RARE EARTH: Mid-Rise Mud

Abstract:

Can mud buildings emerge as mid-rise mediators between low-density urban fabric and true towers? Can we use parametric modeling tools to shape mud, an ancient and elemental building material, into a high performing building elements for new towers that connect earth to sky?

The tall mud structures, in Djenne, Mali, and the walled city of Shibam, Yemen, are the ancestors of the new responsive mud tower. Relatively tall earthen structures have been built for centuries to resist lateral loads and other non-compressive stresses, not merely by mass. Rather than the normative Western paradigm, can alternative towers, shaped by new technology yet constructed with earth, answer the call for a "friendly", "softer" tower?

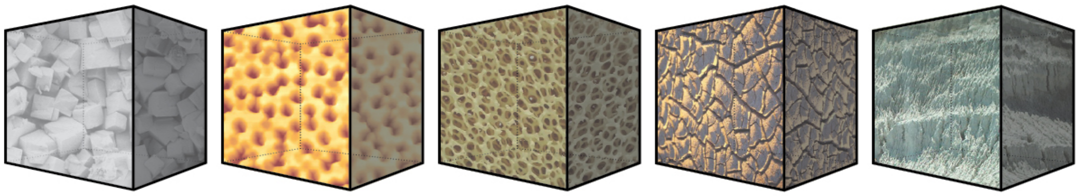
The development of earth towers is promising for contemporary programs in cultural heritage sites, particularly in the developing world. Interventions into historic urban contexts can demand density but also material compatibility. Earthen architecture may be entering a new phase with the application of material studies that recombine previously "unalloyed" substances in novel ways. Rapid virtual testing allows reconfiguration of new material into forms at micro and macro scales. A fibrous, granular, and cohesive earthen-based structural material, with new understanding of its behavior, can be formed into sensuous, three-dimensional, and human-scaled buildings.

This paper presents our proposal for a midrise earthen tower for an historic city in North Africa, and discusses current developments in the design of earth towers, including a variety of earthen and baked bricks and structural ceramics being designed today for the towers of the future.

Mid-Rise: Urban Design Mediator

The incongruous juxtapositions of rapidly expanding cities have gone beyond popular notions of unregulated speculation and have entered the phase of alienated landscapes. Surreal transitions between the extremes, high-rise and ultra high-rise developments against low-rise habitations, industry and movement are particularly sharp in developing and non-western urban contexts. Usually the divide is physical and social, manifested by well-secured precincts of high-rise towers, overlooking and directly adjacent to simple undeveloped low-rise compounds and family dwellings. There are many ways of dwelling in a high-rise, from the shallow sublimity of a corporate boardroom to the precarious spontaneity of squatting families in an abandoned apartment tower. Though such incongruity may be considered the essential character of the growing city, midrise construction makes it feasible to confront contextual anachronisms in the life of the streets, and offer human-scaled urban environments. We propose to explore the densification of urban centers without extremes in configuration, and design the mid-rise building as a relational structure; in the new vertical city the mid-rise has a place as a spatial and social mediator. The traditional mix of uses in mid-rise development – shops, restaurants at street level with offices and dwellings above exemplifies the livable urban neighborhood. The innumerable combinations and specializations of use at this scale demonstrate the tremendous functional and social utility of the block building between skyscraper and sprawl.

What we are addressing here is that redevelopment, perhaps, could be better if considered as a very localized phenomenon that increases density and re-functionalizes neighborhoods, but also includes steps of scale in building type. Further, it is possible to make incremental adjustments and start new relationships within the odd, uncanny zones between low-rise neighborhoods and high-rise buildings by inserting mediators, mid-rise blocks.



[m $\times 10^{-5}$] **Alunite** [m $\times 10^{-4}$] **Cell Growth Film** [m $\times 10^{-3}$] **Ceramic Filter** [m $\times 10^{0}$] **Dried Mud** [m $\times 10^{2}$] **Clay Excavation Pit**

An Earthen Mid-Rise Unit

As the important role of the mid-rise is established in the context of rising skyscrapers, the relatively low height prompts us to think about material experimentation. The middle ground of urban buildings, comprising most of the volume constructed in cities around the world, is where innovation and continuity can coexist. Earth, a most abundant, local, commonly known material may be a fruitful choice for experimentation, and lead to new manifestations of its use in structural, architectural and urban design.

The well-designed mid-rise urban building recognizes its limitations and opportunities. The availabilities of construction systems worldwide for buildings of this scale tend to concentrate toward earthen, masonry, and concrete materials simply because wood is obsolete and steel is expensive. New buildings of mid-rise bulk and height do not have to strain to stand out in height and appearance in a shocking way, and they may use the expressions of innovative technology discreetly.

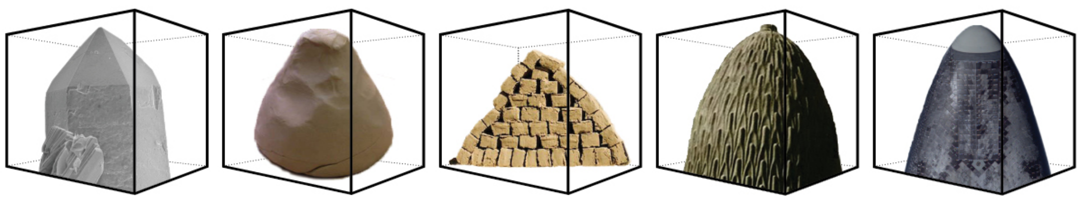
Innovation, especially for arid cities, might be claimed in mid-rise design in two ways, which we name Intelligent Earth and Simple Mechanisms. Intelligent Earth is defined as using the benefits of earthen materials—availability, formability, massiveness, load-bearing, sound-deadening, color, texture, durability, and sensuality—in new configurations and patterns of structure that extend their use for new programs and requirements within the conditions of mid-level urban environments. Architects have unrestrained access to applicable knowledge in the fields of modern geology, soil mechanics, and extractive technology, to name a few. Certainly, these fields can inspire approaches, actual prototyping and, eventually, standardization in the realm of earthen buildings. And, with parametric software, we can model 3-dimensional prototypes quickly with performance testing in the process.

Simple Mechanisms can be defined as a fresh look at old and ancient ways of keeping a building ventilated, cool or warm, and naturally lighted. Particularly of interest to us is that in arid climates, the temperate building was perfected over millennia; it makes sense to reapply that knowledge within new architectural configurations. The tempering of air and light through shafts of space and filtering devices is a scientific and cultural legacy hard to ignore, inseparable from the nature and potential of earthen architecture. As we develop the cross-sectional scheme for a mid-rise structure, we can see the opportunities for integral, Simple Mechanisms that provide comfort for every space with minimum need for energy procured remotely. (fig 2)

Abundant Precedents: ancient and contemporary parallels

In Mali, Yemen and other North African and Middle Eastern cities, dried earthen block structures have been maintained for centuries. Some of these are multi-storied and tall. Shibam, Yemen is the site of very tall historic structures constructed entirely of dried adobe bricks and timber. Designed for a single extended family and organized vertically for security and defense, they present a paradigm of functionality at a scale suitable for the development of the mid-rise city. Certainly, we are impressed with the height and stability achieved with mere mud. It would be interesting, and perhaps useful to take a “core sample” of the lowest layers of adobes to determine whether there are morphological changes effected by the tremendous load of the structure on the brick material. Over a thousand years, has the mud become more like stone?

Earthen structures in civil engineering projects have demonstrated the ongoing accumulation of wisdom concerning soil and rock behavior from empirical testing and, of course, trial and error. The geometric arrangement of loose earth materials to withstand tremendous lateral loads (e.g., a water dam) has provided engineering knowledge that can be applied to habitable earthen structures. Compaction and the cross-sectional disposition of various materials have become computationally verifiable tools of design toward outcomes that could be transferred to earthen buildings.



[m $x10^{-5}$] **Dickite** [m $x10^{-3}$] **Clay Lump** [m $x10^{-1}$] **Mud Blocks** [m $x10^{0}$] **Musgum House** [m $x10^{1}$] **Space Shuttle**

A New Process of Earthen Architecture

Is it possible to imagine the “reverse-engineering” of the erosion process in earthen structures human-made and natural? The entropic process in natural systems is not only about catastrophic collapse and dissolution; there is consolidation, stabilization, and duration over very long time. For example, we look at a mesa in the American Southwest. The earth-form is a structure of stabilized earthen layers of various sedimentary materials. The almost vertical wall of the mesa endures because of the internal bonding strength and gravity-formed geometry of horizontal layering—the basic integrative and morphological facts of its existence.

We project our mimicking mentality onto these material architectures and imagine them as dwellings of the spirits. They are solid earth, of and by the slow movements and violent eruptions of the planet. Yet, these masses have been inhabited for eons. We have found hollows, overhangs, clefts, caves, and shelves and made our homes. We have learned to carve, dig, break off and buttress space in the earth. We became masons, plasterers, miners, excavators, mudslingers, sculptors and painters in these earthen shelters. Our bodies respond viscerally to the sense and awareness of the presence of earth around us, and over us.

So, we know about earth, rocks, shales, muds, sands, boulders, liths, clays and pigments. We know how to chisel, stack, grind, sand, cleave, pulverize, sift, mix and make into paste these materials. We can make walls of earth arise from the earth and profile against the sky. The mesas seem as inspirational models for our houses, ceremonial structures, and cities.

The time character of earth materials is an inherent quality we exploit in the construction of architecture. The sediments of geological cross-sections are compressed, and trapped in a general morphology that remains stable until greater forces disrupt it. The wind and water-carved surfaces of geological strata are signs of the interaction of energy, matter, and time. In our hands we have imitated the forces at work by pressing clay, puddling mud, spinning, molding, and baking earth.

The modern technique of rammed earth construction is derived from a "reverse-engineering" process of compression, sedimentation, and molecular bonding evident in natural, geomorphic deposits. The parallel forms are like blades cutting slices of earth layers and represent or replace the vast continuity of mass on each side of the newly created section. A tamping machine applied to each subsequent "pour" or layer is imitating the weight of countless tons of earth acting downwards. The knowledge of bonding materials in the mix of rammed earth is critical because the practical limits of the ratio of thickness to height could not be respected without it. The use of loam earth, a wide range of mixed clay and sand with a specific moisture content (6-7%), has been crucial in the success of rammed earth construction. Relative to examples from nature, the vertical section of compressed earth created in the forms is quite thin, given its coarseness and relative porosity; compression and bonding of materials in the matrix hold it all together after the forms are removed.

In relation to its natural inspiration, a wall of rammed earth is a “module” of continuous earth mass. For practical reasons, it is a rectangular “prism” of earth that can be economically planned and joined with other rectangular building components. Recently, it has been shown to be practical to pre-fabricate rammed-earth wall sections and crane them into position in a very short amount of time. Research, design and construction of rammed earth structures by Martin Rauch have greatly contributed to the understanding of engineered soil materials in architecture.

Parametric modeling of earthen mid-rise structures can enable innovative re-thinking of traditional construction methods. Predictability in the structural performance of a moderately vertical structure can be acquired by computer modeling, combining accepted engineering design with the performance of compressed earth. We imagine that the key concept is the development of 3-dimensional “diagrids” and “packing networks” that incorporate large-scale modules. And we imagine that the greatest liability of earthen materials in this application, its weak strength in tension, can be greatly mitigated by the intelligent arrangement of shear planes—cracks. We have observed the settlement of very long, unreinforced earthen walls and the consistent pattern of large cracks to relieve stresses. Once relieved, the wall is relatively stable and the mass load resists lateral forces. It is possible to exploit this action by designing a system where tensile stresses are conducted along shear paths and, ideally, rendered non-destructive by resolving down to the foundation. In this way, earthen mass is allowed to do what it does best, take compression.

If we can successfully model a stable, durable earthen mid-rise structure composed of large-scale “cells” or “prisms”, then we need to envision a construction technique that makes the outcome feasible. A new kind of formwork is required. Formwork concepts need to be radically developed in light of potential structural innovation. We can imagine formwork that may be permanently “imbedded” in the mass of the earthen materials, arranged in a manner that resolves stresses, and becomes a complete assembly of formed earth; optionally, the earth is not brought up and compressed in formwork at each level, but is pre-packed in formwork at grade, allowing the placement of large sections of compressed earth, craned into place like giant slabs of stone.

The orientation of the modules can go beyond the Cartesian conventions of orthogonal arrangement. The internal disposition of joining planes may be extrapolations of mathematical “boulder” packing, rotational offsets, and wedged “strata-packs” that may be pre-assembled or loaded in place.

We imagine that since many phenomena in the geological studies are of a complex, irregular, 3-dimensional nature, efforts in the current research are creating ever-more sophisticated geometric and, thus, calculable structural modeling. If we can process this modeling from observational and verifying programs in earth sciences into constructive, synthetic programs of earthen construction, a new phase of design in the field can emerge.

It is possible to imagine a system of geotextile sheeting that incorporates tensile properties while serving as formwork for compacted earth. Already, interesting techniques have been established with geotextiles in landscape and civil engineering projects. The crossover thinking holds great potential.

While we are planning for earthen structures employing new methods of structural reliability, we should investigate further ways of making them eminently habitable by avoiding the use of overly-mechanized and artificial environmental systems. Day-lighting strategies may be thought of as antithetical to massive earthen structures, but thinking about the climate and intensity of sunlight in the traditional locations may help us to find ways innovative structures can control light and distribute it. A prismatic solid of earth can also be conceived of as a prismatic void of reflective surfaces that direct and expand daylight. The challenges and complexities of properly ventilating a multilevel building (without presupposing the consequences of internal separate spatial units) are beyond the scope of this paper. Nevertheless, it is not hard to imagine the engaging of synergies of structure, space and comfort in earthen architecture. Earthen walls temper extremes between interior and exterior. We welcome the development of hybrid concepts based on earthen architecture that might include the incorporation of intelligent HVAC and artificial lighting systems.

The thesis we are presenting is an adaptation of so-called *rapid prototyping* of structural and architectural design that can help us to innovate and bring it into the process of earthen materials construction. We all know the environmental impact differences caused by choice of materials, their extraction, processing and transport, and, finally, their true cost to maintain as comfortable habitations. It is probably true that earthen architecture has not gone through rapid development and research like other construction systems because there is little profit in it. We hope the measure and value of this technology replaces cash-incentivized ones.

An Illustrated Case Study: Artisan Workshop Block in Fez, Morocco

The midrise block of earthen construction we consider as a test-case prototype is located on Place lalla Yeddouna, a World Heritage site in the medina of Fez, Morocco. The program is for craft finishing workshops, also serving as shops for tourists who are interested in the setting for craft production as well as the products and artisans. In this speculative proposal we illustrate an idea for construction.

The proposal is for a structure of approximately 35 metres square, somewhat irregular, out of respect for the property boundaries and adjacent river. The required area for the program dictates a height of four stories above grade.

After laying out and constructing the fundamental plinth, by installing infrastructural connections and consolidating the salvageable materials from the preceding demolition into a level floor, the superstructure begins. Rammed earth

Strata-Packs are constructed at the base area that consist of fixed, ribbed, ceramic sheets configured as half-hexagons with a depth of .75 meters, and overall length of 2.3 meters and height of 1.0 meters. A crane positions the Packs in interlocking courses where every fourth course supports a floor.The Strata-Packs will become the envelope and the core of the building. Floors consist of hollow precast triangular beams with a leveling layer and structural floor of concrete. The floors are finished with cast glass slabs. Joints are packed with elastomeric putty to achieve fully distributed pressure planes.

The shape of the Strata-Packs, when stacked, allows for geometric voids that can be windows, doors, vents, etc. The Packs can be tamped in half-length units to build vertical planes and interlock across the depth of the envelope. Wall surfaces are left exposed or covered with lime-plaster on the exterior.

The geometric distribution of mass is, of course, answerable to the structural requirements for stability and load-path management to the foundation. Consideration should also be given to the most feasible balance between maximum Strata-Pack volume and its constructability in the field.

The envelope is necessarily massive and openings for daylight are not typically expansive. Thus the need for top-lighting of the mid-rise block by opening up the roof level to bring daylighting down through the floors. The top-down lighting concept can be combined with a ventilation scheme, exploiting the voids in the floor or between the floors and the earth walls. The core may become an adaptation of the traditional *dur-qa*, venting the entire structure naturally.

As the holistic concept unfolds, and we project its construction on a real site, we strive to integrate structure, envelope, floors, daylight, and air by exploiting prismatic form. Rather than think of the whole block as a stack of floor levels with thick walls, let us think of it as an interlocked network of solid and void 3-dimensional volumes. With parametric design tools, we can configure and assess results quickly and repeatedly as we plan the construction. The primary materials of the building, compressed earth, ceramic and glass work in spatial, thermal and structural concert to express a new kind of architecture that works in the context of age-old urban form and offers an alternative path for future development.

Project illustrations:

fig 4 Strata-Pack

fig 5 midrise elevation

fig 6 midrise exploded elements

fig 7 midrise medina Fez

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