Down to Earth: Using Natural Building Materials for Community Resiliency

LOLA BEN-ALON
Columbia University

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Natural building materials offer a minimally processed, non-toxic, and community self-sufficient alternative to conventional building materials. Constructing with these materials maximizes the potentials of freely available resources, while engaging local communities, regardless of skills, including families and children.

In this paper, a design-build methodology that fosters academic and community connections for building with earth is presented. Specifically, the presented teaching structure equips interdisciplinary teams of engineering and architecture students with both theoretical knowledge and hands-on building experience of a range of natural materials for different climates.

While making a sensitive choice of materials, technical details, and participatory processes, students collaborate with local communities to foster circular economy, create know-how to improve living conditions in the local context, and support a bottom-up form of capacity development. Hands-on workshops provide students with insights from field and give the opportunity to gain expertise of alternative building modes.

The presented methodology resonates with current research on natural building materials that aims to enhance the performance, perception, and policy of these materials. The long-term implications these endeavors hope to achieve are the catalysis of low-carbon construction in community development and mainstream projects, as well as the development of a complete, safe, and user-friendly building guidelines and material standardization.

WHY ON EARTH? BENEFITS AND CHALLENGES TO USING EARTH-BASED MATERIALS

Earth is considered one of the oldest building materials, often combined with bio-based fibers and used in building methods such as rammed earth, adobe, light straw clay, cob, and compressed earth blocks. While still sheltering approximately a third of the world's population, particularly in developing countries (Wanek, Smith, and Kennedy 2002; Kahn 1990), earth materials have been regaining popularity in contemporary construction due to their environmental, economic, and health advantages.

From an environmental standpoint, earth materials offer a low carbon, minimally processed, and fully recyclable alternative to conventional mass materials such as concrete (Ben-Alon et al. 2021). Economically, earth construction can be extremely affordable, due to the use of readily available soils and fibers from or around the construction site (Hardin, Merry, and Fritz 2003; Schroder and Ogletree 2010). From an indoor environment quality point of view, earth assemblies were shown to act as passive removal materials for VOCs (Darling et al. 2012), while acting as a relative humidity "fly-wheel" that absorbs and desorbs moisture from and to the ambient air ((Minke 2012), Chapter 1). Finally, tests have shown that walls made of earth materials are able to dampen high-frequency electromagnetic fields (emitted from antennas, radars, mobile phones, etc.), much better than other building materials (Röhlen and Ziegert, 2011).

Despite their benefits, earth- and bio-based building materials are far from being mainstream due to missing technical data that could quantify their true performance for different climatic and environmental conditions (Miccoli, Müller, and Fontana 2014; Ben-alon 2020). Specifically, there is a need to provide analytical and numerical insights to facilitate the design process and allow a broader inclusion of natural materials in building codes by means of incentives from a life cycle perspective (Swan, Rteil, and Lovegrove 2011). Recent research by the author has questioned the broader implementation of earth-based materials into the construction industry by analyzing building policy (Cob Research Institute 2019) through a technical synthesis of structural, thermal, and environmental data on a range of earth-based construction technologies (Harries, Ben-Alon, and Sharma 2019; Ben-alon 2020; Ben-Alon et al. 2020), as well as developing life cycle assessment (LCA) measures for earth materials (Ben-Alon et al. 2021; 2019) (Figure 1).

Previous research has shown the following five basic immediate barriers to the implementation of earthen building in contemporary construction (Ben-Alon et al. 2020): (1) Technical gap, due to a growing body of research on the structural, thermal,

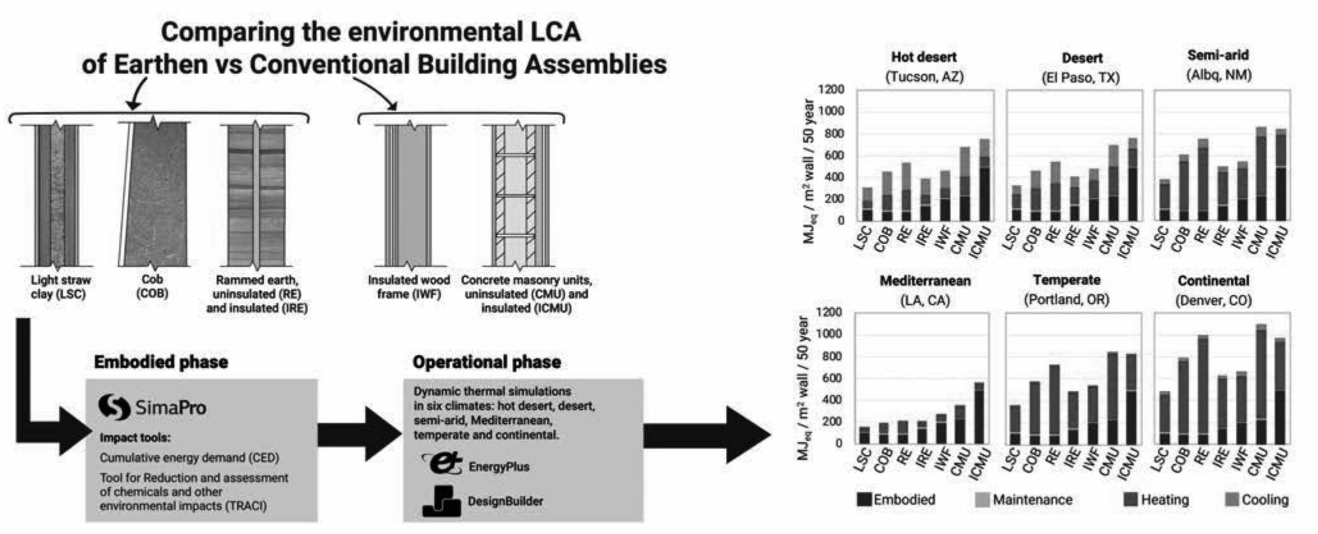

Figure 1: Embodied and operational (heating and cooling) energy demand impacts for earthen vs conventional wall assemblies in six climates (Ben-Alon et al. 2021). Abbreviations: Light Straw Clay (LSC), Cob (COB), Rammed Earth (RE), Insulated Rammed Earth (IRE), Insulated Wood Frame (IWF), Concrete Masonry Units (CMU), Insulated Concrete Masonry Units (ICMU).

and durability perfoamnce of earth materials that has not yet been efficiently synthesized; (2) Perceptual gap, where earthen building is perceived as 'low-tech' and poor in its performance; (3) Regulatory gap, where earth building construction is omitted from building codes; (4) Field gap, due to lack of educational experience by building professionals such as architects, engineers, and builders; and (5) Innovation gap, where innovative solutions for durability and constructability are held back, constraining earth construction within a "traditional" niche.

FIELD GAP—LACK OF EDUCATION FOR BUILDING PROFESSIONALS ON EARTH BUILDING

Previous research has surveyed and interviewed building professionals as to the barriers to implementing earth materials (Ben-Alon et al. 2020). According to interviewees, lack of experienced and trained professionals lead homeowners who are interested in earthen building to either use other, more conventional materials, or to seek an independent construction path as owner-builders. Especially for earthen techniques that require machinery, such as rammed earth, experts reported challenges in identifying trained designers, engineers, and builders. Interviewees reported that successful projects were made possible by project managers (usually architects) with extensive knowledge on earth materials performance that could communicate these performance parameters to the local code official.

Lack of education and training experience to building professionals also stalls back innovation solutions through, for instance, mechanization, enhanced mixtures and quality control tests, digital fabrication and 3D printing, and BIM processes.

THE IMPORTANCE OF IMPLEMENTING EARTH MATERIALS IN ARCHITECTURAL PEDAGOGY

Independent earth building workshops

Earth-based materials are often considered self-sufficient modes of construction, often applied as a community engaging activity. Due to their affordability, vernacular nature, and non-toxicity, earth materials are easy to learn by lay people who are non-experts, thus providing local employment opportunities and enhancement of local economies. Therefore, there is a plethora of earth building workshops, offered independently by builders such as (Evans, Smith, and Smiley 2002).

According to previous studies by the author (Ben-Alon et al. 2020), there is a severe lack of experience and training in earth construction for building professionals, which leads interested homeowners to "give up" on using earth materials or to take on an independent construction path as owner-builders.

Training for code officials

One key to overcoming unfamiliarity with earthen building codes is providing education and hands-on training. For instance, it was shown that workshops for permit officials about earthen materials helped make the permitting process easier, as interviewed architects mentioned (Ben-alon 2020): "I was asked by the State to go to their annual meeting of all of their permit official representatives… and I got a whole day with them to talk about straw bale and cob and adobe and rubble trench foundations and living roofs… And now in this State, it is so easy to get a building permit for natural buildings, partly because of that… if every state did something like that…"

This effective way to disseminate information is key to fostering earth building education and to enhance familiarity among building officials, but it should also be introduced in the early stages of architectural and engineering education. This is imperative since both building professionals and permit officials discourage clients from implementing natural building materials, as stated by one of the interviewed architects (Ben-alon 2020): “I just had an email today from someone who has been trying to build a straw bale home in Colorado, a very responsible thing to do, and they have been going around in circles with their permit official and their engineer, around and around until they just wear this person out and they decide not to pursue it. … if architects and engineers have [nonconventional construction] as part of their education, then they know how [to properly support] someone … who comes to them.”

Modules for training building professionals on earth construction should include theory, field awareness, and practical experience modules, while partnering with local academic institutes, vocational universities, and sustainable construction and products firms. As illustrated in Figure 4, programs should draw from existing inspiring projects while being exposed to current research in the field. An example of such an approach is the Grounded Materials training at ETH Zurich. As shown in Figure 5, this program aims to train specialists on the effective use of earth and bio-based materials in a 5-week module for projects managers, building contractors, and members of the City Technical Services.

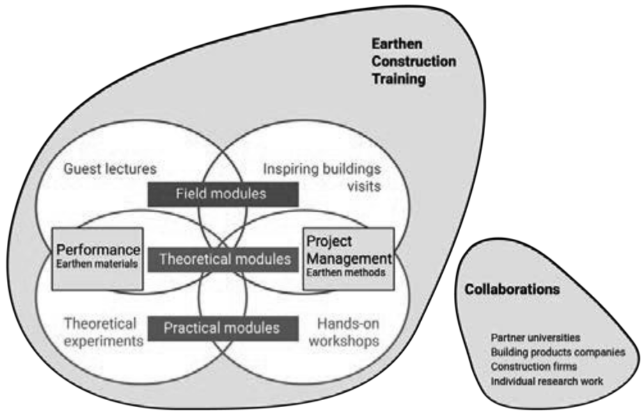

Figure 2.Earth construction training modules. Image by Ben-Alon, following Grounded Materials by (ETH 2017).

DOWN TO EARTH COURSE: AN EDUCATIONAL CASE STUDY

To address the growing need for expanding the education on architectural materials, a class on earth-based materials was offered in the fall of 2019 and spring of 2020 at the School of Architecture at Carnegie Mellon University’s. The course, entitled Down to Earth, was offered to both architecture and civil engineering undergraduate and graduate students. Following a structure of a project-based seminar, Down to Earth proposed an integration of theory, lab experiments, and design-build of an actual, small-scale, earth construction project.

Course structure and objectives

The course Down to Earth converged both theoretical knowledge and practical experience related to a range of earth-based materials including rammed earth, cob, clay plasters, and straw bale construction. Community engagement, as well as performance and environmental benefits of both residential and commercial projects that use earth materials in a wide of range of contexts were introduced and analyzed. The course also included 1-2 guest lectures in each semester to provide insights from the field. Lastly, a design-build workshops provided practical experience, providing students with the opportunity to gain hands-on expertise in designing optimal mixtures and applying the materials in both the core and finish assemblies of a project.

As a final deliverable, the class at Down to Earth designed a realistic earth construction project such as an earth-based sitting modality or a real-scale building assembly, while making a sensitive choice of materials resource extraction, technical details, and participatory processes. The project was delivered through a competition-like format, intended to foster the local economy, create know-how to improve living conditions in the local context, and support a bottom-up form of capacity development for and with communities.

The course was designed with the following learning objectives in mind:

Theory: students should learn to identify history, current practices, and technical performance of various natural and earth-based building techniques, including rammed earth, cob, adobe, light straw clay, straw bale construction, and clay plasters.

Performance: students should assess the technical performance of case studies of earth-based projects.

Design: students should gain experience in designing a small-scale earth project in a competition-like proposal setting.

Build: students should work collaboratively in interdisciplinary teams of design and engineering professionals to construct an actual earth-based project.

Figure 3: Students designing optimal earth- and bio-based mixtures at the course's materials laboratory.

Materials Laboratory

The hands-on process was initiated using a materials lab session, in which students experimented with earth-based mixtures and processing techniques. Students first characterized raw subsoil specimens that were sourced from local quarries located up to 100 miles away from the Carnegie Mellon University campus. After characterizing the soils, students experimented with designing optimal mixtures for construction, as depicted in Figure 5. These experiments allowed students to comprehend issues of buildability and workability using earth-based materials, while asking how the material behavior dictates design considerations.

First pass soil characterizations were conducted by students according to the recommended applied testing methods by ASTM and international standard for earthen walls (Eisenberg 2017; New Zealand Standards 1998; Walker and Standards Australia 2001). These tests acknowledge typically used on-site tests that can be applied with little or no access to material testing facilities:

The Sedimentation test, also known as the "Shake Test" (soil composition) (Figure 4). The sedimentation test provides a first pass quantitative measurement of the fine gravel, sand, silt and clay fractions within an existing soil sample (Walker and Standards Australia 2001). As part of the test, a loose sample of soil is soaked into water within a transparent container of approximately 500 mL. The container is vigorously shaken for 1-2 minutes, after which it is left undisturbed until the test has been completed. Readings are taken 1 minute after shaking to measure the combined layers of fine gravel and sand, 45 minutes after shaking to measure the combined layers of sand and silt, and 24 hours after shaking to measure the layer of clay. The layers are measured in height as a percentage of total soil height.

The Ribbon and ball tests (clay content). The ribbon and ball tests are fast field tests that qualitatively determine relative grading of a soil and its suitability for earth building. While providing a quick on-site field assessment, these tests should only be treated as a basis for further testing. For the ribbon test, an approximate quantity of

50g soil is worked in the hand so as to extrude a ribbon of damp soil approximately 150 mm long and 20 mm thick. The ribbon should be able to hang from the hand without breaking. The length of ribbon attained before it breaks is an indication of the relative sand, silt and clay content. For the ball test, a wet mass of soil is rolled in the hands so as to make a ball of approximately 2 cm diameter and set aside to dry. After drying, the ball should not be breakable between the thumb and fingers of one hand.

The Drop test (optimum moisture content). The drop test is a qualitative test used to determine the optimum moisture content of soil. This test should be undertaken regularly during material preparation and before the shrinkage test. Moist soil is dropped from shoulder height at arm's length onto firm ground. The manner in which the ball breaks on impact is interpreted to determine whether the soil mix is at its optimum moisture content.

Figure 4: Students conducting the shake test to assess particle composition percentages within a specific soil sample.

Design-Build workshop

The final project in Down to Earth included a design-build of a small-scale project. The selected project for Fall ’19 was a sitting area for Grow Pittsburgh, a local nonprofit that serves as a resource and guide for other urban farmers across the Greater Pittsburgh region.

Following a site visit at the urban farm location, interdisciplinary teams of engineers and architects each developed a design proposal for the sitting area. This process generated proposals using a range of earth-based mixtures and techniques, including flat rectilinear rammed earth benches, curved cob, and straw bale infill bench and ottoman, as shown in Figure 5. A final design was chosen by the class by using the cob-based fibrous mixture to ensure durability and combining the added ottoman to allow versatile sitting arrangements.

The construction phase took place after generating construction drawings and materials quantities, allowing students to demonstrate their knowledge and receive critical experience in actualizing their design with earth materials. Students analyzed the required budget for purchasing local materials, according to the materials quantities and cost analysis of the final design. As part of the project management, students translated the final design into documents that are legible at the construction site. Additionally, farm community members have joined the construction workshop, as well as additional students from the University, making the build phase a collaborative process with a diversity of backgrounds and skills.

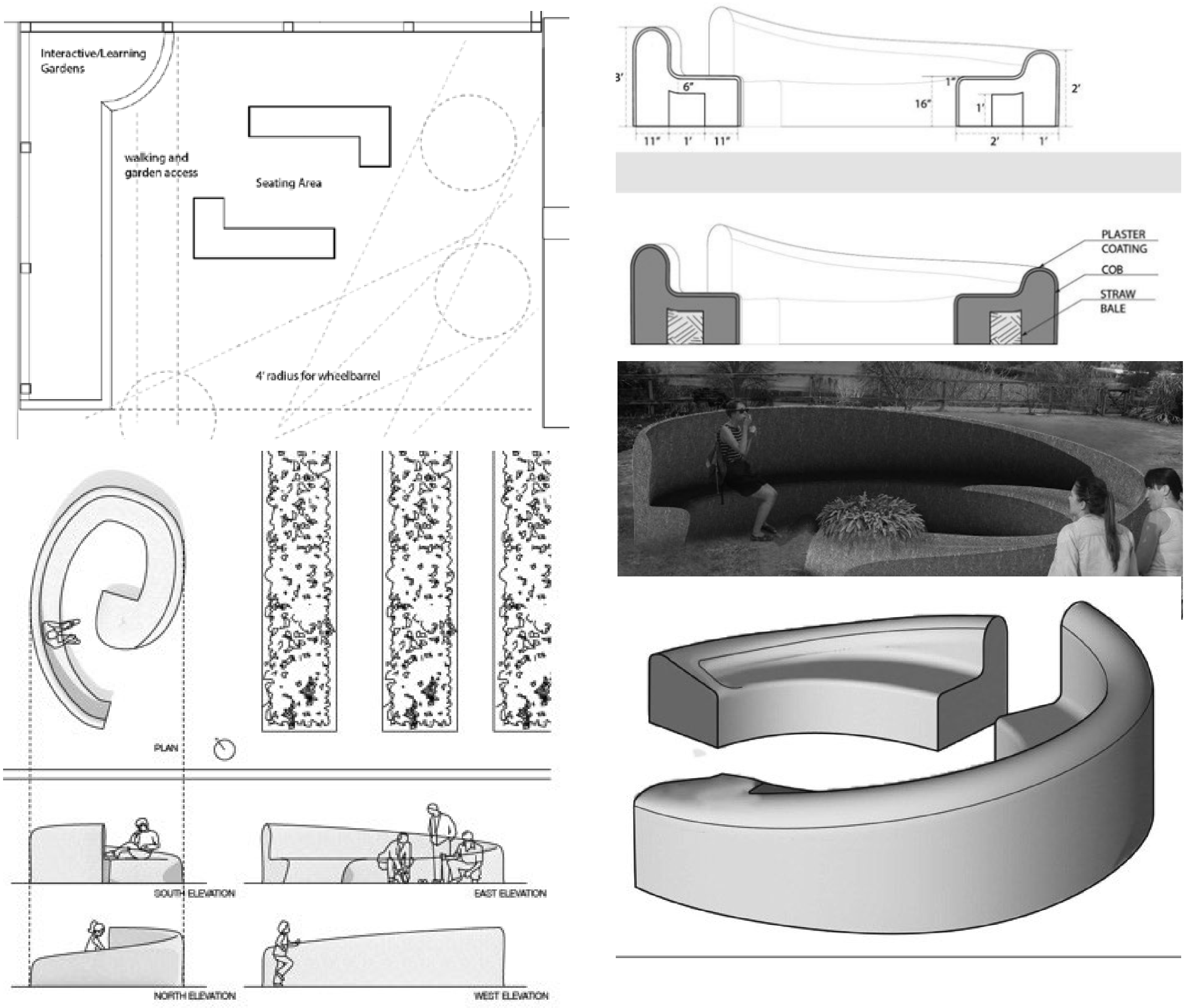

Figure 5: Design proposals by student teams, each uses different earth-based mixtures and building techniques.

The construction included designing and mixing the earth-fiber mixtures on-site, according to the following steps (fig 06):

1. Adding water to a mixture of subsoil and sand
2. Adding straw fibers, while
3. Stamping the plastic soil-fiber mixture, until
4. Mixture has "body" and can withhold weight, and
5. Dividing the mixture into small balls that can be tossed to nearby the buildup area.

The mixing process was repeated by the construction team throughout the construction workshop for multiple batches.

The building and sculptural process of the sitting area included the following steps, as illustrated in Figure 7:

1. Building up the rubble trench foundation to a 1 ft height.
2. Adding cob layers on top of the foundations.
3. Building up and sculpting the shape of the sitting area
4. Making corrections to the shape and reducing matter as necessary
5. Applying a finish cob plaster layer with chopped straw

Figure 6: The steps for designing and mixing the earth-based mixture on site

Figure 7: The steps for building and sculpting the cob bench and ottoman.

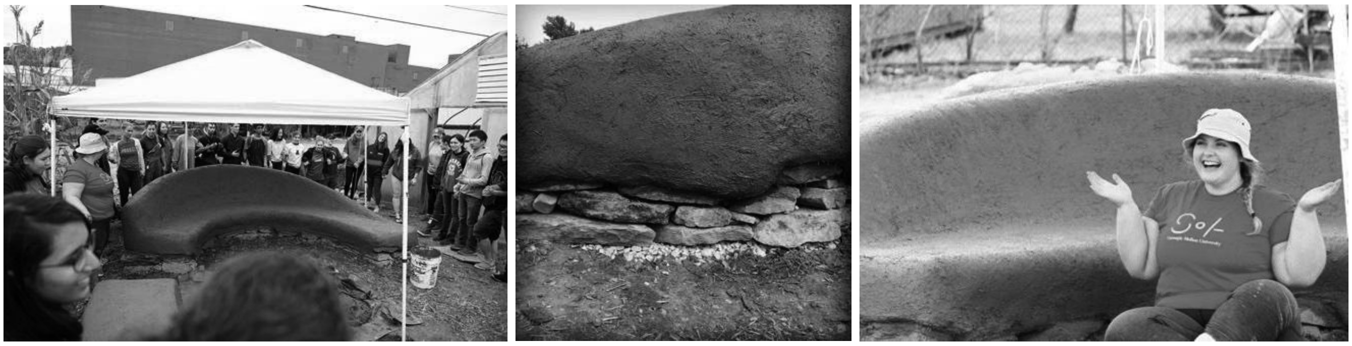

Figure 8: Celebrating the final outcome.

TAKEAWAYS AND FUTURE DIRECTIONS

The presented earth construction project-based course was developed to provide training on a new generation of manufacturing using sustainable, natural, and healthy building materials. This pedagogical case study integrates architectural pedagogy with a broader hands-on training, while providing students and community members with building tools for earth- and bio-based building materials. While working in interdisciplinary teams of engineers and architects, students gained invaluable experience of actualizing their own designs, optimized through laboratory materials tests.

The pedagogical collaboration with the local community contributed to a broader interdisciplinary scope on quantitative and qualitative expertise related to the construction, mechanical, thermal, and environmental impacts of natural building materials. Using earth materials, this course helped students perceive earth not as a “poor-man’s materials” and “low-tech”, but as a viable construction material that can be adjusted to the design/construction needs.

Future educational avenues should provide know-how on developing and upscaling sustainable alternatives to carbon intense cementitious materials, while combatting negative perception. Additionally, future trajectories in architecture technology curriculum should elaborate on the proposed manual manufacturing mode to equip students with innovations in 3D fabrication technologies, to address digital futures and combine vernacular and digital approaches for earth building materials and assemblies.

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