Earth Construction: Alternative Building Strategies for More Equitable Housing

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Abstract

Objective:

The US Gulf South is currently experiencing a housing crisis that has been intensified by increasingly severe storms fueled by climate change, the high cost of industrialized building materials, and a shortage of construction workers. Can locally available materials such as cost effective and sustainable earthen mediums, which are often overlooked compared to more industrialized materials, be utilized by minimally trained individuals to construct enduring residential structures suitable to hot wet climates?

Methodology:

Maintaining the practices of our current building culture, dependent on unsustainable and cost prohibitive building materials and techniques, will only continue to make housing matters worse and disenfranchise many individuals across the region. This situation requires a consequential shift in how we think about building to help alleviate the impacts of unavailable or unsuitable housing on the well-being of our community. Sourced from locally available materials, earthen building mediums and techniques have the potential to offer a sustainable and cost-effective alternative approach to our current dependency on ineffective building habits. Compressed earth blocks have been proven to be a viable building material for use in the US Gulf South, however traditional masonry assembly techniques using mortar rely on specialized constructors that are expensive to employ and are in short supply. Working in teams of 3 to 4, architecture students were presented with this scenario and tasked with the challenge of developing interlocking earth blocks and mechanically fastened block wall assemblies buildable by individuals with minimal to no construction experience. Taking into consideration the performance of different material mixes (local soil, natural additives, and water) from previous inquiries, preliminary block shapes and how they could fit together into wall assemblies were designed. To assess the proposed designs, molds were built and tested by fabricating earth blocks. This was very much a trial-and-error process with modifications being made to the block shape, mold, and mix ratios after the initial experiments. A critical consideration in each of the block designs was understanding how the modules would be mechanically fastened into a wall assembly. To incorporate various types of fastening devices, voids were placed in the blocks during the fabrication process using PVC pipe placed either horizontally or vertically in the mold. After the molds were refined, each student team fabricated between 50-70 earth blocks depending on the size of the individual modules. The goal was for the students, novices at masonry construction, to construct structurally sound wall assembly designs mechanically fastened together without the use of mortar.

Achieved Outcomes:

Structurally feasible prototype wall assemblies composed of mechanically fastened earth blocks were designed and constructed by the student teams. Through testing,

analyzing, and carefully considering issues of precision, mechanically fastened interlocking earth block wall assemblies offer a readily accessible and economic way of building in the US Gulf South. This method of construction offers a viable alternative to our current, unsustainable, building practices reliant on industrialized building materials. Supported by the design, fabrication, and assemblies built by the student teams, earthen mediums can be utilized by minimally trained individuals to construct enduring residential structures suitable to the US Gulf South hot wet climate.

1.0 Objective:

The US Gulf South is currently experiencing a housing crisis that has been intensified by increasingly severe storms fueled by climate change, the high cost of industrialized building materials, and a shortage of construction workers. Can locally available materials such as cost effective and sustainable earthen mediums, which are often overlooked compared to more industrialized materials, be utilized by minimally trained individuals to construct enduring residential structures suitable to hot wet climates?

2.0 Methodology:

Maintaining the practices of our current building culture, dependent on unsustainable and cost prohibitive building materials and techniques, will only continue to make housing matters worse and disenfranchise many individuals across the region. This situation requires a consequential shift in how we think about the future of building to help alleviate the impacts of unavailable or unsuitable housing on the well-being of our community.

Sourced from locally available materials, earthen building mediums and techniques have the potential to offer a sustainable and cost-effective alternative approach to our current dependency on ineffective building habits. Compressed earth blocks have been proven to be a viable building material for use in the US Gulf South, however traditional masonry assembly techniques using mortar rely on specialized constructors that are expensive to employ and are in short supply (Holton 2024).

Working in teams of 3 to 4, architecture students were presented with this scenario in a three-hour lab course and tasked with the challenge of developing interlocking compressed earth blocks and mechanically fastened block wall assemblies buildable by individuals with minimal to no construction experience.

2.1 Earth Compositions and Property Attributes:

To begin this investigation students were introduced to the unique compositions and property attributes associated with locally sourced soil as well as the regional building customs of the US Gulf South. An abundantly available resource, earth is commonly used around the world as a building medium. Nevertheless, it is almost not at all considered for construction in the US Gulf South, a region dependent on industrialized building materials and techniques. To identify the unfulfilled capacity of earth as a building material, students learned about the distinct regional characteristics of the material (Kumar et all. 2018). Tests showing the makeup of earth samples from South Louisiana were presented and evaluated to see if the material was suitable for building using a US Department of Agriculture soil classification chart (USDA 1999). Samples taken at two locations varied compositionally, one was classified as a sandy loam (high amounts of sand, low amounts of clay and silt) and the other a silty clay (medium amounts of clay and silt, low amounts of sand). Both soils were categorized on the margin but within the acceptable range of materials appropriate for building.

2.2 Earth Block Design, Fabrication, and Wall Assemblies:

Taking into consideration the performance of different material mixes (local soil, natural additives, and water) from previous inquiries, preliminary block shapes and how they could fit together into wall assemblies were designed (Holton 2023). To assess the proposed designs, molds were built and tested by fabricating earth blocks. This was very much a trial-and-error process with modifications being made to the block shape, mold, and mix ratios after the initial experiments. A critical consideration in each of the block designs was understanding how the modules would be mechanically fastened into a wall assembly. To incorporate various types of fastening devices, voids were placed in the blocks during the fabrication process using PVC pipe placed either horizontally or vertically in the mold. After the molds were refined, each student team fabricated between 50-70 earth blocks depending on the size of the individual modules. The goal was for the students, novices at masonry construction, to construct structurally sound wall assembly designs mechanically fastened together without the use of mortar.

2.2.1 H Shape Earth Block and Wall Assembly Example:

Design - Block, Wall, and Mold: Based on a 4” module, the block design was 4” in height and width and 8” in length with a 2” diameter half round indention at the center. Two 1” diameter vertical holes were placed at each end to provide openings for internal fasteners. Initially the blocks were 3” in height, but this dimension was modified to increase the number of ways in which they could be stacked in a wall assembly.

The design of the H shape block wall assembly was made up of courses laid in a running bond pattern. Organized around the width of the bridge in the H shape, the blocks were set apart by a 2” gap. This placement aligned the vertical holes and provided a space for the system of mechanical fasteners. It also allowed for light and air to be filtered through the assembly (Fig. 1).

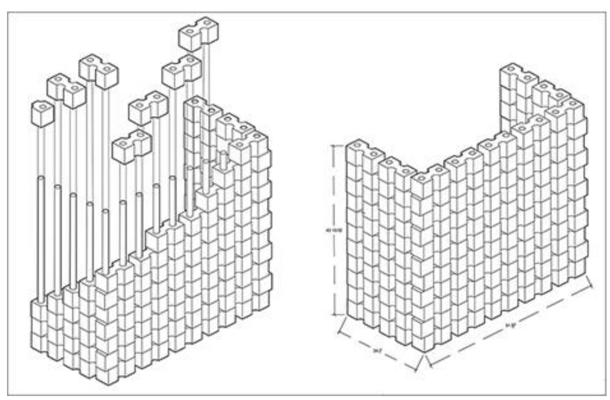

Fig. 1. H shape earth block and wall assembly design.

Constructed out of ¾" plywood, the mold design consisted of two 4"x16" side panels separated by 4"x4" end panels. Vertical supports for the end panels and a 2" diameter half round wooden dowel to form the bridge of the H were glued and screwed to the interior of the side panels. Two vertical 8" long PVC pipes 1" in diameter were located on the interior of the mold by a base plate with two holes that the pipes fit into. Open at the top, the mold components were fastened together with two 8" bolts at the end of the side panels (Fig. 2). To help facilitate the process of unmolding the blocks, the interior was painted to minimize the earth mixture sticking to the mold.

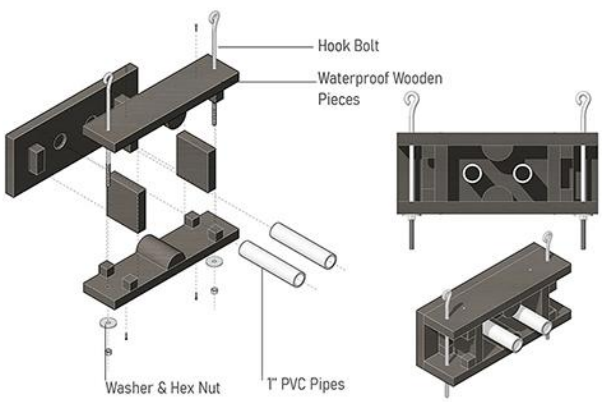

Fig. 2. H shape earth block mold.

Block Fabrication: The fabrication process of the H shape block started by pounding and sifting earth to a particle size not greater than ¼" in diameter. The earth was then mixed with a sand additive at a ratio of ten to one. Based on previous research, sand was added to increase the compressive strength and durability of the blocks. Also, from prior tests, due to the overall compact rectangular shape of the block it was determined that a fiber additive would not be necessary to reduce cracking that sometimes occurs in more complex shaped blocks (Holton 2024). Measured by volume, 10% water was added to the dry material and thoroughly mixed to an even consistency (Fig. 3). Before placing the earth mixture in the mold, baby oil was applied to the interior faces and PVC pipe to reduce sticking and help ensure

Fig. 3. Block fabrication – mixing the materials.

the finished block would be easily released with minimal distortions. From the open top side, the earth mixture was added to just over the top of the mold and then compressed with a flat board and a mallet. After compression, any excess material was scraped away, the top surface smoothed, and the mold unfastened and removed from the earth block (Fig. 4).

Fig. 4. Block Fabrication – molding the block.

The use of guidelines from previous research such as designing simple compact block shapes without complex angles, using additives to increase the strength and/or ductility, and applying a release agent to the interior faces of the mold significantly helped to facilitate a successful outcome (Holton 2024). Overall, the resulting quality of the blocks was good with a consistent regularity of shape and surface with minimal distortions. Achieving a high level of uniformity from one block to the next was especially important to accomplishing the objective of constructing a mechanically fastened block wall assembly with minimally trained individuals.

After the initial earth block production techniques were tested and refined, the student team began the systematic process of fabricating 80 to 90 earth blocks that would be incorporated into the wall assembly. Throughout the course of the fabrication process the ratio of the dry materials remained steady, however the percentage of water used in the mix slightly varied depending on how moist the soil was and the daily humidity levels. After unmolding, successfully fabricated blocks were placed on a shelf and stored 30 days in an airconditioned space.

Wall Construction: Due to dimensional and surface irregularities from one H shape earth block to the next, the process of placing the blocks was very provisional. The location of each block had to be tested with those in the previous course to make sure that the degree of surface contact, levelness, and stability were sufficient. After an initial mock-up was completed in the lab that met acceptable standards the wall was disassembled, the blocks were numbered and prepared to be reassembled at a specific site in the US Gulf South where their performance in the natural environment could be observed.

Fig. 5. Wall construction – foundation and anchor bolts.

The selected site for the earth block wall assembly was flat with little to no topographic variation to minimize the ground preparation. A foundation of five 4”x8”x16” solid CMU pavers was placed and leveled to lift the assembly off the ground which is often saturated with water in the winter season. The first course of earth blocks was temporarily placed on the foundation and the location of each interior hole was marked to position the anchors. A 2” deep x 3/8” diameter hole was drilled at each location to hold the 6” long x ¼” diameter all-thread anchors which were secured with anchoring cement. To attach the 42” all-thread rod that would run through the inside of the wall assembly coupling nuts were placed on the ends of the anchors (Fig. 5). The first course of earth blocks was then reinstalled and the 42” all-thread rod was fitted to the coupling nuts. Following the running bond pattern with a 2” space between the blocks each course was placed over the all-thread rod and carefully aligned with the previous course below.

At the top of the eleventh course, 44” above the foundation, washers were placed over the blocks with the all-thread rod passing through and then the entire assembly was fastened together with nuts (Fig. 6). The wall was finished with two additional courses held in place with construction adhesive to conceal the mechanical connection. However, the height of the wall could have been extended by adding another series of coupling nuts and all-thread rods.

Fig. 6. Wall construction – all-thread rod and fasteners.

Analysis: The completed H shape earth block wall assembly including the foundation blocks and finishing courses was 56” high x 38” wide with 14” returns at each end forming an S in plan (Fig. 7). The on-site process of assembling the earth block courses with mechanical fasteners into a wall by individuals with no prior training

Fig. 7. H shape earth block wall assembly.

was reasonably efficient. Predetermining the ideal location for each block in the lab and the absence of mortar significantly contributed to the timely and well-choreographed construction process. It will be interesting to see if this remains to be the case in the construction of future wall assemblies of greater scale and complexity. One issue may be the rigid nature of the 42" long all-thread rod which will require scaffolding or a ladder to place block courses as subsequent rod lengths are attached to achieve greater heights. The necessity to continue to refine the tolerances of the earth blocks will also become an issue as the height of the wall assemblies increases. When viewed in elevation it is evident that a few courses are slightly out of level, a condition that would become more extreme as the assembly increases in height. The inclusion of shims between the blocks may resolve this issue to some degree but would include an additional step in the assembly process. Structurally, after tightening the nuts at the end of the all-thread rods the whole assembly was remarkably secure and did not deflect when substantial lateral force was applied. It will be interesting to see how future wall assemblies of greater size with multiple series of coupling nuts and lengths of all-thread respond to similar and exceedingly stronger forces. However, even taking into consideration these potential likely hurdles as mechanically fastened earth block wall assemblies get closer to building scale, the prototype H shape earth block and wall assembly makes considerable accomplishments towards achieving the objective.

In addition to the H shape type, some of the other earth block and wall assembly designs were based on Duck, Bow Tie, and Zig Zag shapes. Following a similar process, each of these shapes and the resulting assemblies evolved over many iterations to confront unforeseen issues, adjust, and ultimately build the final wall.

2.2.2 Duck Shape Earth Block and Wall Assembly Example:

The design of the Duck shape earth block and wall assembly was also based on a 4" module with overall dimensions of 4"x8"x12" for each unit. Wall assembly courses were laid in a stacked bond pattern without any spaces between the blocks. The mold had a similar four-part design but notably oriented the internal PVC pipe in a horizontal position (Fig. 8).

Fig. 8. Duck shape earth block fabrication.

Block fabrication included 10% cement in the material composition to increase the compressive strength and compensate for the geometric shift of the shape (Holton et all. 2018). The wall construction was mechanically fastened with PVC pipe that was epoxied to a wooden base at the bottom and ran continuously through the assembly to the top course. Once finalized the Duck shape earth block wall assembly was 48" high x 36" wide with 8" returns (Fig. 9). The overlapping placement of the blocks in a stacked bond without gaps created a wall with a very solid appearing surface. The horizontal orientation of the PVC pipe in the mold produced consistent, flat, and smooth surfaces to stack the blocks. This resulted in courses that were more level and had a greater degree of accuracy compared to the H shape blocks. The shifting geometric shape of the block occasionally resulted in cracking along the center that may have been resolved with a fine grain fiber such as bagasse in the material mixture (Holton 2024).

Fig. 9. Duck shape earth block wall assembly.

2.2.3 Bow Tie Shape Earth Block and Wall Assembly Example:

The Bow Tie shape earth block and wall assembly was designed around a 7"x10"x14" unit which was the largest size tested. Courses of the wall assembly were laid in a stacked bond vertically, but due to the geometry of the blocks produced an offset running bond pattern across the surface horizontally. The mold had a six-part design that included top and bottom panels to produce the three-dimensional shape of the block. Like the Duck shape block, the mold oriented the internal PVC pipe in a horizontal position (Fig. 10). Due to the compact nature of the geometry, the material mixture to fabricate the blocks consisted of only earth and water. The wall

Fig. 10. Bow Tie shape earth block fabrication.

construction was mechanically fastened with ¼" diameter all-thread rod like the H shape block. Due to the reduced height, only a single vertical rod was needed to secure the assembly compared to multiple links coupled together. The constructed Bow Tie shape earth block and wall assembly measured 42" high x 56" wide with 18" corner returns (Fig. 11).

Fig. 11. Bow Tie shape earth block wall assembly.

The three-dimensional block geometry and offset vertically stacked courses yielded a wall with a deep surface texture. Although the same fabrication technique of orienting the PVC pipe horizontally as the Duck shape blocks was used, the large overall size of the blocks produced very inconsistent shapes. Greater drying times were also required due to the increase in mass of the blocks.

2.2.4 Zig Zag Shape Earth Block and Wall Assembly Example:

The design of the Zig Zag shape earth block and wall assembly was based on 4”x8”x14” units. Initiated by the geometry of the blocks, the stacked bond courses of the wall assembly undulate in plan. Like the Bow Tie shape blocks, the mold had a six-part design with top and bottom panels to produce complex three-dimensional interlocking blocks (Fig. 12).

Fig. 12. Zig Zag shape earth block fabrication.

Block fabrication included 10% coir in the material composition to reduce cracking and help bind the intricate interlocking tabs with the main mass. In this case the wall construction relied solely on the interlocking tabs and grooves to hold the assembly together, mechanical fasteners were not used. The final Zig Zag shape earth block and wall assembly was approximately 30” high x 42” wide and 12” deep (Fig. 13). The 90-degree orientation of the blocks to one another made the wall appear to advance and recede with a pronounced change in light across the surface. The complex mold necessary to form the interlocking shapes made it difficult to evenly place the earth mixture and unmold the blocks. Consequently, the overall production of each block took the longest amount of time and resulted in the reduced size of the final wall assembly. The coir fiber additive was essential to successfully fabricating the blocks which were the most geometrically complex of all the shapes produced.

Fig. 13. Zig Zag shape earth block wall assembly.

3.0 Achieved Outcomes:

Structurally feasible prototype wall assemblies composed of mechanically fastened earth blocks were designed and constructed by the student teams. Through testing, analyzing, and carefully considering issues of precision, mechanically fastened interlocking earth block wall assemblies offer a readily accessible and economic way of building in the US Gulf South. This method of construction offers a viable alternative to our current, unsustainable, building practices reliant on industrialized building materials. Supported by the design, fabrication, and assemblies built by the student teams, earthen mediums can be utilized by minimally trained individuals to construct enduring residential structures suitable to the US Gulf South hot wet climate.

4.0 Notes:

Holton, R. (2024). “Earth Construction: Building Techniques Toward a More Equitable Architecture”, Earth USA Conference, Santa Fe, New Mexico.

Holton, R. (2023). “Earth made urban living: earthen construction materials and techniques for contemporary housing”, Building Technology Educators Society Conference, Scottsdale, Arizona.

Holton, R., Barbato, M., and Kumar, N. (2018). “Resilient & Affordable Housing for the US Gulf South: Earthen building materials re-appropriated for use in hot wet climates”, Architecture Research Centers Consortium Conference, Philadelphia, Pennsylvania.

Kumar, N., Barbato, M., and Holton, R. (2018). “Feasibility Study of Affordable Earth Masonry Housing in the US Gulf Coast” *Journal of Architectural Engineering*, American Society of Civil Engineers.

USDA (1999). Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys, US Dept. of Agriculture, Soil Conservation, Washington, DC, US.