Earth Made Urban Living: Earthen Construction Materials and Techniques for Contemporary Housing

Robert Holton
Louisiana State University, Baton Rouge, Louisiana

ABSTRACT: *A recent press release by Freddie Mac states three major challenges the US currently faces: a sparsity of affordable housing, skilled laborers, and sustainable materials. A significant portion of the population across the US Gulf South region lacks access to affordable housing, a fundamental element to bringing down homelessness, developing employment opportunities, and encouraging economic prosperity.*
This 4th & 5th year studio concentrated on the potential of earthen construction materials and techniques, specifically compressed stabilized earth blocks (CSEBs) which are reasonably priced, widely available, and sustainable, as a potential resource to address present-day housing challenges. The aim was to develop design proposals focused on contemporary, cost efficient, urban housing for up to 40 families using earthen building technologies suitable for use in environments with a hot wet climate. Over the course of the semester, students engaged this challenge using virtual and hands-on techniques to develop design proposals constructed of earth block building assemblies. In congruence with explorations into site, program, organization, structure, enclosure, and systems, investigations into earthen property attributes, block design and fabrication methods, and wall erection strategies were happening at the same time. Working concurrently, students utilized both architectural representations (scaled drawings) and actual material mock-ups (full size building components and assemblies) to guide the design process. Prototype interlocking compressed earth blocks were designed and then fabricated using a CINVA-Ram manual press with inserts shaped to specific block forms. Earthen mixtures composed of varying percentages of silt, sand, clay, additives, and water were developed relative to the specific block geometries to minimize cracking and enhance structural performance. Following fabrication, the blocks were stacked, at varying orientations, into wall assemblies allowing students to test drawn design decisions and inform potential revisions to the proposed building enclosures.
Critical questions explored included: Are there by-products of regional industrial processes that are readily available, cost effective, and sustainable that could be used as an additive in the earthen mixture to strengthen CSEBs? How can CSEB walls be assembled to a consistent set of standards in communities that only have access to minimally trained constructors? How can CSEB walls, customary to hot dry central US regions, be modified to perform in hot wet coastal US regions dependent on air conditioning to reduce humidity and climatize interior spaces?
Students engaged questions critical to earthen construction materials and techniques for contemporary housing at multiple scales, simultaneously addressing inquiries into context/site/building and materials/components/assemblies. This diverse approach presented students an opportunity to explore in a boundless undefined manner, continually open to the influence of new discoveries through the iterative processes of drawing, fabricating, and assembling. Students worked in teams (2, 3, or 4 persons), engaged this challenge, using virtual and tactile techniques, and developed contemporary housing design proposals constructed of earth block assemblies. This was a very hands-on studio with approximately 50% of the time devoted to fabricating earth blocks, constructing block wall assemblies, and details.

KEYWORDS: Earth, Construction, Fabrication, Assembly, Housing

1. MOTIVATION
A recent press release by Freddie Mac states three major challenges the US currently faces: a sparsity of affordable housing, skilled laborers, and sustainable materials. (http://www.freddiemac.com/fmac-resources/research/pdf/Dec_Insight_Press_Release.pdf)

2. PROBLEM
A significant portion of the population across the US Gulf South region lacks access to affordable housing, a fundamental element to bringing down homelessness, developing employment opportunities, and encouraging economic prosperity.

3. APPROACH
This 4^{th} and 5^{th} year option studio concentrated on the potential of earthen construction materials and techniques, specifically compressed stabilized earth blocks (CSEBs) which are reasonably priced, widely available, and sustainable, as a potential resource to address present-day housing challenges. The aim was to develop design proposals focused on contemporary, cost efficient, urban housing for 30 to 40 families using earthen building technologies suitable for use in environments with a hot/wet climate.

Are earth construction materials and techniques a contextually viable building alternative capable of addressing the numerous ecological issues of pressing concern in our contemporary society?

Over the course of the semester, students engaged this challenge using virtual and hands-on techniques to develop design proposals constructed of CSEB building assemblies. In congruence with explorations into site, program, organization, structure, enclosure, and systems, investigations into earthen property attributes, block design and fabrication methods, and wall erection strategies were happening at the same time.

3.1 Earthen property attributes and compositions

Commonly used around the world as an abundantly available building material for housing, earth is rarely considered as a viable contemporary option for construction in the US Gulf South. Developing an understanding of earthen property attributes and compositions was a critical first step to realizing the potential of earth as a modern construction material.

Sourced from Southern Louisiana, the earthen material was extracted from a depth of greater than 3 feet to establish a base mixture made up of non-organic particles. This was necessary to start with a consistent composition comprised of identifiable components which could be analyzed to ensure the structural stability of the earth blocks. The extracted soil was tested and plotted on a US Department of Agriculture soil classification map to establish if the mix percentages were within the guidelines suitable for construction (USDA 1999). Earthen mixtures, composed of varying percentages of silt, sand, and clay, vary widely from one location to another. Knowing the ratio of components is key to understanding how the material will perform in a particular context (Kumar et al. 2018). Composed of high percentages of sand and silt and a low percentage of clay the earth mixture was classified as a sandy loam. This classification was within the guidelines, but at the outer limits of acceptable compositions. The high sand percentage provided sufficient strength; however, the low percentage of clay reduced the ductility of the material.

To address the near sub-optimal composition of the earthen mixture varying percentages of stabilizer were tested to address potential structural and durability concerns. Both cement and lime were considered as possible stabilizers. Although the less sustainable alternative of the two options, cement was used to stabilize the earthen mixture due to availability and cost effectiveness. Lime would have been the superior sustainable choice and interestingly could have been produced from an abundance of locally available oyster shells. However, this time-consuming process was unfeasible given the constraints of the semester schedule. A range of compositions that included 5 to 15 percent cement in the earthen mixture were tested and formed into blocks. Ultimately most blocks included around 10 percent cement, a convenient balance especially when taking into consideration the straightforward mix ratios. Based on previous research, this amount of stabilizer was more than sufficient given the earthen material composition. However, due to the hot/wet Southern Louisiana environment, which receives over 60 inches of rainfall annually, the inclusion of a stabilizer would help ensure the durability of the blocks when exposed to these natural conditions. Intriguingly, the naturally high-water content in the atmosphere may be beneficial to the curing process and allow the strength of the blocks to continue to increase over a prolonged time, a phenomenon observed in previous research (Holton et al. 2018).

Preparing the earth to fabricate blocks required reducing the particle sizes to less than ¼ inch. This was achieved through a process of hand pounding the material in a mixing tub with rubber mallets and then passing it through a metal screen. The reduced particle size allows for the earth to be more evenly mixed with the stabilizer while also increasing the surface area and yielding greater cohesion when compressed in a mold. In addition, smaller particles produce more consistently dense blocks which perform better structurally and are less susceptible to weathering. Due to the low percentage of clay, which can be quite hard, this step was relatively efficient. Following crushing and sifting, the stabilizer was incorporated with the earth and these dry components were then combined with a ratio of 8 to 12 percent water (Fig. 1). This percentage fluctuated depending on how dry the earth was, amount of stabilizer used, and the level of humidity.

Figure 1: Multi step process to prepare the earth mixture for block fabrication. Source: (Author 2020)

In some cases, it was necessary to structurally compensate for specific block geometries through the inclusion of additives in the earth mixtures to minimize cracking and enhance structural performance. Block shapes with angles ranging from 45 to 90 degrees were especially susceptible to cracking during the drying process. The corners where also potential points of failure depending on their orientation when stacked in wall assemblies. To improve the performance of blocks with these geometric characteristics, especially L, T, and U shapes, a range of organic and non-organic fibers were tested. Depending on the overall size of the block, the most successful additives were hay, bagasse, and coconut. The fine bagasse and coconut fibers were easy to mix and functioned well in lighter weight small to medium size blocks under 12 inches, while the courser hay fibers responded suitably to the increased weight of larger blocks. In our location and for most block types, bagasse is the more sustainable alternative. It is a locally available by-product of the regional sugarcane crushing industrial process. The inclusion of the material as an additive helps to address the control of waste that would otherwise be burned.

3.2 Block design and fabrication methods

Prototype interlocking CSEBs were designed and then fabricated using a CINVA-Ram manual press with inserts shaped to achieve specific block geometries. Constructed out of ¼" thick plate steel, the manual press is primarily comprised of a compression chamber, cam action lever, and stabilizing legs. To fabricate a block; the earth mixture is placed in the chamber, the chamber pivot lid is closed, the lever is lifted from a horizontal position to a vertical position and engaged with the top of the lid. The lever is then returned to the same horizontal position to compress the block. After compression, the lever is lifted back up past the vertical position, the lid is opened, and the lever is placed in the opposite horizontal position to lift the block out of the press. This process produces a maximum 10"x6"x3" generic module size, a parameter of the press that presented a clear framework for the students to work within (Holton et al. 2018). Inserts of varying shapes were developed to place within the manual press compression chamber along with the earth mixture to modify the geometry of the generic module size (Fig. 2). A primary goal was to develop interlocking block forms that would allow the CSEB walls to be more easily assembled to a consistent set of standards. This objective is especially important for building in communities that only have access to minimally trained constructors.

Figure 2: Compression chamber with insert, adding the earth mixture, and compressing the block. Source: (Author 2020)

Initial insert design strategies focused on primarily modifying the top and bottom 10"x6" block surfaces with a centrally located projection on one side and recess on the other. These modifications, typically in the shape of a circle, square, or cross allowed the blocks to interlock in a stacked pattern (Fig. 3). To achieve a greater variety of possible bond patterns double projections and recessions, one on each half of the 10"x6" surfaces, were developed (Fig. 3). The increased number of projections allowed the blocks to interlock when overlapped in a running pattern. This strategy also allowed the blocks to interlock when placed perpendicular to one another, an effective technique to secure wall assemblies with corners and/or multiple wythes.

Continuing to expand on the potential relations between juxtaposed blocks, the use of interlocking projections and recessions with unequal dimensions were investigated. The iterations tested included a design with double circle projections on one block face and a continual lozenge cross recession on the opposing face. This provided a loose fit between blocks while still allowing them to interlock, further expanding the potential relationship between blocks from solely orthogonal to an almost infinite array of non-orthogonal patterns.

Figure 3: Geometric refinements: single cross, double cross, double cross & edge. Source: (Author 2020)

Elaborating on these interlocking stretcher and header block orientations, additional inserts were developed for the 10"x3" and 6"x3" surfaces. This further geometric refinement of the double cross on the 10"x6" block surface along the 3" faces made it possible to also interlock the blocks when placed in a rowlock or rowlock stretcher orientation (Fig. 3). In another iteration, additionally focused on the smaller block faces, a continuous 90-degree tongue and groove interlocking ridge and channel were investigated. The uninterrupted nature of this system allowed for shifting and/or sliding configurations that had the potential to incorporate voids of varying sizes between adjacent blocks. With this interlocking strategy the blocks could be potentially placed in a soldier or sailor orientation, adding to the range of possible adjacencies explored in the student's investigations.

In concurrence with these explorations into geometry, working hands-on, fabricating the blocks, was equally challenging. Making and using the inserts was very much a trial-and-error process. Taking into consideration available equipment and resources, cost effectiveness, and time constraints the inserts were fabricated out of wood. Depending on the intricacies of the geometry the type of wood used played a crucial role in the durability of the insert. Simple forms could be constructed out of a medium to heavy grained hard or soft wood while complex forms were more successfully constructed from medium-density fiberboard to prevent cracking. Of course, craft, precision, and overall quality of the constructed insert were essential to fabricate blocks with accurate dimensions, a necessary attribute to properly interlock (Fig. 4). This proved especially difficult when attempting to construct circular and angular forms, or rounded edges.


Figure 4: Removing the insert from the press and unmolding the block. Source: (Author 2020)

The use of inserts to shape the block modules also added unforeseen complications to the fabrication process. Due to the increased surface area of the forms, the unmolding and insert removal process became more complicated, initially producing torn, cracked, warped, and damaged results. To reduce adhesion between form and block an assortment of surface finishes ranging from several layers of high gloss paint to plastic coated films and tapes were tested. Along with the use of a release agent, such as oil or silicon spray, the unmolding process was fine-tuned and became consistently successful (Fig. 4). Of note, in some cases, the relative humidity from one day to the next could be an additional factor and influence the unmolding process. Ultimately, working through multiple iterations, students gradually refined the inserts and expanded the ways in which the resulting CSEBs could be interlocked and oriented.

3.3 Wall erection strategies

Following fabrication, the blocks were stacked, at varying orientations, into wall assemblies allowing students to test design decisions and inform potential revisions to proposed building enclosures. Like the fabrication phase, bringing the blocks together in a unified construction was very much a trial-and-error process. Erecting walls that were straight in plan and section with level courses was a primary concern to achieve structurally stable assemblies. The block building sequence of dry stacking, unstacking, reorienting, and restacking was repeated multiple times to find the most secure placement for each module. This methodical succession of steps, primarily due to the imperfections of the handmade blocks, was necessary to achieve assemblies as safe and secure as possible. Numerous plan configurations, linear, two linear segments connected by a 90-degree corner, and curved, were tried to find the soundest arrangement for each unique block type. Typically, a corner or curved plan resulted in the most well-built assemblies, however, these organizations were only possible with some of the interlocking block CSEB geometries (Fig. 5).

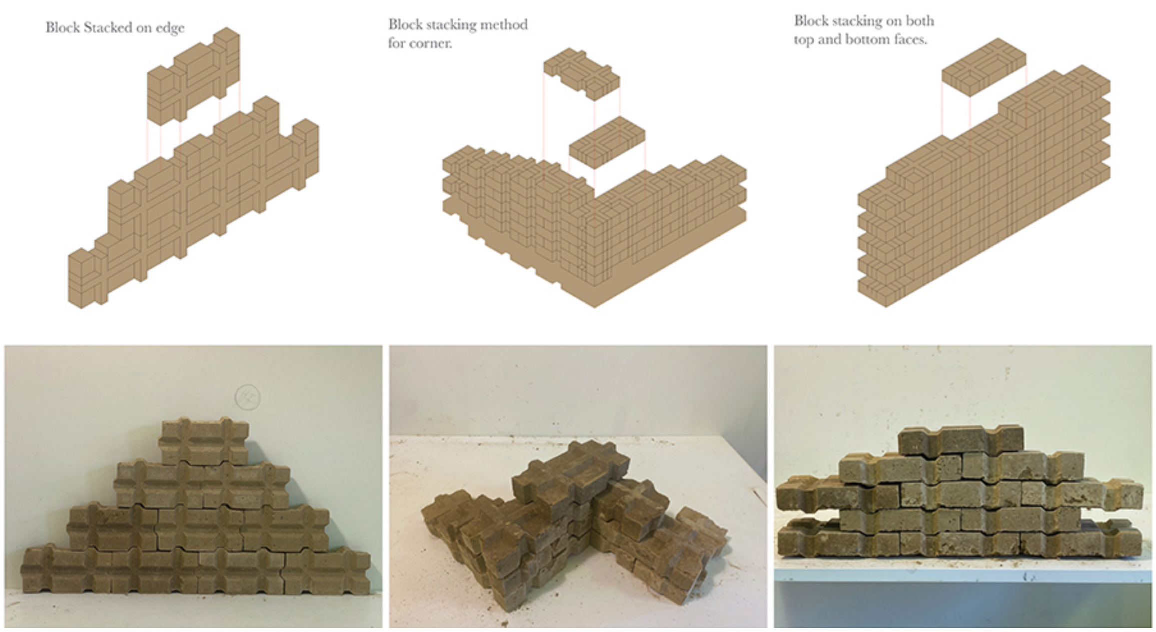

Figure 5: CSEB wall configurations. Source: (Author 2020)

Although most test builds remained as dry stacked assemblies, varying block adhesion strategies were explored. Mortar, masonry adhesive, and concrete with steel reinforcing were all viable options. In response to the material composition of the blocks, a mortar mixture of earth, sand, and cement was used for the assembly mock-ups. Much the same as the CSEBs, the inclusion of cement had the benefit of increasing the strength and durability of the mortar even though a greater percentage was necessary to achieve an appropriate level of solidity. The incorporation of sand also added to the overall strength of the blend. Working with the mortar presented many challenges for first time or minimally trained constructors. Even though the material ratios were carefully measured it proved difficult to bring the combination of constituents to an even and consistently dense mixture. These complexities resulted in mortar that would often have minimal adhesion to the block face and inconsistent thickness between block surfaces. Despite the fact it was the messiest and least predictable operation in the whole fabrication and assembly process, using the earth sand cement mortar to adhere the CSEBs was a critical step to understanding the potential capacities of this building technique.

Working concurrently, students utilized both the material mock-ups (full size CSEB building components and assemblies) and architectural representations (scaled drawings) to guide the design of assemblies for multi-story contemporary urban housing proposals. As is often the case in urban sites, the size of the lot required a multi-level vertical structure to accommodate the 30 to 40 family living units outlined in the program. Taking into consideration the site constraints and depending on the organization of each proposal, the building designs would need to rise 70 to 100 feet in height. To accommodate the structural loads and forces commonly affiliated with mid-rise typologies it was necessary to explore novel hybrid approaches to reinforce the primary building material, the CSEBs.

Three main approaches to the structural system were examined: a concrete frame, a steel frame with cantilevered trusses, and concrete load bearing walls. In the concrete frame system, the one most typically associated with multi-story housing projects, the CSEBs were used as formwork for the columns. Inspired by the Roman constructions at Ostia Antica, where masonry was used as permanent formwork for concrete walls, this strategy proposed CSEBs stacked into hollow columns for concrete to be poured into. The blocks would bind to the concrete, remain in place, and reduce overall amount of concrete normally used for this type of construction (Fig. 6). The steel frame system, influenced by large scale bridge structures, proposed a central super structure around the building core with cantilevered trusses supporting CSEB clad living units. In this scheme the perimeter of each block wall would be supported by steel plates on four sides to form a solid wall element that could be hung from and anchored to the cantilevered steel trusses. Comparable to the concrete frame system, the concrete load bearing wall design also proposed to use the CSEBs as formwork that would remain permanently in place. In this scenario the compressive strength of the blocks would work in tandem with the concrete to help support and distribute the building forces (Fig. 6).

In addition to the structural systems each of the design proposals used CSEB partition walls, spanning up to 10 feet in height, to enclose individual programmatic spaces. Unencumbered by the need to transfer building loads these lighter and thinner block wall assemblies engaged several environmental and social topics. Depending on the program of a particular area, walls of varying porosities were developed that allowed for natural ventilation and light. Similarly, contingent on the public/private character of the program, these openings also provided for visual and audible connectivity between spaces. This potentially endless variation in pattern and texture, made possible by modifying the module spacing and orientation, articulated the scale and expressed the unique capabilities of the CSEBs as a building material and the wall surfaces, they composed.

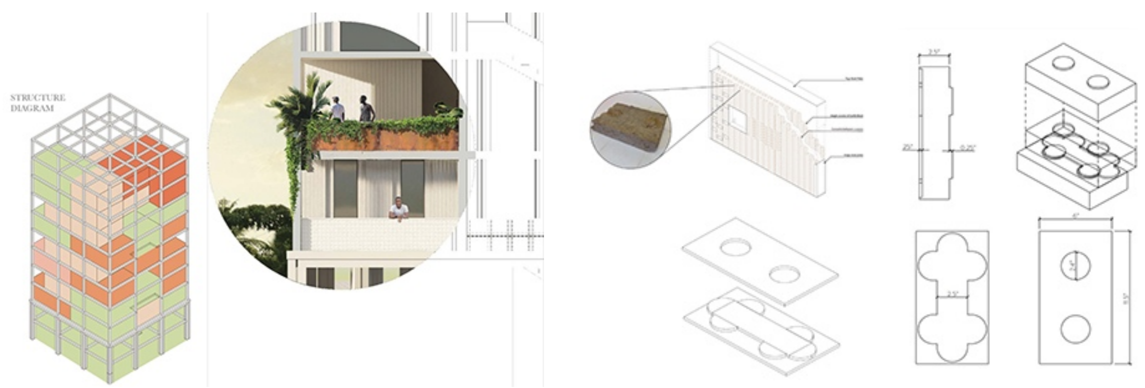

Figure 6: Frame and load bearing wall structural systems. Source: (Author 2020)

4. RESULTS

Students engaged questions critical to earthen construction materials and techniques for contemporary housing at multiple scales, simultaneously addressing inquiries into context/site/building and materials/components/assemblies (Fig. 7).

Questions explored included:

Is it feasible to use locally available earthen materials, composed of varying ratios of silt, sand, and clay, to build enduring structures in a hot/wet environment?

Are there by-products of regional industrial processes that are readily available, cost effective, and sustainable that could be used as an additive in the earthen mixture to strengthen CSEBs?

How can CSEB walls be assembled to a consistent set of standards in communities that only have access to minimally trained constructors?

How can CSEB walls, customary to hot/dry central US regions, be modified to perform in hot/wet coastal US regions dependent on air conditioning to reduce humidity and climatize interior spaces?

This was a very hands-on studio with approximately 50% of the time devoted to fabricating earth blocks, constructing block wall assemblies, and details. This diverse approach presented students an opportunity to explore in a boundless undefined manner, continually open to the influence of new discoveries through the iterative processes of drawing, fabricating, and assembling. Students worked in teams of 2 or 3 members, engaged this challenge, using virtual and tactile techniques, and developed contemporary housing design proposals constructed of earth block assemblies. The resulting fabricated blocks, constructed wall assemblies, and mid-rise housing designs attest that earth is a viable building material for use in an array of building types that span various scales and meet the expectations of a contemporary way of living. The project proposals verified that earth construction materials and techniques have the capacity to effectively engage and positively respond to the very important present-day questions of contextually viable and sustainable resources and how these commodities are utilized in a socially beneficial and ecological way (Fig. 7).

Figure 7: Earthen construction for contemporary housing. Source: (Author 2020)

5.0 References

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