Resilient & Affordable Housing for the US Gulf Coast:

Earthen building materials re-appropriated for use in hot wet climates

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ABSTRACT:

Objective:
Southern Louisiana is currently under great pressure to increase the quantity of resilient and affordable housing available within its local communities. Can earthen building mediums traditionally used in hot dry climates be re-appropriated for use in hot wet climates to help address this need?

Methodology:
In our current period of climate change, unpredictable events have and will continue to displace thousands of residence in the coastal region of Louisiana. This historic unseating of entire communities necessitates a reconsideration of standard housing solutions. Constructed primarily of materials accessible from the building site, compressed stabilized earth block design and building techniques offer an economical and sustainable approach to the current increase in demand for weather resistant housing.
To investigate the composition of earthen material in Southern Louisiana, a United States Geological Survey soil classification map and chart were consulted to identify locations of different regional soil types. Several locations in the area proved to be potential sites being composed of material that fell within the guidelines for soil compositions suitable to making compressed stabilized earth blocks. Forming the tested soil into earth blocks was realized by fabricating a manual block press to produce the 10” x 6” x 3” modules. Varying mixtures with differing percentages of cement, the stabilizing agent, were formulated to test how the stabilizer influenced the blocks strength and durability. After curing for 28 days, blocks were tested for resistance to compressive and tensile forces with successful results in line with building regulations of hot dry areas.

Achieved outcomes:
In response to the need for affordable, climate responsive, housing in coastal Louisiana single-family prototype designs were then developed using compressed stabilized earth blocks as the primary construction element. The critical demand for housing in regions around the gulf coast has been recently documented in the article, *Resettling the First American ‘Climate Refugees’* by Coral Davenport and Campbell Robertson published in the New York Times on May 3rd 2016. The article, focusing on Isle de Jean Charles located along the Louisiana gulf coast, details the experience of resettling local residents due to flooding. Unfortunately, this phenomenon of water inundation is more than an isolated event. In August 2016 thousands of residents across southern Louisiana were displaced by severe flooding, a likely outcome of climate change. The need for affordable housing for the numerous families driven out of their homes, as well as for other low-income families, is an essential and pressing concern for the region.

Through the novel use of engineered earth blocks in a hot wet environment and an awareness of local contextual parameters, the prototype designs offer an affordable, resilient, and sensitive way to bring about housing for the many individuals in need. From our research we have concluded that it is feasible to re-appropriate earthen building materials found in hot dry climates to construct enduring structures responsive to a hot wet environment.

KEYWORDS: Affordable, Sustainable, Housing, Climate-Change

1.0 OBJECTIVES:

The US Department of Housing and Urban development recently published data showing that almost 400,000 low-income households in Louisiana are in need of affordable housing (LHFA. 2010). The critical demand for housing in regions around the gulf coast has been recently documented in the article, *Resettling the First American 'Climate Refugees'* by Coral Davenport and Campbell Robertson published in the New York Times on May 3rd 2016. The article, focusing on Isle de Jean Charles located along the Louisiana gulf coast, details the experience of resettling local residents due to flooding. Unfortunately, this phenomenon of water inundation is more than an isolated event. In August 2016 thousands of residents across southern Louisiana were displaced by severe flooding, this disaster impacted entire neighborhoods and caused an enormous financial hardship at both a state and local level. To this day, many individuals forced out of their home due to the flooding have yet to return to adequate living conditions. The need for affordable housing for the numerous families driven out of their homes after natural disasters is an essential and pressing concern for the region. Southern Louisiana is currently under great pressure to increase the quantity of resilient and affordable housing available within its local communities, not only in response to population displacement after severe hurricane events, but also for large portion of the low-income families that cannot afford adequate housing at the current marketplace cost. Can earthen building mediums traditionally used in hot dry climates be re-appropriated for use in hot wet climates to help address this need?

2.0 METHODOLOGY:

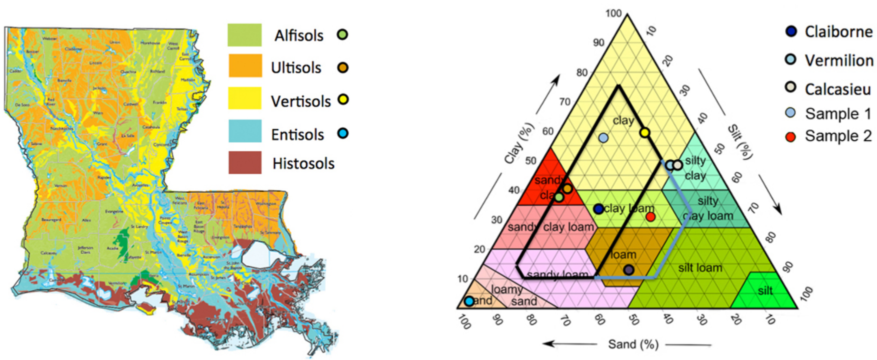

Figure 1: Louisiana soil textural classification map (left) and soil composition chart (right). Source: (US Dept. of Agriculture)

2.1. Soil composition

To investigate the composition of earthen material in Southern Louisiana, a US Dept. of Agriculture soil classification map and chart were consulted to identify regional soil types and compositions (Fig.1) (USDA 1999). A further understanding of the ground makeup was achieved by collecting samples from depths of 40 to 80 inches. It was necessary to extract the soil from this depth to ensure a uniform consistency of the material and minimize the amount of organic components. These samples were analyzed by performing cigar and jar tests to see if the soil possessed the necessary qualities to be made into earth blocks (Fig. 2) (Kumar et al. forthcoming 2018). Following successful testing, additional lab tests were undertaken to further analyze the suitability of the soil. The results from both sieve and hydrometer testing substantiated that the soil was composed of material that fell within the guidelines for soil compositions suitable to making compressed stabilized earth blocks (Fig. 2) (Kumar et al. forthcoming 2018).

Figure 2: Soil sample analysis: cigar test (left), sieve test (center), and hydrometer test (right). Source: (Author)

2.2. Modular components

Forming the tested soil into earth blocks was realized by fabricating a manual compression block press capable of producing 10” x 6” x 3” modules. The press was constructed of plate steel to withstand the forces exerted when compacting the soil. A cam mechanism was used to compress the soil when the lever was positioned to one side and then lift the compressed block from the mold when positioned on the other side. The press design was modified several times in response to performance demands and safety concerns. Fabrication of the blocks was a multi step process including preparing the soil, mixing ingredients, pressing the materials, and curing (Fig. 3). Soil preparation followed a process of removal from the site, dehydration for several days in a conditioned environment, crushing to a relatively fine grain, and then passing it through a 1/4” screen to achieve a particle like consistency. All materials were weighed, measured, and recorded in preparation of specific ratios. The idea was to develop several unique mixes that could be tested for comparable strengths and weaknesses at a later time. An electric concrete mixer evenly unified the three main ingredients: soil, cement, and a reactive agent. The mixture was then placed into the press and compressed into the module block form and lifted out with the cam action of the machine. Varying mixtures with differing percentages of cement, the stabilizing agent, were formulated to test how the stabilizer influenced the blocks strength and durability. Post fabrication the blocks were cured using both the covered wet and open-air dry methods.

Figure 3: Multi-step compressed stabilized earth block fabrication process. Source: (Author)

2.3. Component Testing

After curing for 28 days, the blocks were tested for resistance to compressive and tensile forces in a controlled environment (Kumar et al. forthcoming 2018). Using consistently calibrated lab equipment, the blocks of varying cement content were mechanically put under pressure to determine their average strength. In addition, each of the block types were tested in a dry state and after an extended exposure to moisture. The minimum strength requirements stipulated in the New Mexico code were used as a standard to evaluate the results (NMAC 2009). Blocks with around 10% cement composition produced successful results that fell in line with the building regulations used in hot dry areas (Kumar et al. forthcoming 2018).

Figure 4: Earth block wall components and construction: earth blocks (right), wall during construction (center), and completed wall (right). Source: (Author)

2.4. Component Assemblies

To better understand how the blocks would perform over time in the hot wet climate of the Mississippi Delta, a wall measuring 48” x 36” x 6” was built on an exterior concrete foundation running from the east to the west (Kumar et al. forthcoming 2018). Made of 40 blocks, the constructed earth wall was 10 rows of 4 blocks each and bound together with a mortar mixture of soil and cement similar to the block composition (Fig. 4). After construction, half of the blocks in the wall were left exposed to the natural weather conditions and half were protected from the environment with a 1/16” thick cement coating. The wall construction was openly exposed to the natural weather conditions for a period of six months, enduring several severe storms with heavy rain and high winds (Fig. 5). On a weekly basis, the wall was inspected and photographs were taken to develop a comparative weathering analysis over time. After the exposure period, the coated side of the wall remained structurally intact with no degradation. The unprotected blocks experienced some surface erosion with the top course and connective mortar showing the most wear. To test the structural strength of the blocks after exposure to the weather, the wall was disassembled and the blocks from both sides were reanalyzed in the testing lab. The results revealed that the protected blocks actually gained strength over time, as the soil-cement mix continued reacting (Kumar et al. forthcoming 2018). After testing blocks exposed to the climate and local weather conditions, compressed stabilized earth blocks appear to be a building material suitable to the rigorous demands of a hot wet environment if a proper protection is provided.

Figure 5: Earth block wall weathering, one month (left) & six month (right) durations. Source: (Author)

2.5. Housing

In response to the need for affordable, climate responsive, housing in coastal Louisiana, single-family prototype designs were developed using compressed stabilized earth blocks as the primary construction element. A thorough precedent analysis was developed in the goal of understanding community values and standards. In appreciation of the rich cultural heritage and environmental context of the gulf coast, the prototype housing designs embrace many qualities inherent to local vernacular architecture. The vernacular architecture, made up of Creole and Acadian influences, presents a heritage of building types composed of common elements that evolved from living in a hot wet climate (Edwards 2004). Fundamental aspects, incorporated into the housing designs, include deep porches, high ceilings, floor to ceiling openings, raised ground floors, and program specific room volumes all help to facilitate air movement by means of passive cross ventilation. Multiple design iterations were explored developing both traditional and non-traditional organizational compositions composed with the vernacular components.

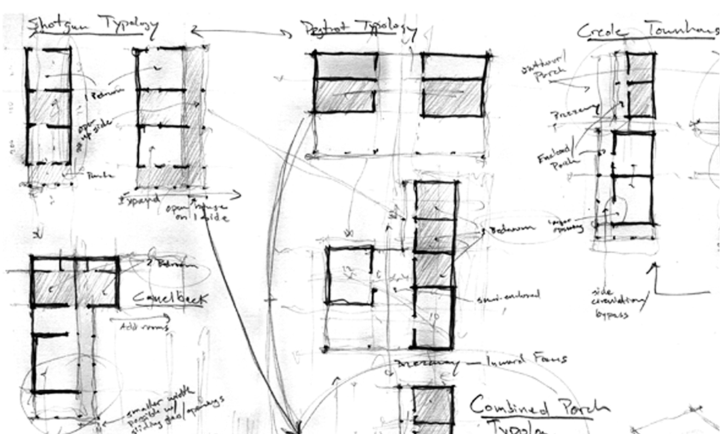

Figure 6: Precedent analysis and iterative design process sketches. Source: (Author)

2.6. Architectural typologies

Two significant housing types, the shotgun and the dogtrot (Edwards 2004), which utilize passive ventilation systems, were influential in the design of the single-family prototypes. Both the shotgun and dogtrot typologies have evolved from traditional regional influences and offer relevant design strategies for living in the local environment. These housing types represent optimal solutions to obtain comfortable dwellings through natural airflow even in the hot humid weather of Southern Louisiana. The shotgun type, based on customs of the Creole citizens who migrated from Haiti, has an organization based on 3 to 5 rooms in a row. The linear arrangement allows for efficient cross ventilation in every room. The main body of the shotgun type has an added outward facing porch that acts as a place of social meeting in urban communities. The dogtrot type, based on customs of the Acadian who stemmed from Nova Scotia, has an organization based on a central porch flanked by public living spaces on one side and private on the other. The central arrangement provides a space for air to flow thru and ventilation for adjacent rooms. The mass of the dogtrot type has a recessed, inward facing porch that functions as a private social space in less dense rural communities. Gradually developing over a century, both typologies are housing models familiar to and accepted by the local communities.

Figure 7: Dogtrot (left) and shotgun (right) housing prototype renderings. Source: (Author)

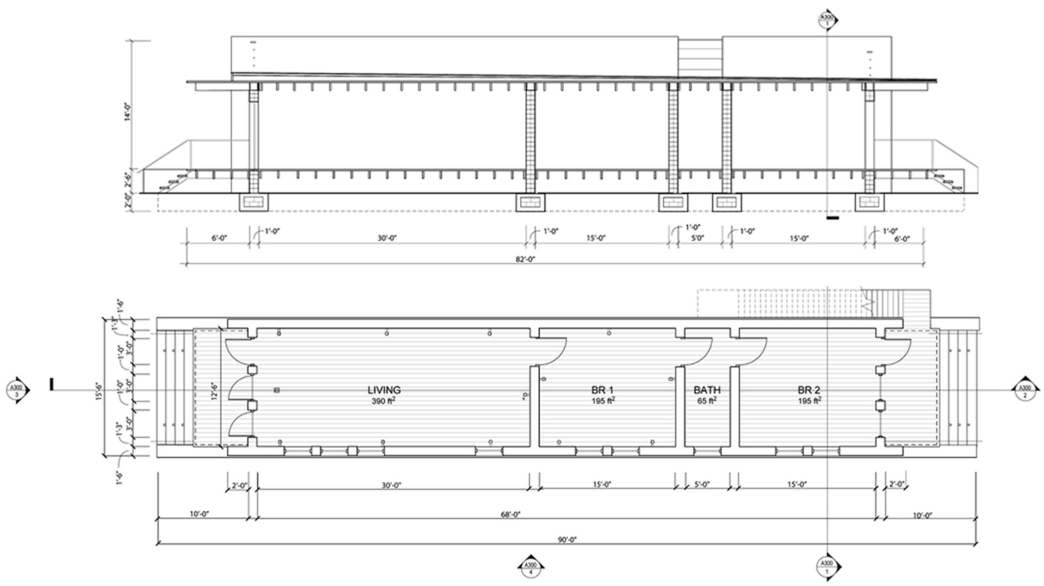

Figure 8: Shotgun housing prototype plan (bottom) and section (top) drawings. Source: (Author)

2.7. Architectural parameters

The architectural parameters of both housing prototype designs have several similarities. Each prototype is based on a single-family program of around 1000 square feet on one level with an interior volume of 10 to 12 feet in height. They are composed of a main living area, kitchen, bathroom, two bedrooms, and outdoor porches. Beyond these equivalent features, unique characteristics of the housing designs were developed based on specific contextual qualities. The urban prototype, influenced by the shotgun typology, has a long thin linear arrangement with minimal frontage following the organization of dense inner-city land allotment (Fig. 7). The rooms are organized in a straight line one after the other entering on the living area then proceeding to the kitchen, first bedroom, bath, second bedroom, and then exiting to a small exterior space in the back (Fig. 8). A covered exterior porch faces the street and is open on the sides to promote social interaction with city residents and adjacent neighbors. The rural prototype, influenced by the dogtrot typology, has a boxy rectilinear arrangement with an expansive frontage following the wide-open qualities of a sprawling pastoral countryside (Fig. 7). The rooms are organized in an arrangement based on two halves with the public living area and kitchen on one side and private bedrooms and bath on the other side. A recessed covered porch, located between the two halves, functions as an entry way and a central exterior space for social gatherings.

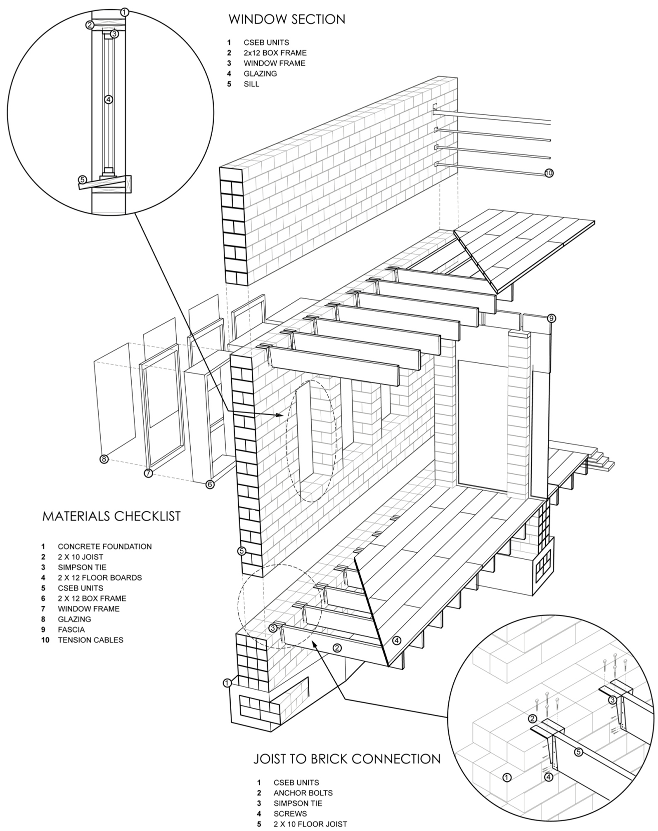

Figure 9: Housing prototype typical foundation, floor, wall, roof, and opening assemblies. Source: (Author)

2.8. Architectural systems

The proposed designs are developed around an architectural logic based on the 10"x6"x3" module of the compressed stabilized earth block (Kumar et al. forthcoming 2018). Each structure is anchored with a continuous grade beam foundation composed of multiple block layers surrounded by a 6" concrete protective coating on all sides. On top of the foundation, a 2'-6" high triple layer block stem wall supports a series of elevated floor joists to promote improved air circulation and ventilation. Wood planks are layered on top of the joists and provide a finished floor for the interior spaces. The raised floor elevation also helps resist building material decay, a common problem when building on moisture rich soils. The load bearing, double layer, exterior block wall continues vertically from the stem wall and rises to a height of up to 17'. With a maximum allowable span of 30', the exterior wall is reinforced by a series of block interior walls that function as buttress bracing for lateral loads. Wall thicknesses and spans were selected based on simple calculations to ensure that the structural system can resist the high wind pressure generated by hurricane force winds (Matta et al. 2015, Kumar et al. forthcoming 2018). The shorter interior walls span between the longer exterior walls and provide a series of thresholds to access the living spaces. The interior is finished with a smooth stucco coating that can remain exposed or covered with a paint finish. Visually similar to the interior walls, the exterior wall is finished with a thin cementitious stucco coating to form a waterproof protective layer. The roof system employs a simple wood joist framing technique supported by the foot thick exterior wall and anchored with mechanical fasteners (Fig. 9). Roof and floor joist connections with the walls are dimensioned to resist lateral and vertical wind loads. Again, wood planks are layered on top of the joists to make the roof enclosure and left exposed on the interior face revealing the structure and sheathing. In the shotgun typology, the exterior face of the roof is finished with a layer of rigid insulation that is sloped ¼" per foot from the front to the back for drainage. The dogtrot typology has a more steeply pitched roof structure and sheds water on multiple sides. Moisture and protection layers are applied to finish the roof exterior. Floor to ceiling openings are located at the front and rear of the houses to bring in light and help foster air flow or in the case of the dogtrot face the covered interior porch. Smaller side openings are supported by a wood box frame and allow additional natural light and air to enter interior spaces (Fig. 9). The frames are mechanically anchored to the compressed earth block walls to provide a high wind load resistant enclosure. The components, details, and connections are intentionally simple to help achieve the goal of affordable materials and labor that are readily available.

2.9. Affordability

Economically, the proposed designs were compared to traditional local building methods to determine the relative affordability of compressed stabilized earth block dwellings (Kumar et al. forthcoming 2018). When constructed by unskilled labor, the comparison showed that the earthen construction materials and techniques were significantly less expensive than brick and concrete masonry unit dwellings. Wood construction, a technique commonly used in the area, was more similar in cost. However, timber constructed dwellings are significantly less resilient to hurricane force winds.

3.0 ACHIEVED OUTCOMES:

In our current period of climate change, unpredictable events have and will continue to displace thousands of residence in the coastal region of Louisiana. This historic unseating of entire communities necessitates a reconsideration of standard housing solutions. Constructed primarily of materials accessible from the building site, compressed stabilized earth block design and building techniques offer an economical and sustainable approach to the current increase in demand for weather resistant housing. Through the novel use of engineered earth blocks in a hot wet environment and an awareness of local contextual parameters, the prototype designs offer an affordable, resilient, and sensitive way to bring about housing for the many individuals in need. From our research, we have concluded that it is feasible to re-appropriate earthen building materials found in hot dry climates to construct enduring structures responsive to a hot wet environment.

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