

Original Research Article

Evaluation of Traditional and Modern Approaches to Reinforcing Adobe Brick Against Environmental Factors*Somayah Pahlevan¹, Somayah Fadaei Nezhad Bahramjerdi^{1**}**1. Department of Iranian Architectural Studies&Architectural and Urban Heritage Conservation, School of Architecture, College of Fine Arts, University of Tehran, Tehran, Iran**

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Abstract

Statement statement: Adobe buildings—among the oldest works and human-made structures—were once the primary shelters for people and, even today, still maintain their use in parts of the world. As one of the oldest construction materials, adobe has continuously been exposed to vulnerability against environmental factors such as moisture, rainfall, temperature fluctuations, and weathering. This issue, particularly in historic adobe structures, leads to gradual deterioration and a reduction in the structures' durability. In this context, the need to protect these adobe ensembles—whose structural damage has already been exacerbated by natural and human factors—becomes evident.

Research objective: This research aims to introduce and evaluate traditional and modern strategies used to reinforce adobe brick against damaging environmental factors, including moisture.

Research method: The present study is descriptive-analytical. Data collection is conducted through documentary studies (library-based research).

Conclusion: The results indicate that although traditional methods remain important due to their compatibility with local climate, accessibility, and low cost, their effectiveness under harsh climatic conditions is limited. In contrast, modern technologies have been able to improve the durability of adobe more effectively, although high costs and incomplete compatibility with historical fabric are among their main challenges. Ultimately, the study emphasizes that combining traditional and modern approaches—and applying findings from research—shows that traditional methods such as adding straw and using straw-clay (kāhgāl) plaster, despite being simple, inexpensive, and environmentally compatible, have limited durability against moisture and severe conditions. Conversely, modern solutions based on chemical and nano-materials provide greater mechanical resistance and stability. Therefore, the best approach is to integrate these two categories of methods to achieve both durability and architectural authenticity.

Keywords: *Reinforcement, Environmental factors, Modern techniques, Local materials, Moisture.*

Introduction

Clay brick, as one of the oldest building materials, holds a significant place in the history of human civilization's development and has played an

influential role in shaping indigenous architecture, especially in dry and semi-dry regions. In Iran, this material has also been a fundamental component of construction, widely used in residential, religious, and military structures. Notably, many exemplary examples can still be observed in the historic fabric of cities such as Yazd, Kerman, and Kashan.

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Despite advantages such as easy access, low cost, environmental compatibility, and good thermal performance, brick faces major limitations. Among the most critical challenges are its high sensitivity to environmental factors such as humidity, rainfall, temperature fluctuations, wind erosion, and earthquakes (Minke, 2000; Rajabi, 2013). This vulnerability has led to the deterioration and destruction of a considerable part of the earthen architectural heritage. Over time, different societies have employed various strategies to mitigate these issues. Traditional methods include adding natural fibers like straw to increase cohesion, using clay and lime-based coatings to reduce moisture penetration, and designing structures suitable for local climates (Dashtizadeh & Gerhani, 2018). Although these techniques align with the local conditions and have somewhat enhanced durability, their effectiveness diminishes under severe climatic conditions and natural disasters. In recent decades, scientific and technological advances have opened new possibilities for improving the performance of clay bricks. The use of chemical additives, nanomaterials, polymers, and protective coatings is among the innovative approaches proposed to enhance the mechanical resistance and durability of these materials (Martínez-García et al., 2020). These methods, by altering the microstructure of the brick or applying protective layers, have significantly increased its resistance against moisture and erosive factors. However, adopting such technologies also presents challenges, including high costs, the need for specialized knowledge, and, most importantly, potential conflicts with the principles of cultural heritage preservation (Khoshbakht Bahramani & Sepehri Moghadam, 2013). In this context, modern restoration approaches emphasize that interventions should not compromise the authenticity and cultural values of historic structures. Therefore, a systematic review and comparison of traditional and modern methods of brick reinforcement is essential in architectural and conservation studies. Such an approach can aid in

selecting the most suitable strategies for protecting earthen structures and foster the development of indigenous, low-cost, and culturally compatible solutions. Within this framework, the present research adopts a comparative approach to examine both traditional and modern methods of brick reinforcement, aiming to address the key question: what are the most important strategies employed in each approach to counteract environmental factors? Additionally, it seeks to analyze the strengths and weaknesses of each method and to propose solutions to increase the durability of bricks and extend the lifespan of related structures.

Research Background

Archaeological findings in the Middle East indicate that the use of earthen architecture has persisted from the Neolithic period to the present day. Among the oldest known examples is the settlement of Jericho, which dates back to around 8000 BCE, covering an area of approximately 4 hectares with a circular plan, providing evidence of the intentional use of clay materials. Following this trend, the civilizations of Mesopotamia and Elam played significant roles in the development of earthen architecture. Notable sites from this era include Mari in Syria, Tell Hassuna in southern Iraq (circa 5000 BCE), the religious complex of Uruk in the city of Ur (3200 BCE), and the Ziggurat of Chogha Zanbil in Khuzestan (2nd millennium BCE), all of which are among the prominent examples. Additionally, structures like the Tower of Babel from the 7th century BCE illustrate the continuity and evolution of this architectural style over time. In the Iranian plateau, numerous pieces of evidence of the use of clay bricks have been found in sites such as the Sialk Hill in Kashan (4000 BCE), the Zaghāh Hill in Qazvin (7000 BCE), and the Ganji Dera (8000 BCE). Furthermore, in the complex of Persepolis, one of the most distinguished architectural sites of the first millennium BCE, insulated clay bricks treated with tar were utilized in areas like underground waterways, showcasing advanced technical knowledge in the application of these materials. In the historical

periods that followed, the use of clay bricks continued. Significant examples of this trend include the cities of Nasā near Ashgabat and Hekatompylos in southwestern Damghan during the Parthian era, as well as the Kakh-e Kouh Khwaja during the same period. In the early Islamic centuries, Sasanian architectural patterns continued to be employed in various regions, especially in desert areas. During the Seljuk period, the use of brick coverings to protect earthen cores became widespread, a practice that expanded during the Ilkhanate and reached its peak in the Timurid period. The Safavid and Qajar periods are also noted for caravanserais, which serve as important examples for studying earthen architecture (Ebrahimi, 2019, 13). In addition to the prominent buildings, a significant portion of living spaces, including houses, residential complexes, and even defensive structures like castles, were constructed using clay bricks and mud in cities and villages, highlighting the extensive role of these materials in the daily lives of past communities (Table 1).

• **International charters, treaties, and summits**

In recent decades, extensive studies have been conducted on earthen materials and the conservation of earthen architecture. The earliest scientific attention to this topic can be traced to approximately the 1950s and 1960s (Alva, 2008, 3). In the 1970s, the International Scientific Committee on Earthen Architectural Heritage was established by ICOMOS, and programs for the conservation of historic earthen buildings were developed. The International Symposium on the Conservation of Adobe Buildings held in Iran (1972 and 1976), and the third symposium held in Ankara, were among the first practical initiatives in this field (Majedi Ardakani, 2004, 148). Following these activities, professional training courses titled PAT were held between 1989 and 1999 for the management and conservation of earthen architecture. In 1989, the Gaia project began as a collaboration between the International Centre for Earth Construction in Grenoble (CRATERE) and ICCROM, and its results were published in the form

Table 1. Technical Characteristics of Adobe (Clay Brick) Structures Across the History of Iran. Source: Maserat, 2022.

Features	Provided
At this stage of human settlement evolution, the use of wattle and daub and adobe bricks was not yet widespread; living spaces were mostly formed as dug pits, whose floors were rudimentarily covered with stone.	9th–10th millennium BC
Handmade adobe bricks became common — use of clay mortar between the bricks and clay plaster for wall surfaces became widespread — walls had corner molding using clay — elongated bricks about one meter long with one convex and one flat face were common — bricks shaped like cigars with one convex and one flat face were also common — evidence of reinforcing adobe structures with wood and reeds — evidence for using grass and crushed stone as additives in bricks — the emergence of adobe brick joints.	8th millennium BC
Simultaneous use of wattle and handmade adobe bricks — bricks produced by cutting a slab of clay paste spread on the ground — use of crushed straw, chopped grass, and fine gravel as additives in bricks — evidence for improving clay paste through processing to enhance product quality — creating indentations on brick surfaces to improve adhesion with mortar and plaster — widespread use of red clay plaster on the surface as a decorative covering — evidence of repairing clay plaster in eroded and damaged areas.	7th millennium BC
Likely use of wood for roofing houses.	6th millennium BC
Evidence of using molds for brick-making (the beginning of transformation).	5th millennium BC
Use of molded adobe bricks for constructing buildings.	4th millennium BC
Simultaneous use of wattle and molded adobe bricks — evidence of wooden beams used for roofing spaces — evidence of floor insulation in some rooms using wooden beams and spatial partitions.	3th millennium BC
Use of protective brick cladding around the adobe core of buildings — use of crushed bricks in adobe to improve drying behavior — application of dry masonry technique under heavy floors.	2th millennium BC
Widespread decorative designs using bricks — use of gypsum as mortar between bricks in some parts.	1st millennium BC (Medes)
Evidence of isolating adobe with bitumen — construction of residential houses using the “Jenaqi” technique — evidence of building curved and domed roofs — execution of flat roofs with bricks laid on their length — use of adobe bricks for flooring in some spaces.	1st millennium BC (Persians)
Use of stone to cover adobe volumes in the late Parthian period.	1st millennium BC (Parthians)
Use of regular clay blocks, approximately one cubic meter in volume. According to André Godard, the construction of adobe domes was common, but all are now lost.	Sasanian period

of scientific papers. In 1994, the Getty Conservation Institute (GCI) expanded its training and research programs on the conservation of earthen structures. Since 1997, an international consortium consisting of the Grenoble School of Architecture, the Getty Conservation Institute, the Aga Khan Foundation, several European universities, and institutions such as Terra, Auroville, and other centers has promoted earthen architecture at the international level. Support from organizations such as UNESCO, ICCROM, and ICOMOS has also played an important role in this field. Numerous field studies have shown that adding different materials to adobe and earthen mortar can improve their durability and mechanical resistance. For example, Ebrahimi (2019), in studies at Chogha Zanbil, tested the addition of straw, ash syrup, lime, river sand, and brick powder to local soil in order to increase the durability of earthen mortar. The use of straw, particularly in the soils of the Isfahan region, reduces the shrinkage coefficient of adobe, while the addition of date palm fibers along with other additives increases soil stabilization and durability (Esmacili & Ghalenoie, 2012). Bater (2017) showed that adding 3% by weight of kaolin with a particle size of 150 microns and 3% zeolite with a particle size of 45 microns reduces the permeability coefficient of kahgel plaster by up to 65% and 85%, respectively, and improves its insulating properties. The results indicated that reducing the particle size of additives has a greater positive effect on the physical and mechanical properties of the mortar. Other studies have also investigated chemical and mineral additives. Namvar and Zarini (2019) demonstrated that a combination of sodium silicate and acrylic significantly increases the compressive, flexural, and moisture resistance of kahgel. Hosseini Keshtan (2019) reduced the permeability and erosion rate of adobe using zeolite and determined its optimal amount. Ebrahimi (2019) tested improved samples of adobe and earthen mortar using indigenous products and showed that the impact resistance of adobe increased by up to 342%, stress tolerance by 214%, and slip resistance by 300%. Mirjalili (2022) reported

that polypropylene fibers with high surface adhesion increase the compressive, tensile, and flexural strength of adobe. Mohammadi (2021) also showed that adding 0.25–0.5% date palm fibers provides the best mechanical performance, whereas adding lime alone results in relatively low compressive strength. Hajirasouliha (2024) concluded that adobe made from fine-grained soil with an appropriate clay ratio has higher mechanical strength than samples containing coarser particles. Particle size and shape, as well as the balance between fine and coarse grains, directly affect porosity, compaction, and the resistance of adobe to water absorption. Yetgin et al. (2008) also state that increasing the content of natural fibers improves the tensile and compressive strength of adobe, although high fiber contents may reduce the uniformity of the material.

Numerous studies have examined methods for improving adobe properties and protecting earthen structures. Quagliarini & Lenci (2010) showed that clay content between 12 and 16% by weight and the addition of natural fibers (straw) help control the plastic behavior of adobe and reduce drying cracks; the use of stabilizers also increases compressive strength. Alavéz Ramírez et al (2012) found that adding 10% lime and 10% sugarcane bagasse ash to adobe blocks improves durability and mechanical resistance. Millog et al. (2014) showed that adding 0.2–0.6% by weight of 3 cm fibers of Hibiscus cannabinus reduces the porosity of adobe and improves its mechanical properties, while 0.8% by weight of 6 cm fibers has a negative effect. Calatan et al. (2016) determined the optimal fiber content for hemp and straw to be 9–10% and 30–40%, respectively. Sharma et al. (2015) demonstrated that adding 0.5–2% fibers of *Pinus roxburghii* and *Grewia optiva* increases the stability of adobe houses. Silva et al. (2020) emphasized that the combination of clay and sand and the addition of stabilizers influence capillary absorption, drying rate, and the mechanical strength of adobe. Oliveira (2021) also evaluated natural and synthetic additives and determined their optimal percentages and performance. Ouedraogo

et al. (2019) found that adding up to 1% rice husk by weight to clay adobe improves compressive strength, reduces thermal conductivity, and enhances resistance to water erosion. Mihić Brkanić (2024), in a study conducted in eastern Croatia, reported the optimal soil composition for adobe as 2.2% medium gravel, 37.9% sand, 49.6% silt, and 10% clay, and determined the average moisture content of adobe walls. Overall, research findings indicate that the use of both traditional and modern additives can improve the durability and strength of adobe. Therefore, evaluating, classifying, and comparing these additives is essential for selecting the most appropriate traditional and modern methods for strengthening indigenous materials.

Theoretical Framework

A large portion of the world’s historical buildings has been constructed using adobe, earth, and rammed earth, and these structures are continuously subject to deterioration and erosion due to environmental conditions. The importance of preserving this cultural heritage has been repeatedly emphasized. The aim of this research is to evaluate traditional and modern techniques for preventing erosion caused by environmental factors, particularly moisture, as a significant portion of these structures is damaged each year by precipitation and climatic conditions. This study focuses on architectural heritage with earthen structures and examines the overarching variables of earthen architecture, environmental factors, and conservation methods. It seeks to reduce the erosion of such buildings through the adoption of

appropriate conservation strategies. In this context, the operational concepts of the research include the strengthening of buildings to increase durability and lifespan, adobe as a subset of earthen architecture, and moisture as a subset of environmental factors. All of these variables are examined through the evaluation of both traditional and modern techniques for the conservation of historic buildings (Fig. 1).

One of the major environmental factors contributing to the deterioration of adobe and earthen structures is moisture. Strengthening refers to the set of actions through which the safety, stability, and rehabilitation of existing and damaged structures can be improved. In Fig. 2, the strengthening approach related to the practical aspect of structural resistance considered in this research is presented.

• Pathology of earthen structures

Among the most significant forms of damage affecting adobe is water erosion, which occurs under the

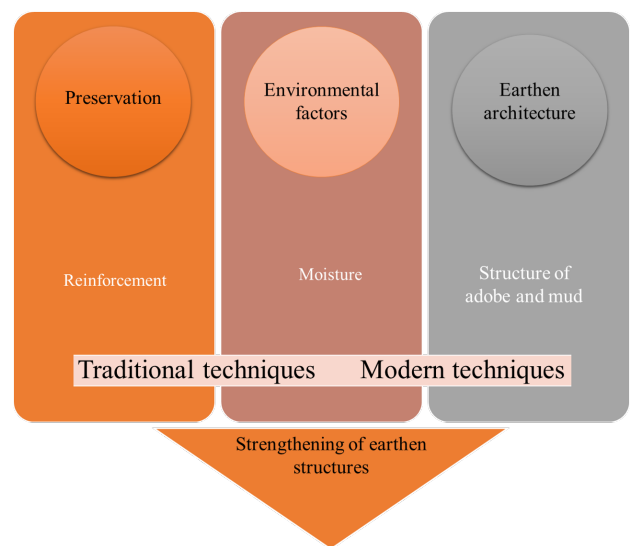


Fig. 1. Variables Presented in the Study. Source: Authors.

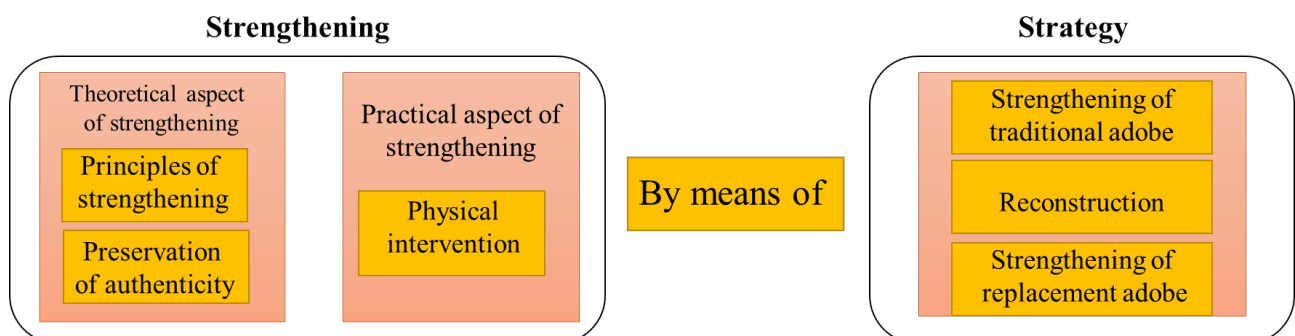


Fig. 2. Diagram of the Approach Related to the Practical Aspect of the Conservation Field. Source: Authors.

influence of rainfall and flooding. This process alters the mechanical and physical properties of the material and changes the form of the structure. Flaking and powdering, caused by prolonged exposure to moisture, and cracking, resulting from repeated cycles of wetting and drying as well as fluctuations in humidity, are other major forms of deterioration that reduce the structural strength of buildings. Efflorescence is also produced by the movement of moisture and its reaction with soluble salts present in the adobe. Different erosion textures can be observed in adobe, including wavy, grooved, scraped, and spongy patterns. These respectively indicate mild water erosion, severe water erosion, the combined effects of wind and rain, and the destructive force of wind carrying abrasive particles. Soils naturally contain moisture, which contributes to the cohesion of soil particles; however, in hot and dry environments, this moisture decreases, making the material more

susceptible to erosion. The damages observed indicate an imbalance caused by destructive factors. Such deterioration begins with visible physical changes, such as erosion and cracking, and ultimately leads to a reduction in resistance against environmental and human impacts. After conservation interventions, these factors can either halt the erosion process or improve the critical condition of the structure. In this research, with a focus on environmental factors—particularly moisture—efforts have been made to evaluate the extent of environmental damage and strengthening methods against different types of moisture. Based on previous studies, moisture in historic adobe buildings originates from several sources (Table 2).

• **Traditional and modern additives for adobe production**

In Iran and across the world, various traditional and modern methods have been applied to strengthen

Table 2. Factors Affecting Damage Related to Adobe Structures. Source: Authors.

Origin / Source	Environment	types	Factors Causing Damage (Visual Representation)
Natural	Climate (Climatology)	Physical	Temperature (cold and heat), moisture (surface water, floods, rain, hail)
	Landform (Geomorphology)	Physical and Mechanical	Materials and substances (quantity and quality, bonding, composition, and material quality)
	Ecology	Vegetal (Plant-based)	From small-scale agents such as mold and fungi to large-scale agents including shrubs, grasses, and short plants; root-induced hollowing caused by tree roots and plant growth; algae and parasitic plants; fungi, mold, moss; shrubs and trees.
		Animal (Biological, Microbiological)	Various animals, including termites and different insects, microscopic organisms and microorganisms, insects (termites, woodworms, moths, etc.), pests (rats, snakes, etc.), birds, animals such as dogs, animal droppings, and their combination with rainwater
Social	Individual	Individual	Lack of cooperation by private owners in restoration and preservation; irresponsibility and negligence (forgetfulness)
		Group	Illegal activities outside official frameworks in historic sites (unprincipled restorations)
	Individual	Individual	Lack of participation in utilization and preservation
Economic	Collective	Collective	Absence of clear frameworks for promoting the tourism industry; lack of budget allocation for conservation, restoration, and revitalization of non-private sectors
		Individual	Individual
Human-made (Anthropogenic)	Cultural	Collective	Lack of promotion by management organizations for cultural preservation and continuity, past and present
		Research (Studies)	Cooperation with specialized scientific bodies in the protection and restoration of historic buildings, laboratory studies, and effective private companies
	Managerial	Policy-making (Regulations and Laws)	Design and implementation of rules, regulations, laws, and agreements with relevant organizations at neighborhood, city, regional, national, and international levels for preservation and maintenance
		Operational (Intervention)	Operational (Intervention)

adobe structures. In principle, any type of soil can be optimized by adding strengthening materials, and the best results are obtained when, before any conservation project, the necessary tests are conducted to determine soil type, select the appropriate stabilizing material, and define its optimal proportion (Houben & Guillaud, 1994,7). The strengthening process can be mechanical, chemical, or physical, and the soil may be reinforced using both natural and synthetic additives, consisting of organic and mineral substances (Fig. 3).

Various types of additives are examined, including natural and synthetic additives, both organic and mineral, in order to identify and determine the additives that will be evaluated in this study.

• **Natural additives**

Natural additives are divided into two categories: organic and mineral. Although the use of synthetic materials for the consolidation and strengthening of earthen materials has increased in recent years, there is a consistent effort to use natural reinforcing materials compatible with the substrate due to the lower cost-effectiveness of synthetic options.

• **Natural mineral additives**

The use of mineral materials in earthen structures has a long history, and the primary materials used for strengthening and increasing moisture resistance typically come from this group (Guillaud, 2011). Sand is the most common mineral additive, influencing many physical and mechanical properties of soil, such as color, texture, tensile strength, compressive strength, and abrasion resistance. The distribution, gradation, particle shape, and their ratio to various types of clay have a significant impact on soil performance. Other minerals, such as cement, gypsum, and lime, are also used in strengthening earthen materials, although the

extent of their usage and their physical and chemical effects remain subjects of debate and criticism among researchers (Hosseini Keshtan, 2019, 74).

• **Natural organic additives**

Extensive research has been conducted on the use of organic additives to strengthen soil against moisture. Recognizing these materials aids in understanding the history and culture of regions possessing valuable earthen architecture. However, the diversity of materials and their preparation methods, site-specific conditions, and differing analytical techniques make their evaluation and adaptation for conservation interventions difficult. Natural organic additives include fibrous supplements such as reeds, straw, hair, animal wool, and plant and animal fats. Their use is not only functional but also reflects a philosophical approach and an inclination toward local traditions (Oliver, 2008).

• **Organic additives of animal origin**

The application of animal products to strengthen materials against moisture has a long history. Products such as blood, urine, excrement, casein, and animal glue have been used for centuries to increase the durability of materials (Minke, 2009, 66). The most important of these additives are categorized in Table 3.

• **Natural organic additives of plant origin**

Among the most important fibers used to improve earthen materials—particularly to prevent cracking—are plant-based fibrous additives, especially chopped plant fibers. Plant additives include the following materials.

• **Natural organic additives of plant origin**

Most natural organic additives of plant origin used in the conservation of earthen materials and adobe are primarily applied as surface treatments or protective layers on earthen or gypsum surfaces. It

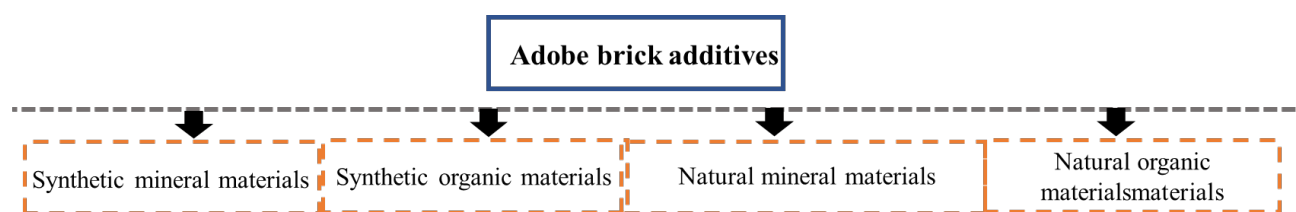


Fig. 3. Classification of Additives Introduced in This Research. Source: Authors.

Table 3. Animal Origin. Source: Authors.

Origin	Additive Name	Property
Animal fats and tallow	Fish oils and animal fats	Waterproofing agent for adobe materials and soils (Ebrahimi, 2019, 304)
Animal droppings	Animal dung, cow dung cake, glue, and donkey droppings	Soil and earthen material stabilizer, increasing wet strength of materials, improving adhesion
Animal proteins and albumins	Protein amino acids (blood, animal glues such as hide glue, gelatin, and casein), skin, bones, and connective tissues, collagen, gelatin, casein, termite saliva, and termite saliva and feces	Increasing soil hardness and strength, soil improvement, soil particle compaction, increasing soil cation exchange capacity, increasing organic matter and nutrient content of soil (Pereira, 2011, 248)

Table 4. Plant origin. Source: Authors.

Origin	Additive Name	Property
Plant fibers	Wheat, barley, and rice straw; grass; reeds; chopped bamboo; coconut fibers; conifer tree leaves (Warren, 2008, 102 & Minke, 2009, 64); maize plant, corn cob, cotton stalk, rice husk, banana stem, palm fibers, coconut leaves, and wood chips (Pinto et al., 2012); alfalfa, hemp, sisal, elephant grass (Bahobail, 2012, 27); cattail (for reinforcement of earthen materials); madder (Ardakan, Yazd); datepalm fibers; bagasse residues; goat hair (Galdieri, 1995); camel wool; oats; kenaf and flax (Laborel et al., 2016).	Binding soil particles, increasing tensile strength, stabilizing soil and earthen materials, optimizing soil moisture content, thinning (lean) clay soil and reducing shrinkage, lightening the soil, converting into a type of thermal insulation (Ebrahimi, 2001, 295 & Esmaeili and Ghaleh-Noei, 2012, 55), reducing the rate of cracking, and making it moisture resistant.
Saps (extracts), resins, and plant gums	Polysaccharides; agave cactus sap; ficus resin; euphorbia resin; eucalyptus resin; banana resin; sandarac resin; wallaba resin; shellac; gum arabic; Ceratonia siliqua resin; Euphorbia lactea; Mazapar discica (banana); and Opuntia ficusindica (cactus).	Soil stabilization and leveling, water insolubility, increasing durability, and reducing the rate of water absorption
Vegetable oils	Fats, oils, and soaps, including coconut oil, linseed oil, and cottonseed oil.	Waterproofing, increased soil resistance.

appears that liquid stabilizers derived from plant-based solid materials—except for less soluble fibers—have rarely been incorporated directly into the soil during the production of adobe and other earthen materials. Instead, their application is more commonly observed in the consolidation and strengthening of earthen surfaces, including plain surfaces or those bearing paintings and decorative motifs. Vegetable oils are also mainly used as binders, fillers, or paints, and apart from traditional applications, their experimental or conservation use is not common. One notable study in this field is the research conducted by Afshin Ebrahimi (2019), which examined the use of sugarcane bagasse residues from sugar factories combined with lime sludge. This research aimed to stabilize and increase the strength of adobe and mud–straw plaster at the Chogha Zanbil archaeological site, demonstrating that the addition of these natural materials can enhance the durability and resistance of earthen materials.

• **Natural mineral additives**

This category includes various types of gravel, sand, and similar materials, which have long been added

as fillers to building materials such as adobe and brick (Table 5).

• **Synthetic organic additives in earthen materials**

This group of additives, commonly referred to as modern additives, is used to increase the durability and strength of earthen materials. Their main advantages include long-term stability, controlled composition, and the prevention of premature changes in color and texture (Avrami et al., 2008, 100). Synthetic organic materials generally exist in three forms and include synthetic resins, paraffins, waxes, and latexes, which have been used primarily for the stabilization of earthen surfaces. However, their effectiveness in the conservation of earthen architecture is debated, as they tend to react negatively to ultraviolet radiation, are relatively expensive, and may impede vapor permeability within adobe and earthen plasters. Long-chain synthetic polymers, such as monomers and copolymers (Minke, 2009), due to their large molecular size, do not sufficiently penetrate the micropores of adobe or the layered clay surfaces, and their in situ polymerization process is difficult to achieve (Warren, 2008). Nevertheless, laboratory studies

have applied ethyl silicate as a spray on the exterior surfaces of unplastered earthen walls. Results from two regions—New Mexico and Grenoble, France—demonstrated that this material reduced surface erosion of the walls. Among the most common and successful synthetic organic additives are acrylic emulsions, which consist of diluted copolymers of ethyl acrylate, methyl methacrylate, or ethyl methacrylate. These are typically used at concentrations below 15% to prevent undesirable changes in water vapor permeability (Atzeni et al., 1993). These emulsions often function as surface binders, connecting clay particles to one another rather than stabilizing the soil through absorption (Hartzler, 1996). Vinyl polymers, such as polyvinyl acetate and polyvinyl alcohol, have also been used for soil stabilization, but they are mainly applied as surface coatings and consolidation layers and exhibit different behaviors in mortars and other earthen materials (Stefanson, 1993). Other studies, such as those conducted by Taylor (1990), compared the use of bitumen emulsions, acrylic paints, and straw in stabilizing adobe walls and identified limitations in the application of synthetic organic

materials due to variations in soil composition and environmental conditions. In addition, investigations on tetraethoxysilane applied to samples from Abu Sir, Egypt, showed that this substance acted as an effective strengthening agent (Warren, 2008). Other synthetic organic materials include silanes, polysiloxanes, silicone resins, siliconates, and ester silicates with hydrophobic additives. Among these, silanes, siloxanes, and silicone resins create water-repellent properties through chemical reactions with the mineral components of soil, reducing moisture absorption in earthen materials by up to 90% (Table 6).

• **Acrylic resins in conservation and restoration**

Acrylic resins are among the most important chemical additives used in the conservation and restoration of historical objects as well as in various industries. Methyl methacrylate, ethyl methacrylate, butyl methacrylate, and cyanoacrylates are the most significant groups of these resins, which are marketed under various trade names. Among the most well known and widely used resins are Paraloid, Acryloid, and Primal.

Acrylic emulsions are high-molecular-weight

Table 5. Natural and Synthetic Additives. Source: Authors.

Type of Additive	Property
Sand	Stabilization of clay soil, uniform grain grading, proper particle distribution, improved cohesion among soil particles, and reduction of soil shrinkage and cracking (Bahobail, 2012, 24).
Aeolian sand	Soil stabilization, improvement of the shrinkage behavior of earthen materials, and reduction of cracking (Rahimnia, 2012, 81).
Silica	The most common nonbiological additive and filler used to increase soil strength (Ghorbani et al., 2012, 50).
Clay	Improvement of the mechanical properties and durability of soil.
Shell and coral powder	A rich source of lime materials for soil stabilization (Ebrahimi, 2019, 304).
Natural pozzolan	Containing silica and alumina, resistant to the presence of moisture.

Table 6. Introduction to Types of Resins Source: Authors.

Type of Resin	Additive Name	Property
Cellulose resins	Various cellulose adhesives (cellulose acetate, cellulose nitrate), ethyl cellulose, methyl cellulose, carboxymethyl cellulose	Resistant to solvents, used for strengthening and protection against moisture.
Furfural resins	Alcohol, acetone, urea, aniline, resorcinol, phenol	
Amine resins	Amino resins, aminoplastics, resins obtained from aldehyde reactions	High transparency and resistance to damaging factors such as light, heat, and weathering; durable and effective for waterproofing walls and historical structures (Bahadari, 2006, 160).
Acrylic resins	Thermoplastics, copolymers	
Vinyl resins	Polyvinyl alcohol	Formation of a flexible film through water evaporation around soil particles.

polymers whose spherical particles are dispersed in water, with particle sizes typically ranging between 0.1 and 1 micron. Well-known examples include Primal AC 33 and Primal AC 634, which are copolymers of methyl methacrylate and ethyl acrylate. Acrylic resins are generally composed of two main monomer types: acrylic acid and methacrylates derived from methacrylic acid. These resins are usually classified as thermoplastics; however, by adding cross linking agents such as diamines, peroxides, or oxidation–reduction systems such as persulfates, they can be converted into thermosetting resins.

In addition to their application as stabilizers and strengthening agents for historical materials, the modification of resin chain branches can produce cyanoacrylates, which, due to their low viscosity, high adhesion strength, and rapid setting, are widely used in conservation treatments. Acrylic resins—particularly polymethyl methacrylate—have an irregular structure and, when highly pure, can transmit up to 92% of white light, exhibiting excellent transparency. These resins also show good resistance to aging and oxidation and only undergo thermal decomposition or depolymerization at temperatures above 200 °C. Another advantage of acrylic resins is their ability to be combined with other polymers to produce customized materials with specific properties. For instance, adding ethyl acrylate or butyl methacrylate to methyl methacrylate increases the chemical resistance, hardness, and abrasion resistance of the resulting polymer (Bahadori, 2007, 160).

• Functional evaluation of traditional and modern methods for strengthening adobe

Natural organic additives have long been used to stabilize and improve the physical and mechanical properties of earthen materials. The abundance of resources, low cost, easy availability, simple application, and preservation of local traditions are among the main reasons for the continued use of these materials in earthen architecture and adobe construction. Despite their many advantages, these materials are vulnerable to environmental and biological factors such as moisture, fungi, bacteria, insects, and rodents.

For this reason, synthetic resins and adhesives have gradually replaced natural materials. Synthetic resins are more resistant to biological factors and generally have a longer lifespan. However, they also present several challenges. These include limited access to imported products, high costs, the need for carriers and solvents, potential toxicity, and restrictions in their application within the internal structure of adobe and earthen materials. Furthermore, these resins are often applied as surface coatings and require periodic renewal to maintain their hydrophobic properties.

In addition to organic materials, mineral additives have also long been used to improve soil grading and reduce cracking during the drying of earthen materials. These natural and synthetic materials, due to their accessibility and relatively low cost, have played an important role in increasing the durability and performance of adobe and earthen construction materials.

The use of additives—both natural and synthetic—in adobe blocks and earthen mortars is considered an effective method for improving mechanical properties and reducing cracking. For example, in traditional Iranian construction, materials such as straw, wood fragments, date palm fibers, and natural lime have been commonly used to reinforce adobe and mud mortars, and this practice still continues in many rural areas. These additives are inexpensive, easily available, simple to use, and have fewer environmental impacts compared with non natural materials such as cement.

• Functional evaluation of traditional and modern adobe stabilization methods

Since ancient times, natural organic additives have been used to stabilize and enhance the physical and mechanical properties of soil and earthen materials. The abundance of resources, economic affordability, easy accessibility, simplicity of application, and preservation of indigenous traditions have been among the most important reasons for the continued and widespread use of these materials over time. Consequently, these materials are still widely used today. However, one of the main

limitations of this category of additives is their vulnerability to environmental and biological factors. Microorganisms, fungi, insects, rodents, and other biological agents—together with environmental conditions such as moisture—can lead to deterioration and decay of these materials. These issues gradually resulted in the replacement of natural organic additives with synthetic organic materials such as adhesives and resins. Synthetic resins generally exhibit greater durability and stability compared to natural organic materials and are less affected by biological factors. Nevertheless, their use is associated with several limitations. Most specialized resins and adhesives used in cultural heritage conservation are imported, and access to them has become difficult under recent economic sanctions. Moreover, their high cost and the large quantities required for strengthening adobe and earthen structures make their large scale application economically impractical. These resins are usually applied as surface coatings and require periodic reapplication to maintain their hydrophobic properties. Additionally, the use of aqueous or non aqueous carriers and solvents to transport these materials into the internal layers of soil may cause further complications. The penetration of water into clay layers can lead to soil swelling, especially in soils containing high amounts of clay minerals such as montmorillonite. Therefore, non aqueous solvents such as light hydrocarbons, alcohol, acetone, and toluene have been considered as alternatives. However, their toxicity and high cost limit their practical application. Many synthetic resins themselves are also toxic and may pose risks to both the environment and human health. Another group of additives used historically to improve soil and earthen material properties consists of mineral materials. These are primarily used to create appropriate soil grading and fill voids within the soil structure, thereby reducing shrinkage and preventing cracking during drying. A wide range of natural and synthetic mineral materials has been employed for these purposes. Their easy availability and economic advantages have made them widely used throughout

history. The incorporation of natural and synthetic additives in adobe blocks is considered an effective method for improving the mechanical properties of these materials. This method has a long history, and in many rural regions of Iran, straw is still used to reinforce fragile adobe blocks and earthen mortars. Adding fibers to soil acts as reinforcement and prevents the propagation of tensile cracks after their initial formation. Many natural additives, such as straw, wood chips, date palm fibers, and mineral lime, are inexpensive, readily available, and do not require complex technology. Moreover, compared with synthetic additives such as cement, they generally have fewer environmental impacts.

• **Analysis of traditional and modern adobe stabilization methods**

A review of the literature indicates that adobe stabilization strategies can generally be classified into two main categories: traditional and modern approaches. Traditional methods have primarily focused on improving soil composition through the addition of plant fibers such as straw and date palm fibers. In addition, the use of protective surface plasters—including straw–mud plaster, sarooj, and natural gypsum—has been one of the most common techniques for protecting wall surfaces against erosion and moisture penetration. Furthermore, in traditional Iranian architecture, structural strategies such as thick walls, the use of buttresses, and the application of arches and vaults have played an important role in enhancing the stability and durability of adobe buildings. In contrast, modern methods developed in recent decades have demonstrated improved performance in enhancing the mechanical strength and durability of adobe. Chemical additives such as lime, cement, and nanoparticles, synthetic fibers such as glass and polypropylene, as well as hydrophobic coatings and resins, constitute some of the key tools of this approach. In the field of seismic reinforcement, techniques such as the use of steel or wooden tie beams, concealed frames, and grout injection have been introduced as modern methods to increase

structural safety. Traditional methods are largely based on local materials and the experiential knowledge of vernacular builders, and they have performed relatively well in arid and semi-arid regions. However, when confronted with modern threats such as earthquakes, intense rainfall, and climate change, these methods reveal several limitations, including low shear resistance and limited durability under high moisture conditions. Modern approaches, by employing chemical additives, synthetic fibers, waterproof coatings, and seismic reinforcement techniques, have significantly improved the mechanical strength and durability of adobe materials. These methods are particularly effective in earthquake-prone regions and in conservation projects involving valuable heritage structures. Nevertheless, their main limitations include high costs, the need for advanced equipment and specialized expertise, and the potential reduction in compatibility with historic fabric and environmental sustainability. Comparative analysis suggests that the most effective performance is achieved when traditional and modern methods are applied in combination. Such an integrated approach allows the preservation of the authenticity and cultural identity of adobe architecture while simultaneously enhancing durability, safety, and climatic adaptability. Therefore, effective stabilization of adobe structures should be based on three key principles: technical sustainability, cultural–aesthetic compatibility, and economic feasibility. A comprehensive evaluation of traditional and modern adobe stabilization techniques indicates that each approach possesses distinct characteristics, advantages, and limitations depending on environmental conditions, project type, and the objectives of intervention. Selecting an appropriate strategy requires a simultaneous assessment of environmental factors, available materials, economic considerations, and conservation goals. Traditional stabilization methods—such as earthen coatings, lime-based mortars, shading systems, straw–mud plasters, and

other natural surface protection techniques—have historically held a prominent place in vernacular and sustainable architecture due to their environmental compatibility, ease of application, and low cost. These techniques are typically based on locally available materials and the accumulated empirical knowledge of generations of builders. As a result, they not only contribute to structural sustainability but also reflect the cultural and regional identity of traditional architecture. However, experimental and field studies indicate that the effectiveness of these methods is limited under severe climatic conditions, including prolonged rainfall, repeated freeze–thaw cycles, and extreme temperature fluctuations. Under such conditions, adobe structures may experience surface erosion, thermal cracking, and gradual loss of mechanical strength, thereby increasing the need for periodic maintenance and repair. Moreover, traditional coatings often cannot fully prevent water penetration and therefore cannot ensure long-term durability in humid environments. Despite these limitations, traditional techniques are still widely preferred in the restoration of historical monuments because they maintain architectural authenticity and cultural values while keeping intervention costs relatively low. Conversely, modern stabilization methods—developed through advances in material science and contemporary technologies—include the use of polymer additives, cement and hydraulic lime, natural or synthetic fibers, and mineral or carbon-based nanoparticles. These additives significantly improve mechanical strength, reduce water permeability, enhance pore structure compaction, and increase the thermal stability of adobe materials. Recent studies show that synthetic fibers and polymers play a crucial role in reducing cracks caused by mechanical and thermal stresses, while nanoparticles and hydraulic cement fill voids within the adobe matrix, thereby decreasing moisture absorption and increasing compressive strength. Nevertheless, the implementation of these modern techniques requires access to specialized technologies, skilled personnel, laboratory testing

facilities, and higher financial investment. In addition, some of these additives may not fully align with the principles of sustainable architecture or environmental considerations. Overall, analytical comparison between the two categories demonstrates that a balanced integration of traditional and modern techniques provides the most effective long-term performance in terms of durability, authenticity, and sustainability. The combined use of earthen and lime-based coatings with polymeric or nano-scale additives can significantly enhance adobe resistance to moisture, wind erosion, and thermal expansion and contraction while preserving its historical identity and aesthetic qualities. Such an integrated strategy is particularly suitable for conservation projects involving historic earthen structures located in harsh and variable climates. Furthermore, recent analytical findings suggest that future research should focus on determining the optimal ratio between traditional materials and modern additives, as well as examining the influence of different additives on the physical and mechanical properties of adobe under various climatic conditions. Such studies can contribute to the development of scientifically grounded, economically viable, and sustainable stabilization strategies for traditional architecture and the restoration of historic earthen heritage (Table 7).

Conclusion

The examination of traditional and modern methods for stabilizing adobe against environmental impacts indicates that each approach has its own advantages and limitations. Traditional methods—including mud and lime coatings, shading systems, and other natural protective techniques—offer greater environmental compatibility and help preserve the cultural and historical values of earthen architecture. However, these methods generally provide limited resistance to rainfall, moisture penetration, freeze–thaw cycles, and severe temperature fluctuations. Consequently, relying solely on traditional techniques may not be sufficient to ensure complete protection of adobe structures under harsh environmental conditions, although they remain valuable due to their economic feasibility and their role in preserving historical authenticity. Modern stabilization methods—such as polymer additives, cement and hydraulic lime, nanoparticles, and synthetic fibers—have demonstrated significant improvements in the mechanical strength of adobe, reduction of water permeability, and enhancement of long-term durability. These techniques make it possible to construct and maintain adobe structures even under severe climatic conditions and significantly extend their service life. Nevertheless, the primary limitations of modern methods include

Table 7. SWOT Evaluation of Traditional and Modern Methods for Adobe Masonry Reinforcement. Source: Authors.

Modern Stabilization Methods	Strengths	Weaknesses	Opportunities	Threats
Traditional (lime plaster, lime, shade)	High environmental compatibility, preservation of historical and cultural values, low cost and ease of execution, historically proven experience, and possibility of easy and rapid restoration.	Limited resistance to moisture, rain, and frost; shorter lifespan; need for frequent repairs; low earthquake resistance; dependence on skilled craftsmen.	Utilization in reconstruction projects of historical buildings, preserving architectural authenticity, attention to indigenous knowledge, the possibility of training, and reviving traditional skills	Rapid erosion and cracking in severe environmental conditions lead to decreased structural durability over time.
Modern (polymeric additives, fibers, nanoparticles, hydraulic lime)	Significant increase in mechanical strength, reduced water penetration and erosion, longer lifespan, possibility of scientific and precise control of materials, less need for frequent repairs, consideration of economic aspects, and adaptability to international standards	High cost and complexity of implementation, sometimes reduced compatibility with the environment and historical context, need for specialized equipment and personnel, difficulty in repair, and reversibility in case of method failure	Strengthening adobe under severe environmental conditions, potential combination with traditional techniques to preserve historical value, support from international organizations, and development of environmentally friendly modern technologies	High cost and economic limitations, lack of compatibility with some historical structures, uninformed use of chemical materials, lack of funding for implementation, fear of compromising the authenticity of adobe

higher costs, greater implementation complexity, and, in some cases, reduced environmental compatibility compared with traditional materials. Comparative analysis suggests that an intelligent integration of traditional and modern approaches can provide the most effective results. Such a combined strategy enhances the strength and durability of adobe against environmental factors while simultaneously preserving the historical and cultural values of the structure. This integrated approach is particularly effective in the restoration of historical buildings and in the construction or maintenance of earthen structures in regions with harsh environmental conditions. Overall, the findings of this study emphasize that the use of modern materials alongside traditional techniques represents a sustainable, scientific, and economically viable strategy for protecting adobe and increasing the durability of both historic and contemporary earthen structures.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the conduct and publication of this research.

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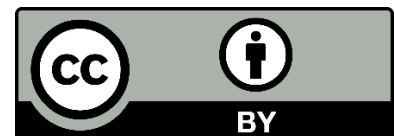
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