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Construction with Earth Masonry in Different American Contexts. A Comparative Study between New Mexico (USA) and Santa Fe (Argentina)

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Abstract **-** This study explores the physical and mechanical properties of adobes and compressed earth blocks (CEBs) produced in the State of New Mexico (USA) and the Province of Santa Fe (Argentina), aiming to develop a sustainable and replicable production model for earthen masonry units in Argentina. The research involved fieldwork in two countries, engaging with local producers and local Universities, and included the analysis of regulatory frameworks, market dynamics, and laboratory testing of materials. The results highlight notable differences between the two regions. New Mexico benefits from a robust regulatory framework, established production enterprises, and consistent market demand, resulting in standardized, high-performance CEBs and adobes. In contrast, Santa Fe lacks uniform regulations, faces irregular production cycles, and exhibits a wide variability in product quality. While some CEBs in Santa Fe meet or exceed international standards, others fall below acceptable thresholds, particularly due to inconsistencies in stabilization methods. The study concludes that implementing province-wide technical standards and supporting local production capacity could significantly enhance the viability of earthen construction in Argentina. This comparative approach offers key insights for strengthening the sector and fostering environmentally sustainable construction practices through the adaptation of successful international experiences.

Keywords**:** Adobe, CEB, earthen construction

1. Introduction

Earth-based architecture and construction have a long-standing tradition in human history. Although their earliest origins date back over 9,000 years, in many contexts they remain as relevant today as in ancient times. It is estimated that more than one-third of the world's population currently lives in earthen homes. The historical continuity of earth architecture and construction is largely due to the abundance of raw materials, the cost-effectiveness of building processes, the bioclimatic qualities of earthen structures, and their harmonious interaction with the surrounding natural environment [1]. This is well understood, upheld, and defended by communities with strong local traditions, particularly those with ancestral spiritual ties to the land. Through popular wisdom, they produce what has been termed "architecture without architects" [2], adapting to the climate and cultural practices of each region and society. These communities promote quality of life through the rational use of available physical resources and optimize construction alternatives to help reduce the housing deficit [3].

There are numerous construction techniques and systems that use earth as the primary material. Of particular interest to this project are masonry techniques involving small, prefabricated components produced prior to the actual construction of the dwelling. These components are joined using earthen mortars. The main representatives of this technology are walls built with adobes and compressed earth blocks (CEBs).

1.1. Adobe

Adobe is a prefabricated earthen component that may include straw or other materials to enhance stability and reduce cracking during the drying process. It is manufactured by manually or mechanically molding a plastic mixture of mud into forms—typically made of wood—which are immediately removed. The blocks are then left to dry outdoors for several days, protected from direct sun and rain, until they are ready for use [4].

Adobe walls are built using an earthen mortar, with or without the addition of plant fibers, and the construction techniques vary depending on local customs and regional expertise. The dimensions of adobes vary widely depending on the area of production, yet they maintain a logical ratio of sides and a final volume and weight that allows a single person to handle them without breakage or physical strain. Adobe and the walls built with it continue to be primarily artisanal systems for manufacturing basic components and constructing wall enclosures, and their use remains widespread globally serving as the main or only building method in some regions [1].

1.2. Compressed earth block (CEB)

Compressed Earth Blocks (CEBs) are masonry units produced by compressing a mixture of earth, typically stabilized with lime or cement, within a press specifically designed for this purpose. The press may be manually operated or automated, depending on the required production scale. The shape of CEBs varies based on the mold used during fabrication, and they can be solid, hollow, or interlocking [5].

Compared to adobe, CEBs are considered by some authors to represent a technological advancement. While they share similarities -such as manual production potential and usage in wall and roof construction as compression-resisting units- CEBs differ significantly from traditional adobe in several aspects. These include water content, mortar composition, production shape and timing, and the use of specialized machinery in the manufacturing process. This latter feature allows CEBs to better integrate with current conventional construction industry practices and facilitates their potential for industrial-scale production [6].

The technical development of CEB construction in Argentina has a long history, with the first documented uses dating back to the 1940s. However, its use significantly expanded during the 1980s, driven by academic and scientific research and its promotion in rural housing programs by government agencies [6].

2. Objectives

2.1. General objective

The main objective of this study is to deepen the understanding of the production process, and the physical and mechanical properties of adobe and compressed earth blocks (CEBs) produced in the state of New Mexico (USA), comparing them with their counterparts manufactured in the province of Santa Fe (Argentina). The aim is to propose improvements that contribute to the development of a productive model for earth masonry that is technically, socially, economically, and environmentally sustainable and replicable throughout Argentina.

2.2. Specific objectives

The specific objectives of this article are:

1. Analyze the regulatory framework governing the manufacture and use of CEBs and adobe in both contexts, identifying its scope and limitations.
2. Examine the characteristics of CEB and adobe production and commercialization in New Mexico and Santa Fe (Argentina), assessing market stability, key stakeholders, and factors influencing demand.
3. Compare the mechanical and morphological properties of CEBs and adobe produced in both regions.
4. Evaluate the impact of existing regulations on the quality and strength of masonry units in each region, considering minimum required values and variations in local production.
5. Analyze production and sales costs of these masonry units and based on them, the profile of users who choose them for their construction projects.
6. Identify strategies to strengthen the sector in Santa Fe (Argentina), using New Mexico's experience as a reference.

3. Methodology

This study was conducted in the cities of Santa Fe and Rosario (Province of Santa Fe, Argentina), as well as Albuquerque and the indigenous Santo Domingo Pueblo (New Mexico, USA). Collaboration with local researchers and builders provided in-depth knowledge of the manufacturing and use processes of CEBs and adobes in both geographical contexts.

To achieve the proposed objectives, the study was carried out in three main phases, which are detailed below. It is important to note that this methodological approach allowed for a comprehensive comparison of CEB and adobe production and use in New Mexico and Santa Fe, providing key insights for the development of strategies to strengthen the sector in Argentina.

3.1. Survey of manufacturers and equipment

First, a survey was conducted to identify the main manufacturers of adobe and CEBs in both regions, aiming to establish contact with various enterprises dedicated to their production. Additionally, manufacturers of presses and auxiliary equipment for masonry production were surveyed in both New Mexico and the province of Santa Fe, Argentina.

3.2. Factory visits and producer interviews

In the second phase, visits were conducted to CEBs and adobe manufacturing facilities in both regions. During these visits, production processes were recorded, and in-depth interviews were conducted with factory managers. The interviews were designed to explore:

- Production costs and materials used.
- Activity levels and market stability.
- Customer profiles and final sales prices.
- Main challenges faced by the sector.
- Perceived strategies for strengthening the production and commercialization of these masonry units.

3.3. Analysis of physical and mechanical properties

Finally, laboratory tests were conducted at the Centennial Engineering Center at the Department of Civil, Construction and Environmental Engineering at the University of New Mexico (Albuquerque) and the Department of Civil Engineering at the National Technological University (Santa Fe, Argentina) to evaluate the physical and mechanical properties of adobe and CEBs produced in both contexts. The analyzed parameters included physical properties such as dimensions, density, and shape regularity, as well as mechanical properties like compressive strength and dry density.

4. Results and discussions

4.1. Regulatory Framework

One of the main differences between the two study contexts is, without a doubt, the regulatory framework. Currently, the state of New Mexico is one of the few in the United States that not only allows the construction of buildings with earth but also has a specific building code for this type of construction: the New Mexico Earth Building Code [7]. This code is one of the most internationally referenced technical standards in earth construction, as it defines specifications and design and calculation parameters for buildings constructed using techniques such as adobe, compressed earth blocks (CEBs), rammed earth and “terron” (sod blocks). In addition to this code, which focuses on new construction, the state also has specific regulations for the restoration of historic earthen buildings: the New Mexico Historic Earthen Buildings [8], which provides a legal and technical framework for the restoration of such structures.

In contrast, Argentina currently lacks a national regulation for earth construction. In fact, most municipal building codes do not include these techniques and, in many cases, prohibit them. However, despite the absence of national or provincial regulations, some municipalities have incorporated rules that allow the use of earth as a building material within their jurisdiction. An example of this is the city of Santa Fe (in the province of Santa Fe, Argentina), which passed a building code in 2016 in this regard [9]. However, a study conducted by the Argentine Network for Earth Construction in 2021 [10] revealed that 60% of municipal ordinances lack specific technical annexes (as is the case with the Santa Fe city code), while 30% include practical references, and only 10% present a deeper level, referencing international technical standards. The document concludes that the greatest obstacle to the development of earth construction technology in Argentina and its extension across the country is the lack of a national regulation that comprehensively governs the activity.

4.2. Productive Enterprises

Currently, in the state of New Mexico, it is possible to find medium and large-scale plants manufacturing adobe and CEBs, with more than ten years of uninterrupted production and no difficulty marketing their products. Regarding CEBs production, a notable factory located in Santo Domingo Pueblo, where the equipment, manufactured in the States of Texas, U.S., allows the production of CEBs directly at the raw material extraction site. This plant currently operates with a production level of 2,000 CEBs per 9-hour workday, employing four workers. Unlike in Argentina, the high demand for CEBs in the region allows the plant to operate continuously throughout the year.

A different situation occurs with one of the largest adobe manufacturing plants in the state, located in the city of Albuquerque. Due to the nature of the adobe production process, which requires the evaporation of large volumes of water during the drying stage, production is restricted during freezing periods. For this reason, the plant operates only during the late spring and summer, typically between May and September, with a daily production level of approximately 1,500 to 2,000 adobes. Consequently, the total production each season ranges from 100,000 to 500,000 bricks, depending mainly on demand. This variable also determines the number of workers needed each season, which ranges between two and six.

In the Argentine context, two active CEB manufacturing plants can be identified in the province of Santa Fe, each with different installed capacities and production levels. The first, a smaller-scale operation, uses nationally sourced equipment (hydraulic press, mixer, sieve, and grinder) and has a daily production capacity of approximately 500 CEBs, with 8-hour workdays and four workers. The second, equipped with machinery imported from China, can produce up to 2,000 CEBs daily with the same work schedule. Despite their differences, both factories face a common problem: the difficulty of marketing their products. As a result, these enterprises only operate for a few months each year, depending on sales.

Furthermore, in Santa Fe province (Argentina), there are currently no enterprises exclusively dedicated to the production of adobes. However, some brickworks produce them upon request, provided the required quantity is high.

4.3. Geometry of the Masonry Units

There is a clear difference in the morphology of the CEBs produced in New Mexico and Santa Fe, Argentina. The blocks produced in the United States are solid and large, measuring 35×25×10 cm with an approximate weight of 15 kg. In contrast, the CEBs in Santa Fe (Argentina) have a different design, being hollow and interlocking. These blocks are typically made in two main sizes: small format, with 12.5×25×6.5 cm, two 6 cm diameter perforations and an approximate weight of 3.5 kg; and large format, with 15×30×8 cm, also with two 6 cm diameter perforations, but weighing approximately 5.5 kg. Figure 1 illustrates the size and shape differences between the CEBs produced in New Mexico and Santa Fe, Argentina.

The size difference is also evident in the adobes produced in both regions (Figure 2). In the province of Santa Fe (Argentina), as mentioned in the previous section, commercially available adobes are manufactured by brickmakers who use molds like those employed in ceramic brick production. This results in pieces with dimensions ranging from 25×11×5 cm to 30×15×7 cm. In contrast, in the state of New Mexico, traditional adobe manufacturers prevail, producing larger pieces, approximately 35×25×10 cm. It can be observed that the dimensions of the adobes and CEBs produced in New Mexico are very similar.

4.4. Mechanical properties

Figure 3 illustrates the unconfined compressive strength test conducted on various samples of CEBs and adobe produced in New Mexico and Santa Fe (Argentina), with the results presented in Table 1.

Figure 1: CEBs produced in New Mexico (left) and Santa Fe, Argentina (right).

Figure 2: Adobes produced in New Mexico (left) y Santa Fe, Argentina (right).

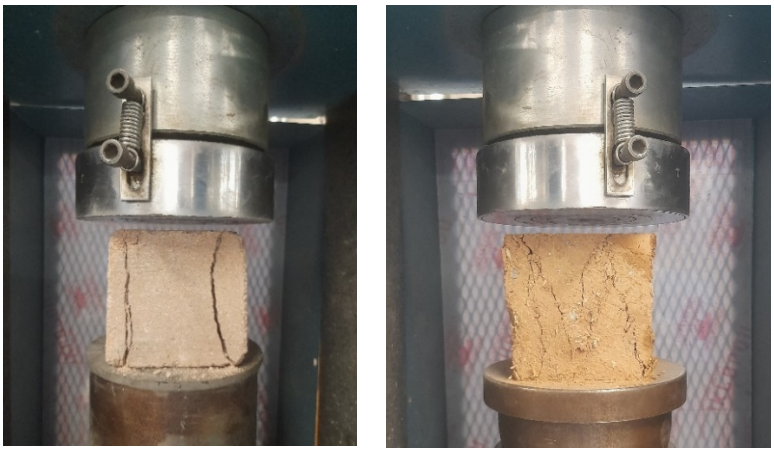

Figure 3: CEB (left) and adobe (right) compressive strength determination

Table 1: Compressive strength and density of Adobes and CEBs.

	ID	Origin	Number of samples	Average Density (kg/m^3)	Average Compressive Strength (kgf/cm^2)	Coefficient of variation (%)
Adobes	A NM 1	New Mexico	3	1602	14.2	4.6
	A NM 2	New Mexico	3	1571	17.0	11.8
	A SF 1	Santa Fe (Arg)	3	1488	46.6	11.2
	A SF 2	Santa Fe (Arg)	3	1434	30.3	9.0
CEBs	C NM 1	New Mexico	6	2037	69.6	5.4
	C NM 2	New Mexico	6	1899	43.6	14.2
	C SF 1	Santa Fe (Arg)	6	1575	111.8	16.42
	C SF 2	Santa Fe (Arg)	6	1605	21.7	11.6

As shown in Table 1, the compressive strength of the different series of adobes and CEBs produced in New Mexico and Santa Fe (Argentina) exhibits significant differences. Regarding adobes, the Argentine samples have a lower density, but higher compressive strength compared to those produced in New Mexico. While it is not possible to generalize the results obtained, it is noteworthy that the compressive strength of New Mexico's adobe is lower than the minimum required by the state's building code, which establishes a threshold of 300 psi (21 kgf/cm^2). However, their strength still exceeds the minimum of 12 kgf/cm^2 set by other international standards, such as those in El Salvador, Brazil, and Peru [11–13]. In this regard, it is important to highlight that the compressive strength of the adobes produced in Santa Fe (Argentina) exceeds the requirements established by international standards, including those of New Mexico.

Regarding the CEBs, the blocks produced in New Mexico have a higher density than those manufactured in Santa Fe (Argentina) and a compressive strength that significantly surpasses the minimum requirement (300 psi = 21 kgf/cm^2) set by the state's building code for load-bearing walls. Furthermore, the blocks produced in Argentina display highly variable average compressive strengths, which can be attributed to the stabilizing mineral content used in their production: the lower-strength blocks contain only 5% cement (by dry weight of materials), whereas the higher-strength blocks incorporate 10% cement in addition to 10% hydrated lime.

4.5. Sale price

The price of CEBs produced in New Mexico ranges between $3.5 and $8 per unit, excluding transportation costs, which, depending on the distance, can equal the sale price of the blocks. This price variability is mainly determined by the quantity of blocks purchased and the possibility of locating the mobile factory near the raw material extraction site. In contrast, the price of adobes in New Mexico is more stable, ranging from $3.5 to $4.5 per unit, excluding transportation costs, which are charged separately and depend on the distance between the production plant and the destination. It is worth noting that CEBs and adobes produced in New Mexico have similar dimensions, allowing for a more direct price comparison.

On the other hand, in Santa Fe (Argentina), sale prices also vary, but within a considerably lower range. In the case of CEBs, the price per unit ranges between $0.75 and $1, while adobes can be found for around $0.50 per unit. When comparing these values, in addition to the regional economic context—a Latin American country versus the United States—it is essential to consider that both CEBs and adobes produced in Argentina have dimensions approximately equivalent to half of their U.S. counterparts.

4.6. Customer profiles

Regarding businesses dedicated to CEBs manufacturing in New Mexico, their main clients are mainly local builders and constructors. In this regard, the owner of a CEB factory states that he recently formalized the sale of 80,000 CEBs to Santo Domingo Pueblo for the construction and repair of state housing. Additionally, this factory has sold CEBs to renowned architecture firms in different states, which use them to build "luxury homes" designed with materials considered sustainable

and innovative. According to the owner's information, the factory does not face demand issues, as it expects to produce between 300,000 and 500,000 BTC by 2025, of which approximately half have already been sold.

Regarding adobes commercialization in New Mexico, the owners of one of the state's largest factories indicate that their main clients are restoration specialists—who work on rehabilitating historic or old buildings—and private homeowners, who use adobes for home expansions, mainly in the construction of perimeter walls. Although it is possible to purchase adobes for entirely new home construction, this type of sale does not represent most of the factory's production.

On the other hand, businesses dedicated to CEBs sales in Argentina face serious difficulties in marketing their products, although the customer profile remains relatively constant: buyers are usually individuals interested in building with a novel material that they also consider “more sustainable” than other masonry materials such as ceramic bricks or concrete blocks. The uniform shape and the ability to assemble these blocks allow for exposed wall construction without the need for protective plaster, making them attractive to this type of customer. Conversely, those who purchase adobes from regional brickyards do so mainly due to their environmental and traditional characteristics, which are the most important factors for consumers.

5. Conclusion

The comparison between the manufacturing and utilization contexts of CEBs and adobes in the states of New Mexico (USA) and Santa Fe (Argentina) reveals significant differences, which are summarized below:

1. Regulatory Framework: While New Mexico has specific regulations for earthen construction, including codes for new buildings and heritage restoration, Santa Fe, Argentina lacks a province-wide regulation governing the use of these construction elements. However, several municipalities, including Santa Fe (the provincial capital), have enacted local ordinances promoting more sustainable materials. These ordinances, though lacking detailed technical specifications, allow for the use of earthen construction elements. Nevertheless, the absence of technical standards in most municipalities within Santa Fe significantly hinders the promotion of this technology, contrasting sharply with the situation in New Mexico, where regulatory support facilitates its adoption.
2. Production Enterprises: In New Mexico, manufacturing plants operate continuously to meet a steady demand over time. In contrast, CEBs factories in Santa Fe (Argentina) struggle to market their products, limiting their production to specific periods of the year. The situation is even more challenging for adobe production, as there are no dedicated manufacturing enterprises in the province. Instead, adobe production is limited to small-scale artisanal methods managed by local brickyards, often made to order.
3. Morphological Characteristics: The CEBs produced in New Mexico are solid and large, whereas those made in Santa Fe, Argentina are smaller, hollow, and interlocking. A similar difference applies to adobes, with those from New Mexico being larger than their Santa Fe, Argentina counterparts. It is important to note that CEBs and adobes in New Mexico have equivalent dimensions, approximately 35 × 25 × 10 cm, which is now the standard size.
4. Mechanical Properties: The CEBs produced in New Mexico have a higher density than those made in Santa Fe, Argentina, due to the larger aggregate size used in their production, and they exhibit significantly higher compressive strength than required by state regulations. On the other hand, CEBs manufactured in Santa Fe, Argentina show considerable variations in strength, depending on the production facility. This variability is attributed to differences in the quantity and type of mineral stabilizer used. Since municipal regulations in Santa Fe, Argentina do not establish minimum strength requirements, a comparison with New Mexico’s standards reveals that the weakest CEBs in Santa Fe meet the minimum required strength (21 kg/cm²), while the strongest ones exceed this value by more than five times (110 kg/cm²). Regarding adobes, those produced in Santa Fe have a higher compressive strength than their counterparts in New Mexico. Notably, New Mexico’s adobes do not meet the state’s minimum required compressive strength of 21 kgf/cm² but do surpass the strength thresholds established by other international standards, such as those in Brazil, El Salvador, and Peru.
5. Sale Price and Market Demand: Both CEBs and adobes produced in New Mexico are significantly more expensive than those in Santa Fe, Argentina. However, this price difference must be considered in relation to the regional economy and the size of the masonry units, as Argentine-made elements are smaller. Finally, regarding customer

profiles, CEBs in New Mexico are primarily purchased by local contractors and prestigious architectural firms, while adobes are mainly used for restorations and home expansions by private clients. In contrast, in Santa Fe, Argentina CEBs buyers are individuals interested in sustainable materials, while adobes are chosen for their traditional and environmental value. However, demand in Argentina is lower and less stable than in New Mexico, limiting sector growth.

In conclusion, New Mexico benefits from an established regulatory framework, stable CEBs and adobe production, and consistent demand. Meanwhile, in Santa Fe, the adobe and CEBs manufacturing and construction sector faces regulatory, commercial, and technical barriers that hinder its expansion. Implementing province-wide regulations with precise technical definitions could be a key step toward strengthening this technology and promoting the development of earthen construction in the region.

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