, color, and existing evidence for earth building and eating.

acting as a relative humidity "fly-wheel" that absorbs and releases moisture from and to the ambient air while maintaining optimal humidity levels for human comfort (Giuffrida, Caponetto, Nocera 2019). Economically, earth construction can be extremely affordable, due to the use of readily available materials from or around the construction site, such as the soils that are excavated for foundations. Therefore, building with earth is arguably healthier for both the inhabitants and installers/construction workers.

CLARIFYING EARTH TERMINOLOGY

Soils, especially those rich in silicates, are the most abundant solid substance in both the oceanic and continental crust (Schulze 2018). Yet, before addressing the science of consuming and building with earth, in order to dispel confusion on interchangeable terms, a much-needed clarification is needed for the terminology of earth substance, as shown in Table 1, in order to dispel confusion on interchangeable terms.

Earthen buildings are defined in the literature as either traditional and vernacular building methods (Niroumand et al. 2017), that utilize natural building materials (Wanek, Smith, Kennedy 2002). However, neither of these definitions is entirely accurate; some earth building materials are historically used in traditional construction (e.g., adobe), some were developed in the past few decades (e.g., compressed earth blocks), and some were used traditionally but nowadays are used with chemical or cementitious binders (e.g., stabilized rammed earth) (Ciancio, Beckett no date; Serrano, De Gracia, Cabeza 2016). Other uses have introduced heat energy; however, in burnt earth or clays, it is not possible to retrieve the microstructure of the natural minerals, unless allowed to undergo weathering for millions of years.

Generally, earth materials for buildings require soils taken from the sub layers of at least 30 cm below ground, termed subsoils. As opposed to topsoil, subsoil does not contain organic matter and will often be more clay-rich. Earth building can be thus defined as construction methods of building elements in which clay-rich subsoil is used as the main component, acting as a geological binder. The clay-rich subsoil matter, used as

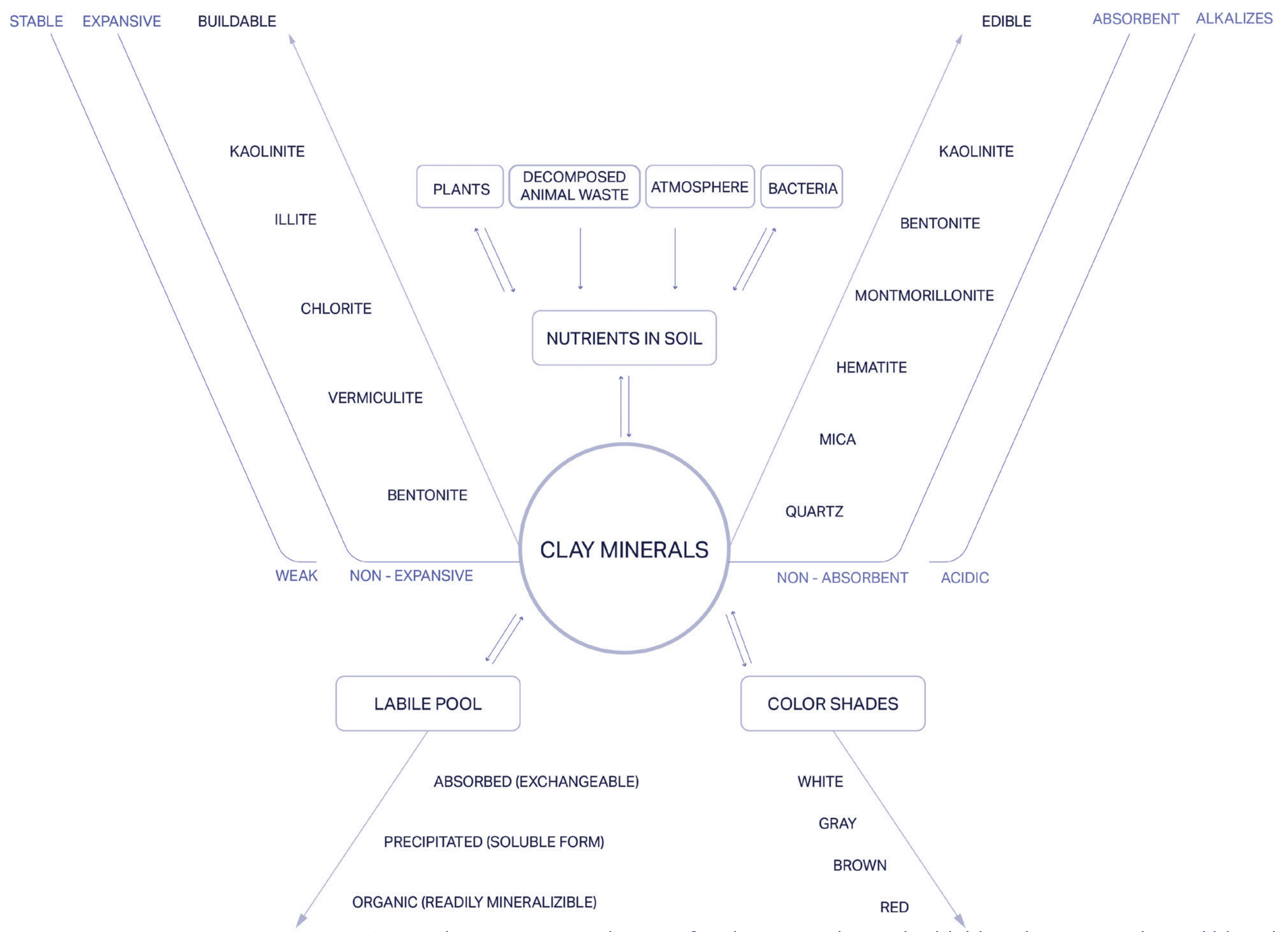

Fig. 4 - Characterization diagram for clay minerals as a buildable substance and an edible substance.

a binder, can be mixed with other additives to achieve different performance parameters. Subsoils that are rich with clay can be diluted with sand. Each constituent material within the earth mixture "recipe" contributes to specific performance characteristics within the mix design: sand and aggregates contribute to compressive strength, vegetable fibers act as reinforcement and contribute to flexural strength. Other additives can be used for sealing (such as flaxseed oil and cactus juice), and increasing the thermal resistivity (such as pumice).

MINEROLOGICAL ANALYSIS

Soil is formed due to natural weathering of rocks in processes taking millions of years. Cohesive soils are composed of both clay and non-clay minerals. Within the soil, clay minerals are the essential component for supporting plant growth, and on a metabolic chemistry level, clay counts as an

Sift Size	Microns	Opening (mm)	Retained Matter (g)	Percentage
4	4750	4.75	0	17.6
8	2360	2.36	0	23.7
16	1180	1.18	0.09	18.8
25	710	0.71	110	9.25
30	600	0.6	228	4.49
50	300	0.3	289	5.24
100	150	0.15	211	5.74
200	75	0.075	102	5.09
Silt/Clay	> 75.0	> 0.075	59.91	9.58

Table 3: Percentage of retained soil from sifted sample for the incorporated soil.

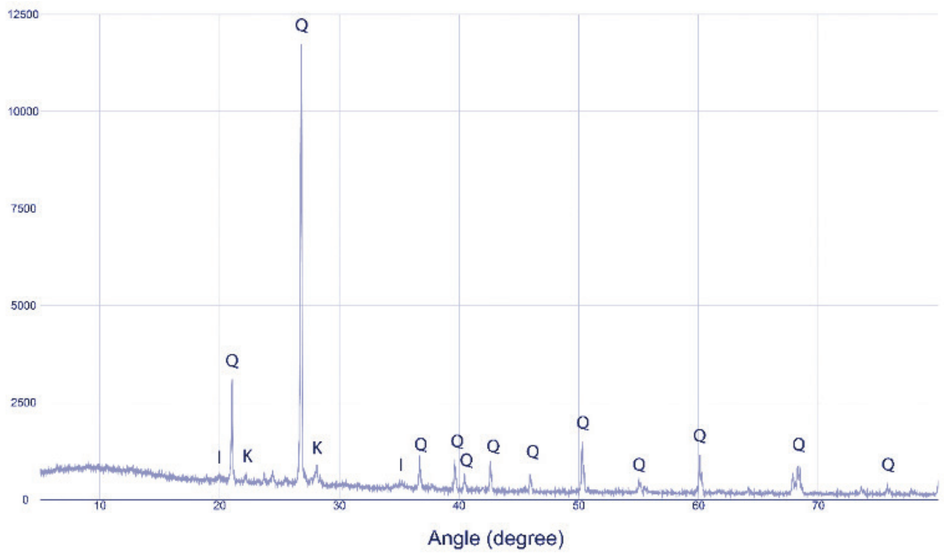

Fig. 5 - The XRD test results for the raw soils used in this experiment. Soil minerals are marked as [Q] for quartz, [K] for kaolinite, and [I] for illite.

Application:	Edible <---> Buildable						
Type of Artifact:	Capsules	Chalks	Cookies	Bricks without fibers	Bricks with fibers	3D Printed clay bricks	3D Printed clay-fiber bricks
Soil (no added clay)	1S	2S	3S	6S	7S	9S	10S
Kaolinite (White)	1W	2W	3W	6W	7W	9W	10W
Illite (Grey clay)	1G	2G	3G	6G	7G	9G	10G
Pyrophyllite (Brown clay)	1B	2B	3B	6B	7B	9B	10B
Montmorillonite (Red clay)	1R	2R	3R	6R	7R	9R	10R

Table 4: Installation artifacts layout, from the edible to the buildable.

Fig. 6 - The research-by-design process of the [EAT ME BUILD ME] project.

Fig. 7 - View of the three video arts projections: edible earth fabrication process, table of elements, and the buildable earth fabrication process.

adsorbent mineral. Clay minerals consist of about 15 ordinarily classified minerals that belong to three main groups: kaolin, illite, and smectite. Among non-clay minerals, the most commonly found mineral is quartz (which can constitute up to 90% of the soil) and iron compounds such as goethite, siderite, and carbonates such as calcite. Clay minerals differ from other minerals due to their cation exchange capacity and their ability to absorb water (Narloch et al. 2020).

As such, the extent to which a certain clay can act as a buildable and edible substance depends on how stable, labile, or bioavailable the mineral is (i.e., able to be made workable during construction and/or be absorbed by the body). Clays are good at adsorbing positively charged molecules' cations, which means that clays can offer an organism protection by binding toxins and pathogens to them before they can even reach the gut wall (Young et al. 2011). In other words, clay can deactivate toxins not by destroying them, but by grabbing them before they can be digested, adsorbing them into some of that space in its crystalline structure. Unwanted chemicals and pathogens trapped in clays then move out of the body with other solid waste.

THE MINERALOGICAL COMMON GROUND FOR EATING EARTH AND BUILDING WITH EARTH

Suitability of clay minerals for eating and building with earth thus share important similarities: for both practices, Kaolin has been a favorite. Kaolin was shown to reduce nausea and poison-related sickness and death (Liu et al. 2005), while also being an ideal clay mineral for earth construction – water is less able to penetrate between the molecular layers; thus, it exhibits higher compressive strengths

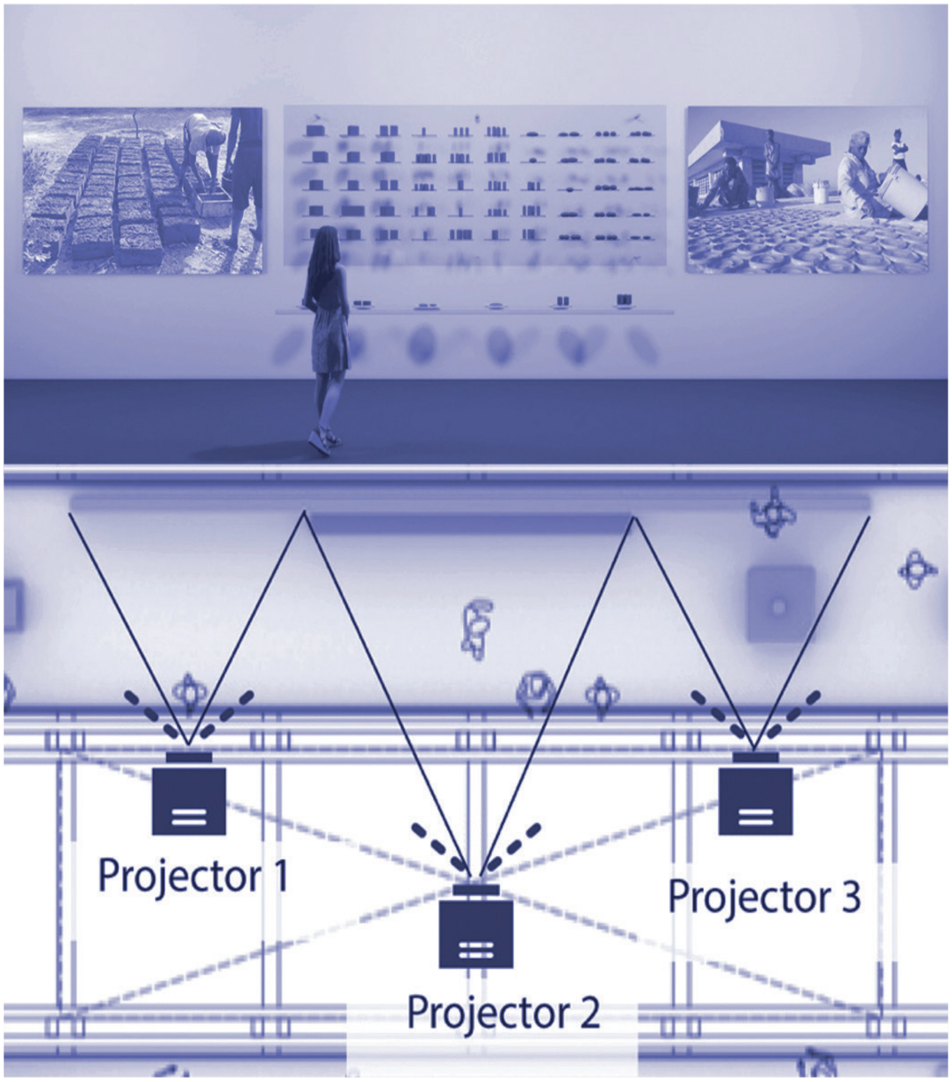

Fig. 8 - A render of the installation (above), and the projection layout (below)

and reduced swelling on wetting (Narloch et al. 2020; Bolton Seed et al. 1962).

WHAT PARTS OF SOIL CAN BE USED FOR EATING?

Surprisingly enough, both the buildable and edible parts of soil share a common mineralogical base: clay. Regardless of their geographic local or cultural habits, traditional earth-based recipes come with clear instructions on what type of soil to use and where to source it from. They all have in common the use of clay-rich soils, which includes minimal organic micro-bacterial activity. Although in everyday speech, "clay," in its plastic, moldable state, is associated with mud and dirt, in its particle state, when not suspended in water, it looks much like other particles of rocks that humans use as spices.

RESULTS AND DEMONSTRATION: THE [EAT ME BUILD ME] INSTALLATION

The mineralogical examination was demonstrated through a research-by-design, hands-on production of edible buildable artifacts. The result took the form of an architectural installation, titled the [EAT ME BUILD ME] project and presented at the 2022 Tallinn Architecture Biennale on "Edible; Or, The Architecture of Metabolism" (Kallipoliti, Markopoulou 2022). As a case study demonstration, the installation examined raw earth, with and without fibers, infused with clay minerals that correspond to Table 2.

As an experimental demonstration, the [EAT ME BUILD

Fig. 9 - Details of the final installation.

ME] project aims to expose the similarities and convergences, the almost parallel historical and geographic routes of building with and eating earth, while asking questions such as: Can we develop edible clay building components that can absorb toxins? Can readily available soils be used as both buildable and edible substances?

MATERIALS GEOGRAPHY, MINERALOGICAL ANALYSIS AND WORK PROCESSES.

The soil used for the installation project was harvested from a recycling quarry located in Goshen, NY, 60 miles from Manhattan. The specimens were then tested for their clay content, particle size, and mineralogical content, to inform the elements arrangements on the scale from buildable to edible.

The results of the grain size distribution test, shown in Table 3, indicate that the soil used for this installation consists of 10% clay and silt. The XRD patterns of the soil show high intensities and broad peaks of silica in the form of α-quartz, as shown in Fig. 6. The analysis also shows that peaks of quartz overlap with the peaks of other minerals in the sample and so the other phases are not discernible. Peaks of other clay minerals include kaolinite and illite with lesser intensity.

The results of the XRD analysis alongside the results obtained from the particle-size sieve analysis indicate that the soil used in the installation requires additional clay minerals to be used for buildable and edible purposes. Thus, the soils excavated on site were infused with clay minerals to achieve a higher clay percentage, which also resulted in coloration of the mixtures.

Using the soil in different compositions, the research-by-design process (exemplified in Fig. 7), traced back traditional methods and developed new “recipes” of earth elements: from chalks, to cookies, to bricks.

INSTALLATION DESIGN AND ARTIFACT LAYOUT

Inspired by the Periodic Table of Elements, the visual language of the installation formed a matrix arrangement from buildable to edible earth artifacts, as detailed in Table 4. On the edible side, earth cookies, chalks, and capsules were fabricated and presented, replicating traditional recipes as well as offering modern interpretations for using earth as a food supplement.
On the buildable side, manually

and digitally fabricated bricks showcase the state-of-the-art in manual and digital earth construction while introducing fiber (straw) reinforcement additives for enhanced strength, durability, and lightweight-ness. A light projection was developed to map the consistency of each element and, the reference to the periodic table.

On each side of the matrix, as shown in Fig. 8 and Fig. 9, a projected video was developed to document the fabrication processes, alongside excerpts of buildable and edible earth practices, as viewed from a Western point of view.

SIGNIFICANCE

As an experiment, the [EAT ME BUILD ME] project is a first-of-its-kind attempt to expose the similarities and to converge the almost parallel historical and geographic routes of building with and eating earth. It speculates upon a larger scope of building supply chain mechanisms, where earth-based materials are perceived, not as an ineffectual matter, but as a multidimensional resource that can be used for both a shelter and a meal, thus offering a futuristic perspective to the growing field of knowledge that investigate healthier substances in building materials. The final installation result, shown in Fig. 10, exhibited ideas and investigations into the nature/culture divide that governs existing paradigms of environment. While it literally maps the raw soil and clay minerals for their buildable and edible potencies, the experimental setup also produces a map of these various ideologies and their tensions, towards the current reformulation of our being in the world.

The installation served as both a tactical and conceptual exercise, aiming to re-discover supply chains of readily available earth-based materials as both building and nutritional substances. It offers a unique perspective on human metabolism and nutrition made possible by ingesting our surrounding building assemblies. As a speculative architectural installation, the project aims to radically suggest that possible earth- and bio-based assemblies can be submerged within building facades as natural, healthy, nontoxic, and presumably - edible building mass. To further stretch the idea of the green façade, where food is grown upon fabric systems or containers, the uniqueness of this experiment stems from its use of agricultural nutritional substance - namely farm to building and building to table as a source for minerals, nutrients, and superfoods within the building itself: an architecture that can be consumed.

CONCLUSIONS AND FUTURE RESEARCH

Earth materials have been used historically for two purposes: as a building material, and as an edible substance. Earth construction has been found dating over millennia and is still sheltering approximately a third of the world population. Similarly, sourced clay-rich earth materials have been traditionally used as edible substances across the world. However, negative modern interpretations have emerged to using earth; Earth building materials are often perceived as "dirty" and poor people's choice for housing, and similarly, eating earth is associated with the pathology and poverty practice called Geophagia. While investigating the past of each tradition, this article finds that the use of earth as a nutritional resource for the built - and human - metabolism stems from the same source: the mineralogical structure of clay.

As part of this research, the mineralogical content of clay is analyzed according to its benefits for buildable and edible practices, resulting in four clays that are proven most potent for gastrotechture purposes: kaolinite, ilite, pyrophyllite, and montmorillonite. Each clay is analyzed for its potency and a map of clay minerals is created. The four clays are used as the base for the research-by-design process concluded in the EAT ME BUILD ME installation displayed as part of "Edible; Or, The Architecture of Metabolism" (Kallipoliti, Markopoulou 2022). As part of this project, raw soils are tested for their particle size and mineralogy content, while mapping their buildable and edible potencies, with the objective of identifying whether clay-rich soils can serve as durable building facades that can be, if such need arises, edible.

Linking anthropology, history, and building technology, this research examines and re-discovers supply chains of readily available earth-based materials as both building and nutritional substances. As a final demonstration, artifact "recipes" of earth and mineral clays are investigated, fabricated, and presented to envision possible integration within the built environment.

ACKNOWLEDGEMENT

The authors would like to thank the students at the Natural Materials Lab who have contributed to this work. In particular, Amy Zhang who assisted with the preliminary stages of the literature review for this project, Zackary Bryson who assisted with the mineralogical and particle size analysis of the soil, and Hazel Villena for her visual renders and fabrication process documentation. We thank Lydia Kallipoliti and Areti Markopoulou for their curatorial leadership and commission support as part of the 2022 Tallinn Architecture Biennale.

BIBLIOGRAPHY

BBC NEWS, 2014. Who, What, Why: Why do people eat clay? . BBC News. Online. 2014. Retrieved from: https://www.bbc.com/news/blogs-magazine-monitor-27323160

BEN-ALON, Lola, LOFTNESS, Vivian, HARRIES, Kent A and COCHRAN, Erica, 2020. Integrating earthen building materials and methods using perception surveys and life cycle assessment (LCA). In: Lehm 2020: 8th International Conference on Building with Earth. 2020. pp. 1–10.

BOLTON SEED, H, ASCE, M, WOODWARD, Richard J, ASCE, F and LUNDGREN, Raymond, 1962. Prediction of Swelling Potential for Compacted Clays. Journal of the Soil Mechanics and Foundations Division. June 1962. Vol. 88, no. 3, pp. 53–87. DOI 10.1061/JSFEAQ.0000431.

CARRETERO, M. Isabel, 2002. Clay minerals and their beneficial effects upon human health. A review. Applied Clay Science. 1 June 2002. Vol. 21, no. 3–4, pp. 155–163. DOI 10.1016/S0169-1317(01)00085-0.

CIANCIO, Daniela and BECKETT, Christopher, no date. Rammed earth : an overview of a sustainable construction material. Third international conference on sustainable construction materials and technologies.

DAHMS, P., 1897. Uber Bergmehl und Diatomeenführende Schichten in Westpreussen. Naturwissenschaftliche Wochenschrift 1. 1897. Vol. 12, pp. 385–88.

DARLING, Erin K., CROS, Clement J., WARGOCKI, Pawel, KOLARIK, Jakub, MORRISON, Glenn C. and CORSI, Richard L., 2012. Impacts of a clay plaster on indoor air quality assessed using chemical and sensory measurements. Building and Environment. Online. 1 November 2012. Vol. 57, pp. 370–376. DOI 10.1016/j.buildenv.2012.06.004.

GIUFFRIDA, Giada, CAPONETTO, Rosa and NOCERA, Francesco, 2019. Hygrothermal properties of raw earth materials: A literature review. Sustainability (Switzerland). 2019. Vol. 11, no. 19. DOI 10.3390/su11195342.

GOMES, Celso de Sousa Figueiredo, 2018. Healing and edible clays: a review of basic concepts, benefits and risks. Environmental Geochemistry and Health. Online. 1 February 2018. Vol. 40, no. 5, pp. 1739–1765. DOI 10.1007/s10653-016-9903-4.

GONZÁLEZ, Raquel, SÁNCHEZ DE MEDINA, Fermin, MARTÍNEZ-AUGUSTIN, Olga, NIETO, Ana, GÁLVEZ, Julio, RISCO, Severiano and ZARZUELO, Antonio, 2004. Anti-inflammatory effect of diosmectite in hapten-induced colitis in the rat. British Journal of Pharmacology. Online. March 2004. Vol. 141, no. 6, pp. 951–960. [Accessed 13 October 2022]. DOI 10.1038/sj.bjp.0705710.

HUANG, Lei, ANASTAS, Nicholas, EGEGHY, Peter, VALLERO, Daniel A., JOLLIET, Olivier and BARE, Jane, 2019. Integrating exposure to chemicals in building materials during use stage. International Journal of Life Cycle Assessment. Online. 1 June 2019. Vol. 24, no. 6, pp. 1009–1026. DOI 10.1007/s11367-018-1551-8.

KACZYŃSKI, R and GRABOWSKA-OLSZEWSKA, B., 1997. Soil mechanics of the potentially expansive clays in Poland. Applied Clay Science. Online. 1997. Vol. 11, no. 5–6, pp. 337–355. DOI 10.1016/S0169-1317(96)00032-4.

KALLIPOLITI, L. and MARKOPOULOU, A., 2022. Edible, Or The Architecture of Metabolism. Tallinn: Tallinn Architecture Biennale.

KARPIŃSKI, B and SZKODO, M., 2015. Clay Minerals – Mineralogy and Phenomenon of Clay Swelling in Oil & Gas Industry. Advances in Materials Science. Online. 2015. Vol. 15, no. 1, pp. 37–55. DOI 10.1515/adms-2015-0006.

LALLANILLA, Marc, 2005. Eating Dirt: It Might Be Good for You - ABC News. abc NEWS. Online. 2005.

LIU, Yong Ling, MALIK, Nasser, SANGER, Gareth J., FRIEDMAN, Mark I. and ANDREWS, Paul L.R., 2005. Pica - A model of nausea? Species differences in response to cisplatin. Physiology and Behavior. Online. 2005. Vol. 85, no. 3, pp. 271–277. DOI 10.1016/j.physbeh.2005.04.009.

MANSOUR, Sabria Malika, 2020. Behavior of self- compacting concrete incorporating calcined pyrophyllite as supplementary cementitious material. Journal of Building Materials and Structures. Online. 2020. Vol. 7, no. 1, pp. 119–129. DOI 10.34118/jbms.v7i1.744.

MARTINEZ, DJS, 2017. Concrete Colonialism: Architecture, Urbanism, Infrastructure, and the American Colonial Project in the Philippines. Online. Columbia University.

MURTIĆ, Senad, ZAHIROVIĆ, Ćerima, KARIĆ, Lutvija, JURKOVIĆ, Josip, ČIVIĆ, Hamdija and SIJAHOVIĆ, Emina, 2020. Use of pyrophyllite as soil conditioner in lettuce production. Nature Environment and Pollution Technology. Online. 2020. Vol. 19, no. 1, pp. 355–359.

NARLOCH, Piotr, WOYCIECHOWSKI, Piotr, KOTOWSKI, Jakub, GAWRIUCZENKOW, Ireneusz and WÓJCIK, Emilia, 2020. The effect of soil mineral composition on the compressive strength of cement stabilized rammed earth. Materials. Online. 2020. Vol. 13, no. 2. DOI 10.3390/ma13020324.

NIROUMAND, Hamed, KIBERT, Charles J, ANTONIO BARCELO, Juan and SAALY, Maryam, 2017. Contribution of national guidelines in industry growth of earth architecture and earth buildings as a vernacular architecture. Renewable and Sustainable Energy Reviews. Online. 2017. Vol. 74, pp. 1108–1118. DOI 10.1016/j.rser.2017.02.074.

NIROUMAND, Hamed, ZAIN, M.F.M. and JAMIL, Maslina, 2013. Various Types of Earth Buildings. Procedia - Social and Behavioral Sciences. 2013. Vol. 89, pp. 226–230. DOI 10.1016/j.sbspro.2013.08.839.

PACHECO-TORGAL, F. and JALALI, Said, 2012. Earth construction: Lessons from the past for future eco-efficient construction. Construction and Building Materials. Online. April 2012. Vol. 29, pp. 512–519. DOI 10.1016/j.conbuildmat.2011.10.054.

RACUSIN, JD and MCARLETON, A, 2012. The natural building companion: a comprehensive guide to integrative design and construction. Choice Reviews Online. Online. 2012. Vol. 50, no. 04, pp. 50-1883-50–1883. DOI 10.5860/choice.50-1883.

SCHNITZLER, Eugene, 2022. The Neurology and Psychopathology of Pica. 1 August 2022. Springer.

SCHULZE, Darrell G., 2018. An introduction to soil mineralogy. In: Soil Mineralogy with Environmental Applications. Online. pp. 1–35. ISBN 9780891188919.

SERRANO, Susana, DE GRACIA, Alvaro and CABEZA, Luisa F., 2016. Adaptation of rammed earth to modern construction systems: Comparative study of thermal behavior under summer conditions. Applied Energy. 1 August 2016. Vol. 175, pp. 180–188. DOI 10.1016/j.apenergy.2016.05.010.

STROSE, K. and SUHLE, H., 1891. Strose, K., and H. Suhle. 1891. Mitteilung uber das... - Google Scholar. In: IX Jahresbericht des Friedrichs-Realgymnasiums und der Vorschule des Fridericianum fur das Schuljahr.

VERMEER, Donald E. and FRATE, Dennis A., 1975. Geophagy in a mississippi county. Annals of the Association of American Geographers. Online. 1 September 1975. Vol. 65, no. 3, pp. 414–424. DOI 10.1111/j.1467-8306.1975.tb01049.x.

WANEK, C, SMITH, M and KENNEDY, JF (eds.), 2002. The Art of Natural Building: Design, Construction, Resources. Online. New Societ Publishers. ISBN 0086571-433-9.

WILEY, Andrea S. and KATZ, Solomon H., 1998. Geophagy in pregnancy: A test of a hypothesis. Current Anthropology. August 1998. Vol. 39, no. 4, pp. 532–545. DOI 10.1086/204769.

WONG-SHING, Kim, 2020. I Tried Eating Clay For 3 Days For The Sake Of My Health. LittleThings.com. Online. 2020. Retrieved from: https://littlethings.com/lifestyle/eating-bentonite-clay

YANGUATIN, H, TOBÓN, J and RAMÍREZ, J., 2017. Pozzolanic reactivity of kaolin clays, a review | Reactividad puzolánica de arcillas caoliníticas, una revisión. Revista Ingenieria de Construccion. Online. 2017. Vol. 32, no. 2, pp. 13–24.

YOUNG, Sera L., SHERMAN, Paul W., LUCKS, Julius B. and PELTO, Gretel H., 2011. Why on earth?: Evaluating hypotheses about the physiological functions of human geophagy. Quarterly Review of Biology. June 2011. Vol. 86, no. 2, pp. 97–120. DOI 10.1086/659884.