Returning to Earth: Analyzing and Designing Earthen Structures for Sustainable Design

Amidst economic instability and building material scarcity, earthen construction presents a viable and readily available alternative to conventional building. Students and faculty at The University of Oklahoma College of Architecture and College of Engineering are evaluating Compressed Earth Block to quantify structural, thermal, acoustical, and energy consumption criteria.

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Mankind has been on an expedition aided by technological advancements to find and conquer new space, but economic instability and building material scarcity introduces a sustainable-laden homecoming. Sustainability and environmentalism are intrinsic to the earth and the natural resources it contains, beckoning collaboration among architecture, engineering, and construction to develop regionally and globally sustainable buildings without blind faith for or dependence upon technology. While exploration fuels design prowess, revitalizing critical resourcefulness aptly results in material conservation, stewardship of the environment, and inhabitant comfort.

Earthen construction, particularly the soil component found within or near most project sites, presents a viable and readily available alternate method of residential and small-scale commercial construction. In changing climates with forecast temperature increases, the density and mass of earthen construction is vital to mitigate thermal transfer, allowing passive heating and cooling to efficiently provide comfortable interior spaces. Students and faculty at The University of Oklahoma (OU) believes Compressed Earth Block (CEB) may prove to be an economical, efficient, and environmentally-friendly option. The collaborative team has secured funding from both the United States Environmental Protection Agency (EPA) and OU sources, coupled with a productive Cleveland County Habitat for Humanity (CCHFH) partnership, to evaluate the research hypothesis. Continued future development will explore differing climates, occupancies, and demographics.

SUSTAINABILTY AS AMALGAMATION

By some account, society is at the leading edge of the most technologically advanced building materials and systems ever created by man but not without particular costs, consequences, and reasonable suspicion. Although technology often receives credit for unveiling emergent materials, assemblies, and practices; it is arguably attributable to the initial demise of indigenous and traditional environmental stewardship. Influenced by the advances and hopeful promises of technology, previous generations either did not understand future repercussions or place much ecological credibility in designing and constructing buildings with environmental or sustainable practices in mind. Retelling this story may seem redundant in today's saturation of "green" initiatives, but it is necessary to question the previous and sometimes undisputed myopic view of technology during mankind's cautious quest for new design and construction methods.

With that in mind, sustainability existed many years before it was considered necessary or trendy. The word "sustainability" is a late 20th century term associated with what was previously regional development. Sustainability is not an island nor a new concept, but rather a cooperative relationship among history, theory, and technology. The term and all the great endeavors accomplished in the name of sustainability may be marginally misappropriated, causing some designers to overlook the most important factor in building design – the people that occupy the space(s). As Lopez Barnett and Browning state, "today's buildings not only are designed without the planet in mind; they also neglect their occupants." [1] Sustainability must focus upon and satiate the triad of people, place, and resources. Functionally competent sustainable design requires creative thinking, innovative use of local materials, and passive design schemes. Lopez Barnett and Browning take it a step further, stating:

> Note that sustainable design is not a new building style. Instead, it represents a revolution in how we think about, design, construct, and operate buildings. The primary goal of sustainable design is to lessen the harm poorly designed buildings cause by using the best of ancient building approaches in logical combination with the best new technological advances.[1]

Terms such as organic, ecotecture, arcology, and off-the-grid (relationally combining ecology, geology, and architecture as depicted in Figure 1 and publicized by varied architects such as Frank Lloyd Wright, Paulo Soleri, and Michael Reynolds) introduce recent generations to a lifestyle where people are responsible for managing local resources, developing labor skills correlated to the particular environment, and using readily available materials. The adage and motivating design mantra – Think Globally, Act Locally – has infiltrated society and matured into a global presence. Sustainable building concepts teach energy conservation, recycling, and living within built environments that are designed and constructed using regional and indigenous materials, including historical and modern examples of earthen design and construction. As Hans Poelzig states in his manifesto *Fermentation in Architecture*, "we cannot do without the past in solving the architectural problems of our own day." [2] Architecture has the ability to span time, assimilating past and present methods of design into hybrid assemblies for particular sites and functions.

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Figure 1: Top to bottom: Adobe building in AZ; positive concrete extrusion of negative earth forming at Soleri's Cosanti; an Earthship near Taos, NM with rammed earth tire and bottle imbedded earth construction; architect Rick Joy's office courtyard showing rammed earth and glass.

LESSONS FROM THE PAST

Precedent and historical studies of vernacular or indigenous designs and methods of construction are lessons for modern adaptation. These examples not only communicate the choice of materials or aesthetics of the completed construct, but much can be learned about the programming, clients, occupancy, use, and politics. Authors Kaltenbach and Anschel state, “the first humans, among other animal species on our planet, always found shelter in the earth.” The authors then conclude, “Here, architecture developed in terms of technique and scale. Over time, the resulting breadth of the knowledge base of common methods and materials forged a cultural connection between the land, habitat, and the people.” [3] Therefore, architecture becomes a study and result of anthropomorphic criteria.

Building with or into the earth, either upward or as a carved shelter, is not a new idea. Earth is actually one of civilization’s first building materials and is still used extensively throughout the world. As author Paulina Wojciechowska states:

> Since the earliest times, people have lived in the earth, taking up residence in existing structures or forming and sculpting earth around them according to their needs. In terms of growth and development, indigenous communities usually lived within the limits of their ecosystem. Nature, technology, and culture maintained balance.[4]

According to 1st century BCE Roman author, architect, and engineer Vitruvius, a good building should satisfy the three principles of firmitas, utilitas, venustas, which translate roughly to durability, utility, and beauty. As mentioned in Ronald Rael’s book *Earth Architecture*, Vitruvius writes about the use of mud brick in the construction of city walls and devotes an entire chapter of *De architectura* (translated to *Ten Books on Architecture*) Book II to mud brick masonry, describing with great respect the methods for making and stacking mud bricks.[5] Earth as a design material equips architects to lead an environmental revolution through historical relevancy. History has proven diverse nationalities from various climatic locations have successfully constructed earthen structures that outlast most other construction types, are structurally sound, and offer passive options for physical comfort, while having minimal impact on the environment. The design profession can advance by re-examining these structures, assimilating traditional and modern approaches, and allowing a hybrid of technologies to emerge. Technology has aided testing to prove stabilizers such as portland cement, fly ash, cement kiln dust, and recycled paper pulp can be added to strengthen soil mixtures. A new enthusiasm for architecture, literally based upon earth, can support a return to an early and basic form of sustainability.

Earthen design and construction is gaining momentum among architects, engineers, clients, contractors, and machine manufacturers. Contemporary architects such as Rick Joy, Wendell Burnette, Will Bruder, Antoine Predock, Alfred von Bachmayr, and countless others use earth as a healthy, safe, and aesthetically pleasing building material. They are also selecting the use of earth based upon both the regional and global benefits such as decreased carbon footprint, thermal efficiency, and regionalism within its context when compared to conventional construction. Recent conversations with Mr. Burnette in his Phoenix, Arizona office reflected upon the history of earth as a construction material, dating back to hand-formed soil balls used in African Mosques and the influence of human form in his firm's approach to designing with earth. The conversation recalls the union of ecology and architecture where shapes and contours found in nature are mimicked, allowing fluidity of form and enclosure. Earthen design and construction, either in pre-made modular units or site cast, holds potential for both particular aesthetics and performance criteria.

THE PEDAGOGY AND BENEFITS OF CEB

Architecture students must combine lessons learned in studios, lectures, and hands-on opportunities with materials to assimilate form, function, and performance criteria. Texts such as Edward and Iano's *Fundamentals of Building Construction* convey simple statistics such as buildings accounting for 30-40% of the world's energy use and associated greenhouse gasses, 30% of U.S. raw material consumption, and 66% of U.S. electricity consumption.[6] Students must also comprehend ecology; it is the essence of context and environmental relation. Ronald Rael defines "ecology" as:

> Earth is an inherently ecological material. Earth has excellent thermal mass properties, which can maintain comfortable interior temperatures without the need for mechanical heating and cooling. The utilization of earth requires little embodied energy and structures made of it are highly recyclable.[5]

Although modern material science is the typical avenue for developing sustainable products and construction techniques, soil remains a leading and viable building material worldwide. As of 2000, statistics show approximately thirty percent of the world's population live in homes of unbaked earth.[7] Even though earthen construction is prevalent, perception is another hurdle. In Mexico and Central America there is a perception that only poverty stricken people live in earthen houses and wealthy people live in concrete houses.[8] This may be due to the mistaken belief that buildings constructed of materials other than soil are safer, healthier, and more durable. This stereotype must be broken in light of current environmental energy requirements, thermal necessities, and material supplies. The various mixtures, forms, and types of earthen construction provide numerous design options for various climates and occupancies. According to Jean Dethier, "there are perhaps twenty different methods of employing earth to construct walls, floors, and roofs of varying dimension and form." [9] Rael continues with "the adaptability of the material has allowed it to respond to a wide range of contexts, cultures, and epochs, including the spectrum of architectural history from antiquity to the modern era.[5]

Compressed Earth Block (CEB), which can be dated back to Francois Cointeraux in the 18th century, shares properties similar to more commonly known types of earthen building materials - such as adobe, cob, earthbag, and rammed earth.[5] CEB units are believed to be inherently sustainable and energy efficient since they require little energy to produce and transport, conserve natural resources, reduce landfill waste, and lessen the energy consumption of the building. All these factors combine to reduce the amount of carbon dioxide released into the atmosphere, helping to reduce the carbon footprint and taking a step toward decreasing global warming. Current students need to be a voice of knowledge and reason to society

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and individual clients as they become tomorrow's architects. CEB units are produced by a hand operated or automated hydraulic press resulting in masonry units with compressive strengths similar to a Concrete Masonry Unit (CMU). It becomes a modular construction material formed when a mixture of subsoil (approximately 30% non-expansive clay and 70% sand), small amounts of water, and an optional 6-7% by gross weight soil stabilizer (such as portland cement, fly ash, or cement kiln dust) are compressed together using either a hand-press or internal combustion machine under approximately 1,500 – 2,500 psi. Various types of machines produce numerous sizes and shapes of CEB, some having variable parameters for height and compression.

Typically known as the three R's - reuse, reduce, and recycle; a fourth and equally important factor is "regional." Author Jon Nunan defines construction waste as follows:

> In terms of home building, conventional construction produces a significant amount of waste; the typical new construction project averages 3.9 pounds of waste per square foot… It is estimated that more houses will be built in the next 50 years than have been built throughout all of human history, which is a lot of potential waste.[10]

CEB embodies the four R's by taking advantage of soil from footings, basements, swimming pools, general cut, and utilities often considered spoils and hauled off site for a fee. Relatively compared to traditional masonry units, the carbon footprint of CEB is minimal since they do not require heat to cure. At a minimum, the embodied energy of transporting soil off site and transporting other materials can be minimized by using existing soil to produce a portion of construction materials for the proposed building. The original soil is the largest commodity to be conserved and utilized. While actively researching CEB, students learn first hand the need for sustainable design.

Figure 2: Students participating in CEB production; and completed CEB site and retaining walls constructed from campus construction donated soil spoils.

A RESEARCH PROJECT WITH COMMUNITY INVOLVEMENT

While designing with earth requires understanding of materials, connections, and climatic conditions; constructing with earth can be laborious and time consuming compared to traditional methods of construction. Community organizations provide not only collaboration with local resources, but also the added benefit of volunteer labor which exponentially decreases the life cycle cost of earthen construction. As an international organization, Habitat for Humanity International (HFHI) strives to use research and building science to develop building systems that are certifiably sustainable, universally accessible, and ultimately provide simple, decent, healthy, and affordable housing. One of the first decisions HFHI made upon forming in 1976 was to use locally available materials to allow a more sustainable building system that is empowering for the community and environment.[11] Wayne Nelson, a trained carpenter and builder who works with HFHI's Department of the Environment, states "most people who build with earth find it quite enjoyable. It can be just plain fun to make your house from the earth under your feet. Enjoy the earth God has given us." [11] HFHI affiliates have used CEB and adobe in Mexico, Central America, and Asia, but somewhat limited in the U.S. (including Santa Fe, NM in the 1990's). Since earthen construction is currently not widely used in the United States, some education toward local community reception may be required to benefit from the resurgence of this type of building typology.

In 2009, Cleveland County Habitat for Humanity (CCHFH) acquired three adjacent lots in Norman, Oklahoma. One lot houses a 1,170 SF, conventionally wood-framed three bedroom, one bathroom residence (completed July 2010) designed and constructed to HFHI's current high standards of durability, energy efficiency, and affordability. This structure has served as a guide for a proposed CEB residence and another wood-framed residence (built simultaneously and used as the experimental control) on the two remaining adjacent lots. Through detailed inspections and testing, the existing model residence achieved a Home Energy Rating System (HERS) index of 54 and was certified by Guaranteed Watt Savers Inc. (GWS) to the National Green Building Standards (NGBS). These same high standards will act as the performance benchmark for the new residences. In addition, the forecast budgets and schedules of the two new residences are being compared to CCHFH's previous detailed construction cost records.

While the use of earthen construction aligns with HFHI goals and guidelines, it has not yet been researched or documented to its full potential. Evidence suggests that buildings properly constructed of CEB meet HFHI criteria for durable healthy residences with low up-front costs, low life cycle costs, and minimal environmental impact on the community.[12] The COA research team believes this technology may be ideal for many HFHI affiliates since it uses relatively inexpensive materials and takes advantage of the abundant volunteer labor with minimal training requirements.

CEB IN THE CURRICULUM

During initial interest and training, the research team was awarded an EPA P3 Phase I Grant and an OU funded Faculty Challenge Grant totaling $35,000 to commence CEB research, develop multidisciplinary earthen design and construction courses, and determine both minimum and actual quantitative data. To become educated with the materials, equipment, soil mixes, and block production prior to embarking on the full-scale CEB residence; the research team and volunteer students from the COA focused on

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preliminary soil tests, defining ranges of compressive strengths, and building student-designed site and retaining walls at another CCHFH site as shown in Figure 2. Some of the preparation was mathematical, while some was more rule-of-thumb to get acquainted with various soil compositions. Since not all soil contains the same proportions of gravel, sand, silt, clay, and moisture; a series of preliminary tests were completed to determine proper additives for required performance. For example, a known practice to determine moisture content is to drop a small handful of lightly pressed soil from a height of approximately 4′-0″ above a concrete slab. The impact can display a widely dispersed scattering [too dry], a tight mound [too wet], or somewhere between the two extremes [typically a good starting point]. Another preliminary documentation of soil composition is simply referred to as a "Jar Test." Stratified layers of silt, clay, sand, and impurities are evident after submerging soil samples in water for 24 hours. Small test blocks, approximately 2 ½″ x 4″ x 15/16″ manufactured with a hydraulic hand press, are subjected to proportionate compression tests to estimate full-scale properties. Test blocks resulting in height greater than 15/16″ refers to a dry mix while less than 15/16″ suggests a wet mix, roughly evaluating the cohesiveness and moisture content of the soil mix.

The team found these tests helpful for gaining a basic understanding of soil properties and behaviors particular to a variety of local soils (Figure 3). The results allowed students and faculty to proceed with initial production of full size 6″ x 12″ x 3 ½″ CEB, yielding compressive strengths ranging from median values of 600 psi at 7 days, 1,300 psi at 14 days, and exceeding 1,500 psi at 28 days and future breaks. These initial values were acceptable to move forward since they proved comparable to CMU typically specified at a minimum of 1,500 psi. Approximately 700 CEB were used for the two landscape walls mentioned above measuring approximately 100′-0″ in length. The curved section of the wall was set with a stabilized slurry mix of soil, water, and portland cement while the retaining wall portion was set in a thicker traditional masonry mortar mix. The process produced positive results, allowing future phases of research and development.

Jim Hallock, a CEB specialist from Instituto Tierra y Cal in Mexico, visited OU in March 2011 and August 2013 (with an "Adobero", a traditional

Figure 3: Left to right: Jar Tests and Small Test Blocks; Small Test Block after compressive testing as initial research with soil; and structural test walls evaluated during in-plane and out-of-plane tests.

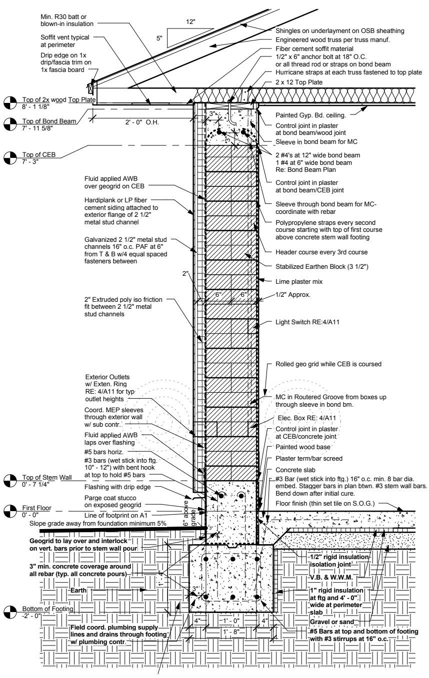

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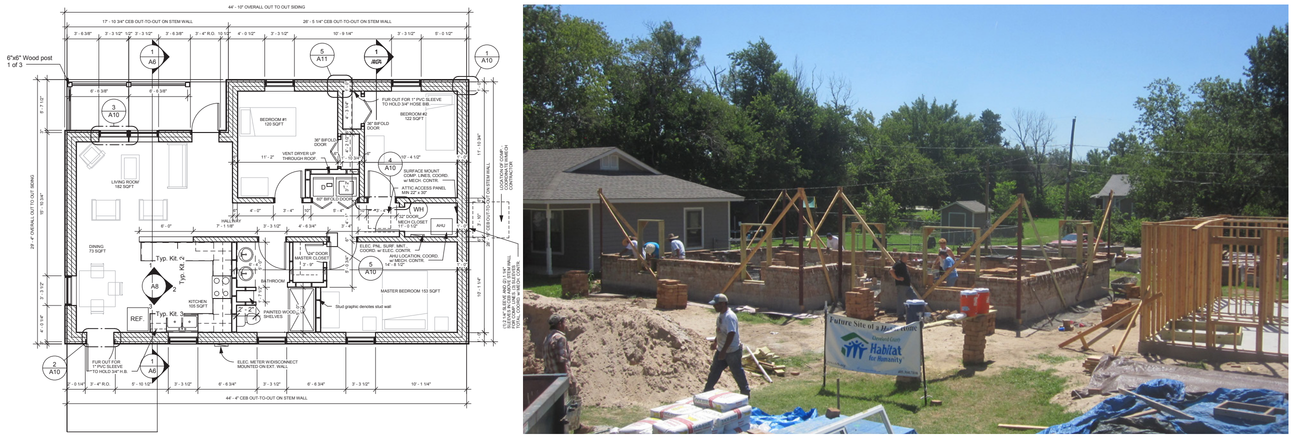
Figure 4: Top to bottom: Students working on scheduling of testing and construction; students building a mock-up wall; team at 2012 EPA P3 Expo; and a wall section from the permit set drawn primarily by students showing the double wythe exterior CEB.

Mexican mason) to expedite the processes of manufacturing, testing, and construction. The team mixed soil spoils donated from various campus construction sites with small amounts of sand, sifting it through a 3/8″ mesh, transferring the mixture with minimal water and 7% portland cement by weight into a mortar mixer, and then emptied the mix into a Impact 2001A CEB Machine purchased by the COA from Advanced Earthen Construction Technologies (AECT). The blocks tested above 300 psi compressive strength within an hour of production and yielded approximately 1,200 – 1,900 psi during the 7, 14, and 28-day cure.

To facilitate continued earthen design and construction research and immersive hands-on interaction, faculty developed a series of interactive courses and independent study opportunities. Twenty-two students from various colleges and departments (Architecture, Construction Science, Environmental Science, and Civil Engineering), enrolled in a Fall 2011 research-focused earthen design and construction course. The course introduced alternative construction methods and focused on design development of the CCHFH CEB residence as a working model of design and construction decisions. The team of students, faculty, and community volunteers committed to constructing the two new CCHFH houses (one CEB and the other wood-framed) directly adjacent to the original conventionally wood-framed CCHFH residence with the same interior volume to compare various criteria over time. Students researched the following topics from wall assemblies to the built environment: block manufacturing process and logistics, schedule, cost estimate, construction details, thermal properties, energy use and HVAC efficiency, acoustical properties, life cycle cost analysis, structural design, codes research, in-plane and out-of-plane strengths (Figure 3), site contours and drainage, soil stabilizers, and sustainability issues. The students were responsible for sharing results with their classmates, fostering collaborative interaction, building mock-up walls, and presenting the research project as a student design competition at the 2012 EPA P3 Expo in Washington, DC, which resulted in a $90,000 award for Phase II funding. Students were also tasked with eventually producing construction documents in Fall 2012 for permitting in Spring 2013.

This research project has allowed students and faculty to actively compare traditional building materials to CEB pertaining to structural capacities (including lateral stability), thermal conductance and resistance, aesthetic qualities, sociologic stereotypes, acoustical abilities, embodied energy, carbon footprint, initial vs. life cycle costs, etc. To facilitate data collection across disciplines, the CEB team began a collaboration with the College of Engineering (COE) and their School of Civil Engineering and Environmental Science (CEES). The COE contributes use of Fears Lab, OU's Structural Engineering Laboratory and Research Facility, providing adequate space for mixing soil, working with admixtures, making and testing sample blocks, building mock-up panels, secure storage, potable water, shaded and enclosed areas, and ample space to load and unload materials. CEES helped develop lateral reinforcement methods using UV-resistant polypropylene geogrid (donated by TenCate Geosynthetics for wall testing and construction) typically used in stabilizing roadbeds and MSE retaining walls.

Analysis and comparison, based upon the existing house and proposed wood framed house, led the team to develop the exterior walls as double



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wythe CEB with exterior 2″ rigid extruded polystyrene insulation covered with fiber cement siding. This allows the CEB portion of the wall assembly to be the only variable determining the quantifiable data. Typically, the exterior walls of most CEB structures are a single entity, providing both the thermal envelope and structural strength of the wall. During future phases of CEB research, students will be challenged to develop specific wall configurations reacting to the local conditions and facing direction. The wall orientation to the sun, site temperature and humidity, and desired noise abatement will be considered in future wall assembly design. This may define the need for a cavity wall, trombe wall, or other concepts to address the variety of needs. Both the CEB and wood-framed residences are currently under construction with scheduled completion in December 2013. The OU research team is actively assisting CCHFH staff, community volunteers, and local contractors during all construction phases. The entire team has weekly formal meetings aside from various impromptu coordination discussions on site. Once construction is complete, the team will monitor the two residences for structural, thermal, acoustical, and energy consumption data comparisons between the two construction types. Results from the testing and data collection phases are expected late 2014 or early 2015.

CONCLUSION

Environmental sustainability has become a mainstream issue, profoundly affecting the architectural profession. This major shift in thinking has reaffirmed architecture schools' focus on the environment and materials which support healthy and functional spaces. Sustainable practices that were at the core of vernacular architecture increasingly provide inspiration for environmentally and socially sustainable contemporary techniques.[13] When technical expertise is woven within a creating and making pedagogy, ideas develop into tangible constructs. Students understand the physical nature of how materials are manufactured, processed, and assembled; providing a vital basis for sustainable design.

The theme overview from the ACSA's 100th Annual Meeting conference stated, "as history has taught us, a change in technological paradigm is rarely absorbed efficiently, or in an undisputed manner, even if its effects are profound or beneficial." [14] Earthen design and construction is perhaps both the support and antithesis of that statement. As a blatant embrace of basic environmental design, it is the disregard for perceived modernity yet

Figure 5: Left to right: Floor plan of typical CCHFH house reflecting double wythe CEB wall; and CCHFH site August 2013 showing existing house (left) and construction of both the new CEB residence (center) and new wood framed residence (right).

the flagrant attempt to reduce, reuse, recycle, and apply regional materials. Not many other building materials are older than dirt. We are in a fight for survival and ultimately need a paradigm shift from depletion to repletion. Perhaps the most overlooked resource is found right under our feet. Technological advances are critical to most aspects of design and construction, but we must not forgo a resource that is typically found on every construction site - soil.

Aside from the environmental benefits, designing and building with earth unites and simultaneously stimulates various social, political, and anthropomorphic relationships. Composing architecture requires attention to intellect, emotions, function, and form; yet a particular response to programmatic needs, climate conditions, sociologic issues, and countless other concerns relating to people, place, and materials. Building with earth may conjure images of poverty or developing nations that do not have access to other building materials, but it should not influence design or society's opinion as a whole. Focusing on how earth buildings react with temperature, humidity, and individual site parameters support or dispel any initial bias or opinions. Materials are the physical manifestation of the design idea defining how spaces relate, how people use the spaces, and how much energy is consumed, recycled, and perhaps (re)appropriated. Suddenly the wall assembly becomes the interface between interior conditioned space and the brutality of seasonal climates. Hence what works with one site may not work in another locale. Earthen construction literally (re)introduces people to earth and allows inhabitable spaces to be more physically comfortable, used more frequently through diurnal and annual climates, and redefine architecture as an effectual haven to inhabitants within local communities.

Academic and professional fields must disseminate earthen design and construction processes and results to establish best practices for a future that is better than the past. Students can learn much from studying CEB and determining how residential construction from earth will impact people, their prosperity, and the planet. The research, teaching, and production process may not always be linear or cumulative, but active hands-on approaches that facilitate multidisciplinary involvement is always fruitful. Collaboration among colleges and departments allows both students and faculty to learn from each other, collectively benefit from diverse research, and physically take part in constructing tangible components initiated in thought, word, and sketch.

Earthen design is a much-awaited return to nature. It also provides an answer to the necessity for responsible design, allowing the inhabitable space to perform more intelligently. As a previous ACSA conference topic session description stated, "when innovation is driven by necessity, design can move building technology beyond conventional resource and economic patterns." [15] Less is definitely more when evaluating the life cycle costs of materials and construction. If the U.S. takes the lead with safe, well-designed CEB structures, perceptions about earthen construction may change around the world and benefit global society. Perhaps the next time you see a "Dirt for Sale" sign near a job site or a dump truck hauling dirt away it will trigger an innovative thought to use the soil for sustainable architecture.

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