PERCEPTIONS OF COMPRESSED EARTH BLOCK AMONG RESIDENTIAL CONTRACTORS IN NORTH CAROLINA: AN EXPLORATORY EVALUATION

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ABSTRACT

Compressed earth blocks (CEB) retain the environmental benefits of traditional earthen construction while reducing labor costs and project duration. Despite these advantages, CEB remains a niche material in the U.S. This study explored residential contractors' perceptions of CEB as a barrier to adoption. A survey was distributed to residential contractors in the North Carolina Piedmont, a region that possesses ideal soil for earthen buildings. Construction professionals in states where earthen construction has a larger market share (New Mexico, Oklahoma, and Texas) were also queried for comparison. Respondents with no CEB experience provided significantly ($p < 0.05$) lower levels of agreement with statements that CEB is cost effective, structurally safe and aesthetically appealing than did respondents with CEB experience. Interviews conducted with an experienced CEB contractor and a manufacturer of CEB production equipment provided additional insight and informed the quantitative results. Findings represent an important step in exploring stakeholder perceptions as an impediment to the adoption of non-conventional materials like CEB in the residential construction sector. Educating the next generation of builders and homeowners is a key component for the implementation of CEB construction. Educational strategies, study limitations and opportunities for further research are discussed.

KEYWORDS

Compressed Earth Block; Non-Conventional Materials; Perceptions; Barrier to Adoption

1. INTRODUCTION

The earliest earthen dwellings in the U.S were made by manually pressing a mixture of moist earth and straw into roughhewn blocks. This method, known as adobe, is durable, ecologically benign, and has been used for hundreds of years in California, Texas, Arizona, and New Mexico (Gerbrandt and May 1980). Despite this history, adobe requires more time and manual labor

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than most conventional materials. As a result, earthen construction techniques and materials have largely been ignored by U.S. residential contractors.

This circumstance is particularly true in the North Carolina Piedmont Region (hereafter "Piedmont"), which is located between the Appalachian Mountains and the Atlantic Ocean. The Piedmont's soil consists of ultisols that are rich in kaolinitic clay (Markewich et al. 1991). Known for their load-bearing capacity and non-expansive characteristics, ultisols are ideal for CEB construction. Stabilizers like Portland cement or lime can also be added to further strengthen CEB. These cement-stabilized compressed earth blocks (CS-CEB), though they have higher embodied energy than traditional CEB, provide embodied energy savings of 86% over fired masonry and 25% over concrete (Maskell et al. 2014).

Despite favorable environmental and performance characteristics, the Piedmont has yet to develop a substantial market for CEB. This absence of CEB construction in the Piedmont may be influenced by builders' perceptions of the material. Scant research exists that investigates the inability of CEB to gain a foothold in the Piedmont residential construction market. This study provides the results of an exploratory mixed-methods analysis of barriers to CEB adoption among residential contractors in the Piedmont. Findings shed light on project stakeholder perceptions as an impediment to the acceptance and adoption of non-conventional materials like CEB.

2. BACKGROUND

Conventional materials form the backbone of our commercial and residential building stock, yet these materials possess product-specific disadvantages. Wood, for instance, is prone to moisture and termite damage. Steel and concrete are heavy, expensive, and require a tremendous amount of energy to manufacture. However, these materials persist in the current construction market despite well-documented shortcomings while effective and environmentally benign alternatives are marginalized, dismissed as impractical, or ignored. In the face of environment degradation, deforestation, and climate change (Mahlstein et al. 2013, Wentz et al. 2007, Hatzikiriakos and Englezos 1993), these patterns of behavior and material selection cannot continue.

Earth has been used as a building material for millennia on every continent except Antarctica (Kraus 2012, Abanda et al. 2014) and nearly 50% of the world's population live in homes constructed using earthen materials (MacDougall 2008, Burroughs 2010; Pacheco-Torgal and Jalili 2012). CEB improves on traditional earth building techniques, materials and methods. In addition, CEB can be produced more quickly and is more durable and resistant to insect infiltration than adobe while retaining its strength. Prior research outside the U.S. has shown that CEB can provide safe, affordable, and attractive homes, particularly for low-income or first-time homeowners (Niroumand et al. 2013, Butko et al. 2013). Despite these documented advantages, implementation of CEB has not markedly increased in the U.S. Research revealed no empirical studies confirming the findings from other countries within the U.S. construction market.

Research in Asia has shown that the opinions of contractors and building officials in the construction industry can influence the adoption of earthen materials (Hadjri et al. 2007, Niroumand et al. 2013). Similar studies in Africa indicate that building professionals and the general public associate earthen materials with poverty, poor performance, and low social standing (Adam and Agib 2001). A lack of earth building standards and codes, fueled by skepticism among government authorities, were also cited as major barriers to Sudanese earth

building efforts (Adam and Agib 2001). Skepticism and the lack of standards may lead to poorly built structures that inevitably fail in poor weather, confirming negative stereotypes about CEB's performance.

Social pressure to emulate the middle and upper classes has led low-income urbanites in South Africa to view earth buildings as structurally unsafe and a social step backward (Ballerino 2002). Sameh (2013) posits that overcoming social stigmas against earthen homes in Egypt will require government subsidies and new regulations. Exceptional examples of earthen architecture can be used to promote earthen homes and engage a larger number of potential homeowners. Lack of earthen architecture awareness and education are also barriers to its acceptance and adoption (Zami and Lee 2010 and 2011). Experts in Iran, Malaysia, and India report the lack of earthen construction education as a major obstacle to its adoption in residential markets (Niroumand et al. 2013). Many of these social and societal barriers were also cited by Gooding and Thomas (1995) over 20 years ago.

Studies in Europe and the British Commonwealth have identified similar barriers to those in developing countries (Williams et al. 2010). These include a lack of earthen-material building codes, lack of knowledge and awareness among building professionals, a skeptical public, and the perception that earthen materials are weak or antiquated. Interviews with earth building professionals in Germany and France revealed that a skeptical public, a lack of knowledge within the construction industry, and reluctant insurance companies inhibited adoption (Williams et al. 2010). Earthen structures in these countries also incurred higher costs compared to conventional timber-framed houses, due in part to a lack of national earthen construction standards and low availability of earthen block producers.

Skepticism and a lack of knowledge extends beyond CEB to other non-conventional materials. Thorpe (2011, p. 57) concluded that homeowners in Great Britain did not trust cob homes and instead preferred concrete and brick, which these participants claimed were "strong, dependable materials [that] will last several lifetimes." The implication that cob, a material made by mixing clay soil with straw, is inherently weak or unreliable is incongruent with the material's history in Great Britain. Cob structures have experienced a renaissance since the mid-1990s and in some cases have been in continuous use since the 16th century in Europe (Smith 2000).

Several studies (Walker 2004, Villamizar et al. 2013, Miccoli et al. 2014) investigating the technical properties of CEB in the U.S. have been conducted. However, investigation of perceptions of CEB and/or barriers to its implementation have received less attention. Kraus (2012) found that earthen materials face broad skepticism and a general lack of knowledge among builders and the public. Specifically, durability was cited as both a positive and negative attribute among respondents indicating confusion and a lack of technical knowledge of the capabilities and limitations of the material. The current study built on previous research by exploring residential contractors' perception of CEB in the Piedmont, an area of the U.S. with ideal soil condition for earthen building but no substantive market share.

3. METHODOLOGY

To quantitatively explore Piedmont residential contractors' perceptions of non-conventional materials (in general) and CEB (specifically) given their experience with the material, the following research questions were developed:

RQ1: Are there significant differences in the perception of non-conventional materials between Piedmont residential contractors' who have, and those who do not have, experience with CEB? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, of the mean perceptions of Piedmont residential contractors' who have and do not have experience with CEB.

RQ2: Are there significant differences in the perception of CEB between Piedmont residential contractors' who have, and those who do not have, experience with CEB? The null (H0) and alternative (H1) hypotheses were based on the equality or inequality, respectively, of the mean perceptions of Piedmont residential contractors' who have and don't have experience with CEB.

Data were collected using an electronic survey (Appendix A). The survey instrument was designed to measure contractors' perception of non-conventional materials in general, their experience with CEB, and their perception of CEB's structural properties, aesthetic qualities, and cost-effectiveness. This survey was based on an existing instrument (Francis and Prosser 2012) and was refined through a focus group with researchers and a pilot study conducted among New Mexico contractors. The finalized instrument was distributed via the internet using Qualtrics survey software. Responses were collected from contractors affiliated with home-building associations (HBAs) in the Piedmont. The researchers contacted HBAs, who sent the survey to their members. Individual contractors were not contacted directly but, received the survey either as a forwarded email or as part of a regularly distributed HBA newsletter. A total of 10 HBAs in the ten largest cities in the Piedmont region (Charlotte, Raleigh, Durham, Winston Salem, Cary, High Point, Greensboro, Concord, Gastonia, and Chapel Hill) distributed the survey. Contractors in counties located outside of the Piedmont were excluded to limit the analysis sample to homebuilders in the region of interest.

A survey was also sent to contacts in the researchers' network in New Mexico, Oklahoma, and Texas. These construction professionals were targeted for their experience building with CEB. This survey was similar to the North Carolina instrument with the exception of questions tailored specifically to contractors in the Piedmont. Participants in this distribution were encouraged to forward the survey to members of their respective networks. The intent of this snowball sample was to gather responses from construction professionals who had experience with CEB to determine if respondents' perceptions of the material changed with increased exposure to the material in professional practice. The survey assessed contractors' perception of non-conventional materials broadly, CEB specifically and included a section of demographic items.

General Perception of "Non-Conventional Materials" comprised nine questions, including opinions of cost-effectiveness, future relevance, and ease of use under local building codes. This section also assessed respondents' views of the role a contractor should play in directing the public toward or away from non-conventional building materials; the relationship between contractors' interest in a building material and the interest level of their clients; contractors' willingness to invest in training in building with non-conventional materials; and whether or not that willingness was related to the interest of their clients. Each question was scored on a 5-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, and 5 = Strongly Agree).

To qualitatively explore Piedmont residential contractors' perceptions of CEB given their experience with the material, word-association items were included in the survey. The perceptions of CEB section of the survey asked respondents to list the first three words they associate

with the term "compressed earth block." The remaining questions used the 5-point Likert scale described above. These questions assessed contractors' opinion of CEB's cost-effectiveness, environmental impact, attractiveness, structural integrity, and ease of use under local building codes. This section also assesses contractors' perception of the awareness of CEB among their clients and other contractors, as well as other contractors' interest in building with CEB. The prior experience with CEB section of the survey queried participants regarding their construction experience with CEB in the residential sector. The term "residential" was included in the survey items because CEB, due to its weight, is largely unfit for structures over two stories limiting its implementation in commercial construction.

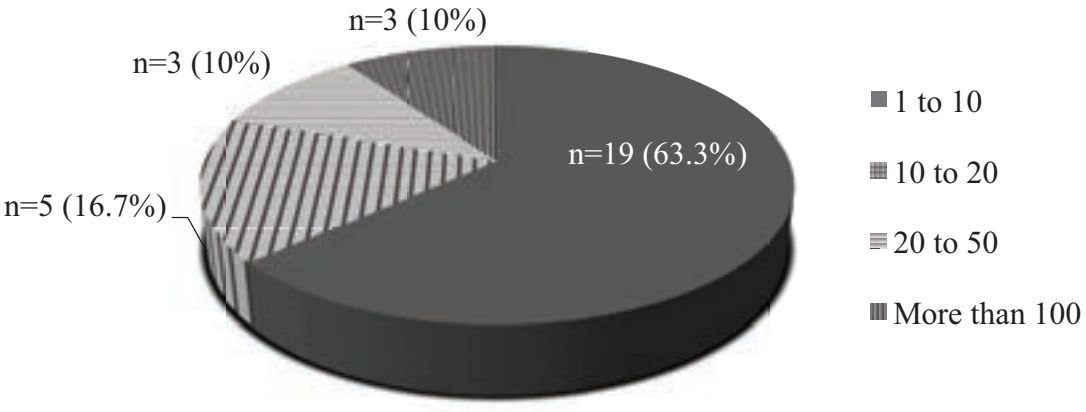
In addition, the researchers conducted two telephone interviews with construction professionals who were experienced in building with CEB to complement the survey responses. The qualitative data were used to inform the results observed in the quantitative analysis as well as guide interpretation of the findings and potential implementation in future research.

4. RESULTS

4.1 Analysis Sample and Demographic Data

The Piedmont survey link was active for five weeks and yielded 31 responses. Seven responses were incomplete and discarded, leaving a final sample of 24 for analysis. The second survey distribution link was active for four weeks and yielded six complete and valid responses. The two survey administrations comprised the final sample of 30 respondents. Because Piedmont HBAs were instructed to forward the survey to their members and the second survey was a snowball sample, a response rate could not be reliably calculated in the current study. The response rate for the second survey distribution was low in part because the four initial participants were the only individuals in the researcher's professional network with experience working with CEB. Though they were strongly encouraged to forward the survey to their colleagues, an initial sample of four may have limited the total number of viable responses received. The demographic data provided by respondents may help explain in part the low response rates among Piedmont contractors. Company size by the number of employees is presented in Figure 1.

FIGURE 1. Size of respondents' businesses by number of employees (n = 30)



The majority of respondents' reported either working for or owning, construction companies with 1 to 10 employees. Eighty percent (i.e., 24 of 30 responses) came from contractors with 20 or fewer employees. While a contractor's employee roster is not the only indicator of size, construction companies with fewer employees are likely to have fewer resources at their disposal than larger companies. Ninety percent (27 of 30) of respondents specialized in single-family residential construction. The Piedmont survey, which yielded 24 complete responses or 80% of the total sample, targeted contractors affiliated with HBAs.

The majority of respondents (22 of 30) reported at least ten years of work as a licensed contractor, with only two respondents reporting 5 or fewer years (Figure 2). The distribution of contractors by the number of projects completed was ten respondents completing 5 or fewer projects per year, ten respondents completing more than 20 projects per year, and the remaining respondents falling somewhere between these two extremes (Figure 3).

4.2 The Effect of Experience on the Perception of Non-Conventional Materials

An independent samples *t*-test was conducted to examine differences in the perception of non-conventional materials between those with CEB experience and those with no exposure to the material (Table 1). Several of these statements generated significant differences in the perception of non-conventional materials, based on an examination of the difference in mean scores and effect size (η). The most striking difference in the perception of non-conventional materials

FIGURE 2. Length of respondents' careers as licensed contractors

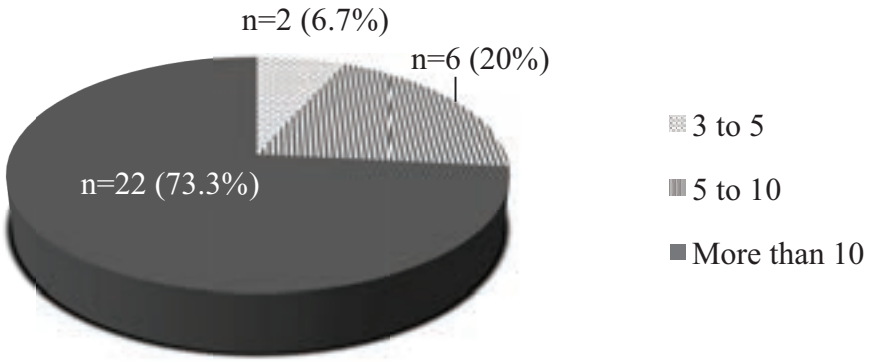
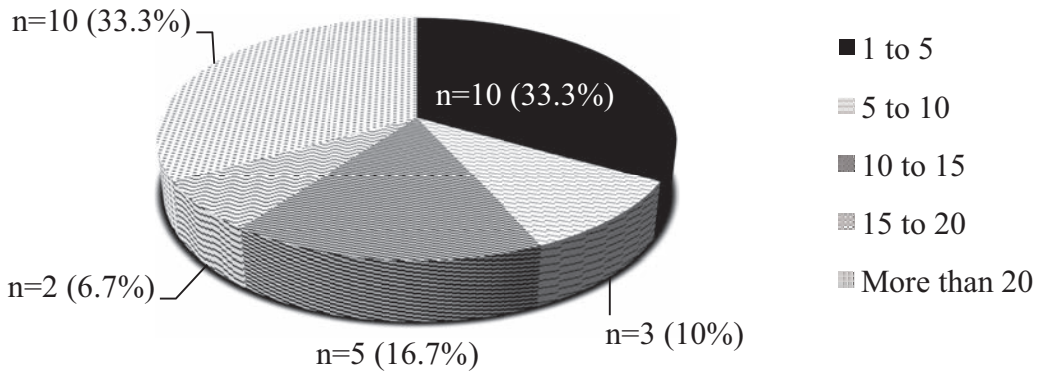


FIGURE 3. Average number of projects completed annually by respondents



was found in responses to the statement "Most non-conventional building materials are not cost-effective." Respondents with CEB experience provided a mean response of 1.83 (Disagree) while respondents with no CEB experience provided a mean response of 3.63 (Agree). The mean difference analysis generated a much larger than typical effect size (η = 0.607) according to Morgan et al. (2007). In addition, two other statements were found to have statistical significance including "I would invest training in building with non-conventional materials, regardless of client demand" and "Clients should play a role in shaping contractors' perception of building materials," with p values equal to 0.019 and 0.022, respectively.

TABLE 1. Effect of experience on respondents' perception of non-conventional materials (n = 30)

Statement	Experience with CEB		t-value	p-value[2]
	Yes (n = 6) (M)	No (n = 24) (M)		
Most non-conventional building materials are not cost effective.	1.83	3.63	3.491	0.011[3,4]
I would invest training in building with non-conventional materials, regardless of client demand.	3.83	2.75	2.495	0.019[3,4]
Clients should play a role in shaping contractors' perception of building materials.	4.33	3.42	2.427	0.022[3,4]
Non-conventional building materials are going to become more prevalent in the next decade.	4.17	3.58	1.488	0.148
Regardless of client demand, I would not invest in training for building with non-conventional materials	3.00	1.87	1.602	0.164
I would invest training in building with non-conventional materials, given adequate client demand.	4.33	4.00	0.954	0.377
Contractors should play a role in shaping their clients' perception of building materials.	4.33	4.46	0.358	0.733
Existing building codes make non-conventional materials too difficult to use.	3.33	3.25	0.243	0.810
My interest in a building material is directly proportional to the interest of my clients.	3.00	2.88	0.227	0.822

1. Mean scores are measured on a 5-point scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree Nor Disagree, 4 = Agree, 5 = Strongly Agree

2. Significant ≤ p = 0.05.

3. η ≤ 0.10 is small; η = 0.24–0.36 is typical; η ≥ 0.37–0.44 larger than typical, η < 0.45 much larger than typical, Morgan et al. (2007).

4. Independent Sample t-test assumptions of normality and equal variance (Leven's > 0.05) we confirmed

4.3 The Effect of Experience on the Perception of CEB

Another objective of this study was to investigate differences in contractors' perceptions of CEB given their experience and familiarity with the material. An independent samples *t*-test was performed to investigate differences in perceptions of CEB between respondents who had used CEB and respondents who had not. Results (Table 2) revealed several statistically significant differences in respondents' perceptions of CEB given their experience.

The greatest difference in mean perception was observed in responses to the statement "CEB buildings are structurally unsafe." Respondents with no CEB experience reported a mean score of 2.79, indicating neutrality or slight disagreement, while respondents with exposure to the material reported a mean score of 1.50, indicating disagreement to strong disagreement ($p < 0.001$, $\eta = 0.611$). The statement "CEB is visually attractive" garnered a mean response of 4.00 from respondents with CEB experience and 3.13 from those with no exposure to it ($p = 0.004$, $\eta = 0.507$). Furthermore, the statement "My clients are not aware of CEB" produced a significantly higher level of agreement ($p = 0.005$, effect size of 0.495) among contractors without CEB experience.

TABLE 2. Effect of experience on respondents' perception of compressed earth block ($n = 30$)

Statement	Experience with CEB		*t*-value	*p*-value[2]
	Yes ($n = 6$) (M)	No ($n = 24$) (M)		
CEB buildings are structurally unsafe	1.50	2.79	4.082	0.000[3,4]
CEB is visually attractive.	4.00	3.13	3.112	0.004[3,4]
My clients are not aware of CEB.	3.17	4.25	3.017	0.005[3,4]
Contractors in my state are not interested in building with CEB.	3.00	3.50	1.549	0.133
Contractors in my state are not aware of CEB.	3.50	3.96	1.237	0.226
CEB is more environmentally friendly than conventional materials.	3.83	3.46	1.003	0.325
Existing building codes make non-conventional materials too difficult to use.	2.67	3.21	1.065	0.331
There are very few, if any, CEB subcontractors in my state.	4.33	4.17	0.505	0.618
CEB is cheaper than conventional materials.	2.83	2.92	0.201	0.848

1. Mean scores are measured on a 5-point scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neither Agree Nor Disagree, 4 = Agree, 5 = Strongly Agree

2. Significant ≤ $p = 0.05$.

3. $\eta \leq 0.10$ is small; $\eta = 0.24$–0.36 is typical; $\eta \geq 0.37$–0.44 larger than typical, $\eta < 0.45$ much larger than typical, Morgan et al. (2007).

4. Independent Sample *t*-test assumptions of normality and equal variance (Leven's > 0.05) we confirmed

4.4 Word-Association Responses

In addition to collecting quantitative data, respondents listed the first three words they associated with the term "compressed earth block." Responses bolstered the quantitative trends and revealed a divergence in both knowledge and perception of CEB between the two respondent groups. Respondents without CEB experience used words like "Never heard of it," "Have not used," and "Unknown." These responses indicate a lack of knowledge of CEB. Some respondents used words that suggest a negative perception of the material, such as "trouble," "unproven," "untested," "temporary," and "costly." Other respondents in the same group used words like "green," "low-impact," "sustainable," "natural," "renewable," and "environmental." Respondents who had worked with CEB tended to associate the material with its technical and physical properties, using words like "fireproof," "breathable," "non-toxic," "non-cementitious," "heavy," and "labor-intensive." Positive words like "earth-friendly" "warm," and "healthy" were also recorded among those with CEB experience. Common word associations provided by both groups were "dirt," "mud," "bricks," and "adobe."

4.5 Follow-up Interviews

The researchers conducted two telephone interviews with CEB-experienced construction professionals. These interviews provided additional insight into the survey results and contributed to future research of barriers to CEB implementation. Both interview subjects were read a short script informing them of their rights as interviewees.

Interviewee A

The first telephone interview was conducted with the owner of a Design-Build residential contracting company located in the Piedmont region. Interviewee A is also the owner of a firm that manufactures CEB. At the time of the interview, he had completed two single-family residential CEB projects with a third project under construction.

Interviewee A identified three major obstacles to CEB construction in the Piedmont: 1) A limited number of subcontractors that are familiar with CEB construction; 2) additional time required to educate other construction professionals and; 3) inclement weather. He pointed out that he had generally been met with caution from building inspectors, rather than open hostility, and that their caution dissipated once they saw an engineer's stamp on the construction documents. When asked what obstacles CEB faces in the Piedmont, and how those obstacles may be overcome, Interviewee A indicated that education and exposure were vital to removing misconceptions and negative perceptions of the material.

Interviewee B

Interviewee B is the owner of a CEB press manufacturing company located in San Antonio, Texas, and has operated for 26 years as a builder, CEB manufacturer, and consultant for residential CEB projects. He has also sold his CEB presses to the U.S. military for use overseas.

Interviewee B indicated that he enjoys working with CEB, but that the ability of contractors and homeowners to use the material has been hampered by mistrust from designers. Interviewee B also reported some initial mistrust from building inspectors and code officials but said that they, along with others who attended CEB training sessions, were impressed by the material. He reported that increased exposure to CEB is the key to overcoming negative perceptions and skepticism from the construction industry and the general public. Interviewee B

concluded by emphasizing the importance of training and education, particularly for engineers, architects, building inspectors, and contractors.

5. DISCUSSION

5.1 Survey and Word-Association Results

An examination of the mean scores of the two respondent groups indicated that the surveyed contractors who had no experience building with CEB had a slightly negative perception of the cost-effectiveness of non-conventional materials and the value of non-conventional materials training. The statement "Most non-conventional materials are not cost-effective" generated a much larger than typical effect size (η = 0.607). Respondents with CEB experience provided a mean response of 1.83 (disagreement) for this statement while respondents with no CEB experience reported a mean score of 3.63 (agreement).

The results indicated a sharp divergence in perceptions of CEB between the respondents with, and those without, CEB experience. Findings suggest that respondents with first-hand experience working with CEB have a more positive opinion of the cost-effectiveness of non-conventional materials in general. Similarly, respondents who had worked with CEB agreed (M = 3.83) with the statement "I would invest in non-conventional materials regardless of client demand," while respondents who had no CEB experience disagreed (M = 1.87); comparison revealed an effect size of 0.427. This result suggests that respondents with CEB experience may implement non-conventional material due to a preexisting independent interest or that these respondents are more likely to seek out non-conventional materials after having worked with CEB.

An examination of the mean scores in Table 2 shows that respondents with no CEB experience did not share an overwhelming positive or negative perception of the material. However, the difference in mean level of agreement was significant. The statement "CEB buildings are structurally unsafe" generated a mean score of 1.50 (disagree) from respondents with professional experience working with CEB and 2.79 (neutral) from respondents who had no CEB experience, a *t*-test revealed a significant difference ($p < 0.001$) and much larger than typical effect (η = 0.611). As noted, a mean score of 2.79 is slightly below neutral and does not indicate a strong negative perception of CEB. However, the large effect size and the disparity in mean scores between the two respondent groups does indicate that respondents with CEB experience had a statistically higher positive perception of the material's safety and structural worthiness. Again, the positive perception may have been preexisting or shaped by respondents' experience using the material in professional practice. The more favorable perception of CEB's visual attractiveness from respondents with experience may be due to a preexisting bias for the material's physical appearance, or it may have been shaped by experience or exposure.

In addition, the statement "My clients are not aware of CEB" produced a significantly higher level of agreement (p = 0.005, effect size of 0.495) among contractors without CEB experience. There are several possible explanations for this difference in perception; one may be that respondents who have built with CEB maintain a client base that is more likely to self-educate and seek out non-conventional materials. Another potential explanation is that respondents with CEB experience have gone out of their way to educate their clients on the material's strengths and drawbacks. CEB might also be non-compatible with the architectural styles common to houses in the Piedmont region, this topics is something that the survey instrument did not account for and should be analyzed in future studies.

These results indicate that respondents with no CEB experience do not necessarily oppose its use based on safety or engineering concerns, but that they do not know enough about the material to make a definitive positive or negative statement. Conversely, these results indicate that experience building with CEB may positively impact respondents' perception of its strength and structural integrity. This absence of a shared perception of CEB among respondents with no experience using the material is also reflected in the variation of words and phrases they associated with the term "compressed earth block." Some responses indicated a complete lack of knowledge of the material, such as "do not know" and "never heard of it." Others provided words like "trouble" and "costly," indicating a negative perception of CEB. Some provided vague descriptors like "green," "environmental," and "hippie." Still, others associated the term with "Africa," "rural," and "third-world," these responses suggest an association with poverty and low social standing, a theme that is echoed in existing research (Adam and Agib 2001, Ballerino 2002, Hadjri et al. 2007).

Both results from the word-association and the two scaled-statement sections of the survey do not show a shared positive or negative perception of CEB among those participants with and without CEB experience. The results revealed that the majority of surveyed contractors did not have a negative opinion of the material. However, those with little or no first-hand knowledge of CEB may not judge the material on its physical or technical properties; but instead, form their opinion based on assumptions or through the lens of past experiences with other non-conventional materials. This became clearer when responses were compared with those from respondents who have worked with the material. While non-significant results were drawn due to the low number of surveyed contractors with CEB experience (n = 6), it is noteworthy that the responses in this group were either positive ("healthy," "earth-friendly," and "warm") or demonstrated an understanding of CEB's technical properties ("fireproof," "non-toxic," and "non-cementitious").

5.2 Analysis of Interviews

Both interview subjects provided responses congruent with studies of barriers to the use of earthen materials in Africa, Asia, Europe, and the United States (Adam and Agib 2001, Williams et al. 2010, Niroumand et al. 2013, Thorpe 2011). Interviewee responses and the literature indicate skepticism, a lack of awareness in the construction industry and the general public as barriers to CEB implementation. They also emphasized the importance of education and exposure to CEB to overcome these non-technical barriers. Responses align with research conducted by Gooding and Thomas (1995), Butko et al. (2013) and Niroumond et al. (2013), all of whom concluded that education and exposure are vital in promulgating earthen materials and dispelling misconceptions of their worth. Kraus (2012) also found that the most significant barriers to adoption of rammed earth in Kansas were a lack of education among public officials, architects, construction professionals, and the general public. Neither interview subject reported outright hostility from their peers, but rather caution and skepticism, which was reduced with increased exposure to the material. This provides additional support for the hypothesis that CEB may not face active hostility or opposition, but rather skepticism due to lack of awareness or exposure in a professional or educational setting.

The authors acknowledge that weather conditions could be a factor for propensity to use CEB as a building material. Observation revealed that North Carolina averages 50+ inches of rain/year while states with high levels of earthen material construction report lower annual precipitation (Average rain by state in Inches; Texas = 27, California = 22, Arizona = 13, New

Mexico = 13). The survey instrument did not include questions pertaining to weather as a variable. Weather may play an important role in the decision-making process to design and/or build a CEB dwelling (Healthcote 1995, Alam et al. 2015). This limitation provides opportunities for future studies in North Carolina, and in countries with both a humid subtropical climate and a history of earthen construction. In addition, the capital investment in CEB equipment and training could be a contributing factor when choosing to use CEB (Kabiraj and Mandal 2012, Alam et al. 2015). Investigating the impact of initial capital investment as a barrier to CEB implementation represents an important and needed area of further research.

5.3 Suggestions for Educating the Next Generation of CEB Builders and Homeowners

Overcoming non-technical barriers to CEB acceptance in untapped markets, such as the Piedmont region in North Carolina, will require concerted and sustained educational efforts aimed at key stakeholders in the residential sector including homeowners, builders, code officials and financial institutions. For example, prospective homeowners must be made aware of the potential benefits of owning a CEB home, while also understanding how CEB differs from wood or concrete in both performance and durability.

Furthermore, builders must be trained in CEB construction means and methods, as well as the strengths and weaknesses of CEB in various climates. Residential contractors and engineers could be educated through targeted outreach programs that connect earth-building consultants directly to HBAs and labor unions. These programs could offer incentives, such as tax benefits or continuing-education hours for trade organizations, to encourage contractors and tradespeople to participate. Prospective homeowners could also participate in these programs, should they wish to build their own CEB home. These programs could be offered by universities and community colleges through community extension or through trade conferences such as Earth USA. Alternatively, future homeowners could meet directly with contractors, engineers, and consultants with CEB experience in a round-table format, either as a structured class or an informal Q & A session.

Interview results revealed skepticism and a lack of participation from banks, insurance agencies, and code officials are perhaps one of the most significant challenges faced in expanding CEB implementation. Addressing this skepticism and lack of participation can be part of educational strategies in order for CEB to gain the legal and financial footing of more conventional materials. The lack of education of these agencies could be addressed with programs similar to those previously described for homeowners and homebuilders. For instance, consultants and experienced CEB contractors could meet with representatives from insurance agencies and discuss CEB's superior resistance to fire and termite damage, while also detailing the challenges they have faced when building in flood-prone or seismically active areas. Code officials who are skeptical of CEB could meet with earth-building consultants and owners of CEB homes in semi-structured round-table discussions to ask questions, pose critiques, and offer input and advice for meeting existing building codes or modifying codes to allow for CEB construction. Forums and panel discussions on the merits and drawbacks of CEB could also be offered at insurance and lending conferences and expos.

Regardless of the format, these efforts should be open, unbiased, and free of any political agenda. Their purpose should be to remove uncertainty and skepticism, allowing builders, homeowners, and other stakeholders to make informed decisions on how and where to build and maintain CEB homes.

6. CONCLUSIONS

This exploratory study demonstrates that, among residential contractors in North Carolina's Piedmont region, those with CEB experience had a more positive perception of CEB than those without experience. The overarching finding that a lack of earthen architecture awareness and education are barriers to its acceptance aligns with recent research (Zami and Lee 2011, Kraus 2012). While this exploratory cross-sectional study aligns with other studies, there are limitations to the interpretation of the results.

This study focused on the perception of CEB among members of the residential construction industry sector. Moreover, the majority of respondents were located in one region of one state, and as such, their responses are not generalizable as perceptions of CEB among contractors across the country, among other construction industry professions, or among contractors in other industry sectors. In addition, the number of complete and valid responses collected during both survey distributions was low (n = 30), with six respondents having experience with CEB. While the t-test is "quite robust to violation of assumptions of normality … homogeneity in variance is most important" (Morgan et al. 2007, p. 144), it should be noted that the current study data did meet the assumptions of normality and homogeneity of variance (Levene's > 0.05) required for independent samples t-test. Even so, the small sample limits the researcher's ability to draw generalized and definitive conclusions about the perception of the material among all North Carolina contractors or building professionals elsewhere. Despite these limitations, this exploratory study offers an opportunity to advance the current body of knowledge regarding the perceptions of CEB, a topic that was previously unexplored in the Southeastern U.S.

Industry penetration is low for non-conventional building materials, including CEB. In order to increase their market share, these products must be studied, tested, refined, and marketed like any other building material. Continuous testing and refinement have allowed most conventional materials to evolve over centuries, and it is the absence of this process that, in part, has hampered the widespread use of non-conventional materials like CEB. For instance, if the construction industry focused only on the shortcomings of timber framing (flammability, susceptibility to rot and termites, and limited service life) perhaps contractors may have been more likely to avoid its use in construction. Conversely, if advocates for CEB focus on its strengths without addressing its shortcomings, then the material will not be able to evolve and gain widespread acceptance.

As building professionals seek out information and educate themselves, and their clients, on the strengths and weaknesses of CEB and other non-conventional materials, more alternatives to energy-intensive materials and methods will become available. With education and training, the intended output would be that material selection decisions will be made based on merit, as opposed to assumptions, second-hand testimony, or hearsay.

Future studies should continue to examine the effect of contractors' perception of CEB on its acceptance and adoption in southeastern states. The Piedmont should remain a geographical focal point given its optimal soil characteristics. Future investigations should focus on the influence of capital investment in CEB equipment and training as barriers to CEB adoption. Studies could also target other professions to determine whether perceptions of CEB change depending on participants' roles in the construction industry. Architects and material suppliers, for instance, may have views that diverge from those held by contractors. These future studies should be increased in scope, covering all states with an identifiable Piedmont region such as Georgia, South Carolina, and Virginia. Future research should also step outside of CEB and investigate whether the perceptions and opinions of contractors, architects, and engineers have

helped or hindered acceptance and adoption of other non-conventional materials. Such studies could examine how respondents' perceptions change depending on the material selected, the construction market, building owners' income level, or the professions of study participants. The overarching goal in the exploration of the adoption of non-conventional and environmentally-friendly building materials is a crucial step in extending their market share. Replacement of conventional, with non-conventional, materials will require specific education and training among targeted groups to increase exposure and field implementation.

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APPENDIX A: COMPRESSED EARTH BLOCK SURVEY

This survey examines your views on Compressed Earth Block (CEB). Responses will be published in aggregate form and kept strictly anonymous. Thank you in advance for completing the survey.

1. To what extent do you agree or disagree with each of the following statements? *Please circle one number for each statement.*

NOTE: The term "non-conventional" is defined as any building material other than timber-frame, steel stud, concrete, CMU, or fired brick.

Statement	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
Contractors should play a role in shaping their clients' perception of building materials.	1	2	3	4	5
Clients should play a role in shaping contractors' perception of building materials.	1	2	3	4	5
My interest in a building material is directly proportional to the interest of my clients.	1	2	3	4	5
Most non-conventional building materials are not cost effective.	1	2	3	4	5
I *would invest* training in building with non-conventional materials, *given adequate client demand*.	1	2	3	4	5
I *would invest* training in building with non-conventional materials, *regardless of client demand*.	1	2	3	4	5
Non-conventional building materials are going to become more prevalent in the next decade.	1	2	3	4	5
Regardless of client demand, I *would not invest* in training for building with non-conventional materials.	1	2	3	4	5
Existing building codes make non-conventional materials too difficult to use.	1	2	3	4	5

2. What are the first 3 words that you associate with the term "Compressed Earth Block (CEB)?"

   _____ _____ _____

3. To what extent do you agree or disagree with the following statements? *Please circle one number for each statement.*

NOTE: *The term "conventional" refers to timber-frame, steel-stud, CMU, concrete, or fired brick construction.*

	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree
CEB is cheaper than conventional materials.	1	2	3	4	5
CEB is more environmentally friendly than conventional materials.	1	2	3	4	5
CEB is visually attractive.	1	2	3	4	5
Contractors in my state are not interested in building with CEB.	1	2	3	4	5
My clients are not aware of CEB.	1	2	3	4	5
Contractors in my state are not aware of CEB.	1	2	3	4	5
There are very few, if any, CEB subcontractors in my state.	1	2	3	4	5
CEB buildings are structurally unsafe	1	2	3	4	5
Existing building codes in my state make building with CEB too difficult.	1	2	3	4	5

4. Do you have any experience building with compressed earth block in residential construction projects?

   _____ No _____ Yes

   If yes, how many projects?

   a. 1–3
   b. 3–5
   c. 5–10
   d. More than 10

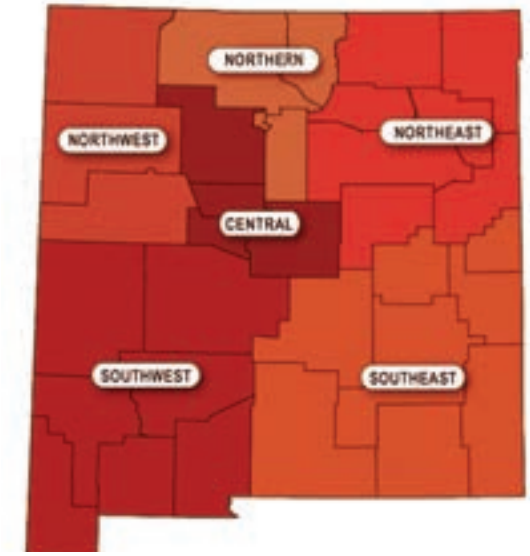
   If yes, what positions best categorize your involvement on CEB projects?

   e. Company owner
   f. Laborer
   g. Mechanical, electrical, or plumbing subcontractor
   h. CEB subcontractor
   i. Project manager

6a. How long have you been a licensed contractor?

   a. 1–3 years
   b. 3–5 years
   c. 5–10 years
   d. More than 10 years

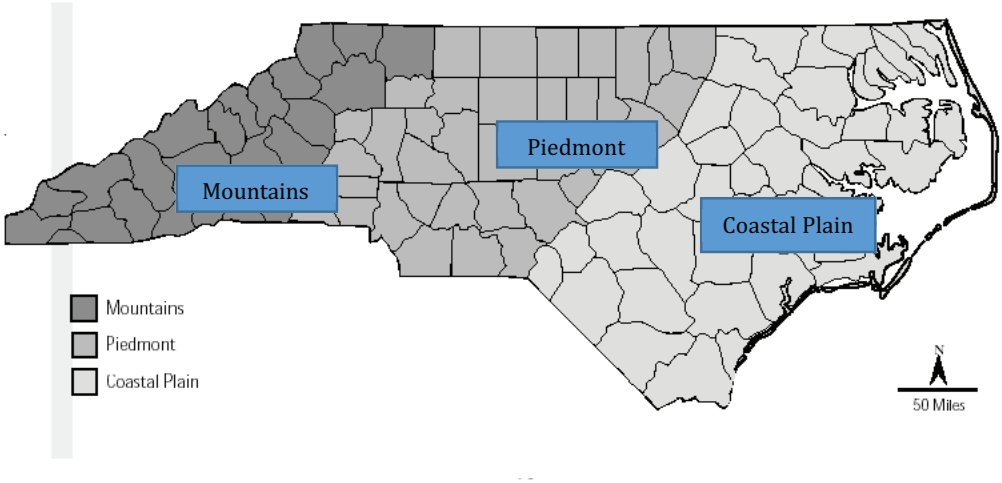
6b. What is your primary area of construction expertise?
   a. Single-family residential
   b. Multi-family residential
   c. Commercial
   d. Other
7. How many projects, on average, do you complete annually?
   a. 1–5
   b. 5–10
   c. 10–15
   d. 15–20
   e. More than 20
8. How many people, on average, do you employ?
   a. 1–10
   b. 10–20
   c. 20–50
   d. 50–100
   e. More than 100
9. Do you have comments about this survey that you would like to share? Please feel free to leave your feedback in the space provided below. Your response will be kept strictly anonymous.
10. Do you have any comments about CEB that you would like to share? Please feel free to leave your feedback in the space provided below. Your response will kept strictly anonymous.
11a. **For contractors in New Mexico:** Where do you perform the majority of your work? Please complete the table below, using the image provided below.



http://www.nmlandconservancy.org/~nmlandco/nmlc_img/img_map_lg.gif

Region	Percentage of Work Performed in Region
Northwest	
Northern	
Northeast	
Central	
Southwest	
Southeast	
	TOTAL: 100%

11b. **For contractors in North Carolina:** Where do you perform the majority of your work? Please complete the table below, using the image provided below.



http://www.secretary.state.nc.us/images/region1.gif

Region	Percentage of Work Performed in Region
Mountains	
Piedmont	
Coastal Plain	
	TOTAL: 100%

Thank you for completing the survey