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# Standard Guide for Design of Earthen Wall Building Systems[1]

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## 1. Scope

1.1This standard provides guidance for earthen building systems that address both technical requirements and considerations for sustainable development. Earthen building systems include adobe, rammed earth, cob, cast earth and other earth technologies used as structural and non-structural wall systems.

1.1.1There are many decisions in the design and construction of a building that can contribute to the maintenance of ecosystem components and functions for future generations, that is, sustainability. One such decision is the selection of products for use in the building. This standard addresses sustainability issues related to the use of earthen wall building systems.

1.1.2The considerations for sustainable development relative to earthen wall building systems are categorized as follows: materials (product feedstock); manufacturing process; operational performance (product installed); and indoor environmental quality (IEQ).

1.1 This standard provides guidance for earthen building systems, also called earthen construction, and addresses both technical requirements and considerations for sustainable development. Earthen building systems include adobe, rammed earth, cob, cast earth, and other earthen building technologies used as structural and non-structural wall systems.

NOTE 1—Other earthen building systems not specifically described in these guidelines, as well as domed, vaulted, and arched earthen structures as are common in many areas, can also make use of these guidelines when consistent with successful local building traditions or engineering judgment.

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1.1.2 The considerations for sustainable development relative to earthen wall building systems are categorized as follows: materials (product feedstock), manufacturing process, operational performance (product installed), and indoor environmental quality (IEQ).

1.1.3 The technical requirements for earthen building systems are categorized as follows: design criteria, structural and non-structural systems, and structural and non-structural components.

1.2This standard does not provide guidance for structural support of roofs made of earthen material.

1.3

1.2 Provisions of this guide do not apply to materials and products used in architectural cast stone (see Specification C1364).

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

C66/C66MSpecification for Specification for Sand for Use in Lime Plaster
D559Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
D560Test Methods for Freezing and Thawing Compacted Soil-Cement Mixtures 1364 Specification for Architectural Cast Stone

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft$^3$(600 kN-m/m$^3$))
D5860 Test Method for Evaluation of the Effect of Water Repellent Treatments on Freeze-Thaw Resistance of Hydraulic Cement Mortar Specimens
2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
E631 Terminology of Building Constructions
E2114 Terminology for Sustainability Relative to the Performance of Buildings
2.2 *ASCE Standards:*[3]
ANSI/ASCE 7 Minimum Design Loads for Buildings and Other Structures
2.3 *New Zealand Standards:*[4]
NZ97 Engineering Design of Earth Buildings, 1998
NZ98 Materials and Workmanship for Earth Buildings, 1998
NZ99 New Zealand Standard, Earth Buildings not requiring Specific Design, 1998 (including amendment #1, December 1999)

## 3. Terminology

3.1 *Definitions:*

3.1.1 For terms related to building construction, refer to Terminology E631.

3.1.2 For terms related to sustainability relative to the performance of buildings, refer to Terminology E2114. Some of these terms are reprinted here for ease of use.

3.1.3 *alternative agricultural products*, *n*—bio-based industrial products (non-food, non-feed) manufactured from agricultural materials and animal by-products.

3.1.4 *biodegradable*, *adj*—capable of decomposing under natural conditions into elements found in nature.

3.1.5 *biodiversity*, *n*—the variability among living organisms from all sources including: terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

3.1.6 *ecosystem*, *n*—community of plants, animals (including humans), and their physical environment, functioning together as an interdependent unit within a defined area. —a community of biological organisms and their physical environment, functioning together as an interdependent unit within a defined area.

3.1.6.1 *Discussion*—For the purposes of this definition, humans, animals, plants, and microorganisms are individually all considered biological organisms.

3.1.7 *embodied energy*, *n*—the energy used through the life cycle of a material or product to extract, refine, process, fabricate, transport, install, commission, utilize, maintain, remove, and ultimately recycle or dispose of the substances comprising the item.

3.1.7.1 *Discussion*—The total energy which a product may be said to "contain" including all energy used in, inter alia, growing, extracting, transporting and manufacturing. The embodied energy of a structure or system includes the embodied energy of its components plus the energy used in construction.

3.1.8 *indoor environmental quality, IEQ*, *n*—the condition or state of the indoor environment.

3.1.8.1 *Discussion*—Aspects of IEQ include but are not limited to characteristics of the thermal, air, luminous and acoustic environment. Primary areas of concern in considering the IEQ usually relate to the health, comfort and productivity of the occupants within the indoor environment, but may also relate to potential damage to property, such as sensitive equipment or artifacts.

3.1.9 *renewable resource*, *n*—a resource that is grown, naturally replenished, or cleansed, at a rate which exceeds depletion of the usable supply of that resource.

3.1.8.1

3.1.9.1 *Discussion*—A renewable resource can be exhausted if improperly managed. However, a renewable resource can last indefinitely with proper stewardship. Examples include: trees in forests, grasses in grasslands, and fertile soil.

3.1.9

3.1.10 *sustainability*, *n*—the maintenance of ecosystem components and functions for future generations.

3.1.10

3.1.11 *sustainable development*, *n*—development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

3.1.11

3.1.12 *toxicity*, *n*—the property of a material, or combination of materials, to adversely affect organisms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adobe*, *n*—*(1)* unfired masonry units made of soil, water, and straw with or without various admixtures; *(2)* the soil/straw or soil/straw/admixtures mix that is used to make them; *(3)* the mud plaster used for covering walls or ceilings, or both; *(4)* the

[3] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.
[4] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.
[4] Available from Standards New Zealand, Radio New Zealand House, Level 10, 155, The Terrace, Wellington 6011, http://www.standards.co.nz.

~~building that is built of adobe and; *(5)* the architectural style.~~ —(*1*) (*building product*), unfired masonry units made of soil, water, and sometimes straw or other admixtures;
(*2*) (*product feedstock*), the soil/straw/admixtures mix that is used to make *adobe (1)*, (here also called *earthen building mixtures* or *earthen material* ;
(*3*) (*building product*), the earth plaster used for covering walls or ceilings, or both;
(*4*) (*structure* ), the building that is built of *adobe (1), (3)*; and
( *5*) (*building design*), an architectural style of earthen construction (see also 3.2.9).

3.2.1.1 *Discussion*—~~The word itself is believed to come from an Arabic word~~ —*The word itself comes from an Arabic word atob*, which means muck or sticky glob or *atubah* ~~"the brick." The adobe style of architecture migrated from North Africa to Spain, so the name adobe is likely to have come with it. In many other countries, the word adobe is meaningless, and it is more accurate to say "earthen-brick." Other forms of the same material with different details and names, such as rammed earth, Pisé, Jacal, Barjareque, cob, or puddled mud are sometimes referred to as adobe.~~ "the brick." In many other countries, the word "adobe" is meaningless, and it is more accurate to say "earthen-brick." "Adobe architecture" also has different meanings in different places.

3.2.2 ~~*adobe construction*~~asphalt emulsion, *n*—~~construction in which the exterior load-bearing and the non-load-bearing walls and partitions are of unfired clay masonry units while the floors, roofs and interior framing may be wholly or partly of wood or other approved materials.~~ —a thick liquid made by combining by-products of crude oil distillation with water and proprietary surfactants.

3.2.3 ~~*adobe, stabilized*~~cast earth, *n*—~~unfired clay masonry units to which admixtures, such as emulsified asphalt or cement, are added during the manufacturing process to help limit water absorption and increase durability.~~ —a construction system utilizing a slurry containing soil plus a chemical binder such as portland cement or calcined gypsum and water, which is sprayed against or poured into forms similar to those used for cast-in-place concrete; also called *poured earth*.

3.2.3.1 *Discussion*—In the sprayed system, modern shotcrete equipment is adapted to spray the wet earth mixture, which is usually stabilized earth.

3.2.4 ~~*adobe, unstabilized*~~clay, *n*—~~unfired clay masonry units that do not meet the definition of stabilized adobe.~~ —inorganic soil with particle sizes less than 0.002 mm (0.00008 in.) having the characteristics of high to very high dry strength and medium to high plasticity.

3.2.4.1 *Discussion*—This size definition for clay, along with those for silt, sand and gravel, is according to Practice D2487. Other standards in the world have slightly different size limitations.

3.2.5 ~~*carbon sink*~~cob, *n*—~~a reservoir that absorbs or takes up released carbon from another part of the carbon cycle.~~ —a construction system utilizing moist earthen material stacked without formwork and lightly tamped into place to form monolithic walls.

3.2.5.1 *Discussion*—~~For example, if the net exchange between the biosphere and the atmosphere is toward the atmosphere, the biosphere is the source, and the atmosphere is the sink~~ —Reinforcing is often provided with organic fibrous materials such as straw.

3.2.6 ~~*cast earth*~~earth, *n*—~~a construction system utilizing a slurry containing soil, calcined gypsum and water, which is poured into forms similar to those used for cast-in-place concrete.~~ —granular material derived from rock, usually with air voids and often with organic content (humus) (also called *soil*).

3.2.7 ~~*clay*~~earth, stabilized, *n*—~~inorganic soil with particle sizes less than 0.005 mm (0.0002 in.) having the characteristics of high to very high dry strength, medium to high plasticity and slow to no dilatancy.~~ —earthen building mixtures to which admixtures are added during the manufacturing process to help limit water absorption, stabilize volume, increase strength, and increase durability (see also *stabilization*).

3.2.8 ~~*cob*~~earth, unstabilized, *n*—~~a construction system utilizing moist earthen material balls stacked on top of one another and lightly tapped into place to form monolithic walls. Reinforcing is often provided with organic fibrous materials such as straw and twigs.~~

~~3.2.9*earthen building systems*~~—earthen building mixtures that do not contain admixtures intended to help limit water absorption, stabilize volume, increase strength, and increase durability (see also *stabilization*).

3.2.9 *earthen construction*, *n*—~~building systems that utilize soil as the principal structural material.~~ —construction in which walls and partitions are comprised primarily of earth.

3.2.9.1 *Discussion*—Roofs and other framing may be wholly or partly of wood or other materials. Common earthen construction systems go by many names, which sometimes connote minor variations. Some of those names are:

*adobe*, or *mud brick, earthen brick, banco, butabu, brique de terre*
*cast earth*, or *poured earth, earthcrete, sprayed earth*
*cob*, or *zabur, puddled mud, puddled earth*
*extruded earth block*
*pressed brick*, or *compressed earth brick/block (CEB)*
*rammed earth*, or *pisé, tapial*
*sod*, or *turf, fale and divet*
*tire houses*, also *earth bags, earth tubes*
*wattle and daub*, or *quincha, jacal, barjareque, nyumba yo mata*

3.2.10 *energy efficient*, *adj*—refers to a product that requires less energy to manufacture or uses less energy when operating in comparison with a benchmark for energy use, or both.

3.2.10.1 *Discussion*—For example, the product may meet a recognized benchmark, such as the EPA's Energy Star Program standards.

3.2.11 *gravel*, *n*~~— inorganic soil with particle sizes greater than 2 mm (0.079 in.).~~ —inorganic soil with particle sizes greater than 4.75 mm (0.187 in.).

3.2.12 *horizon*, *n*—distinctive layer of in situ soil having uniform qualities of color, texture, organic material, and obliteration of original rock ~~material, and more.~~ material.

3.2.12.1 *Discussion*—In *World Reference Base for Soil Resources*, by the Food and Agriculture Organization of the United Nations, seven master horizons are recognized – H, O, A, E, B, C, and R.

3.2.13 ~~*indoor environmental quality (IEQ)*~~loam, *n*~~—refers to the condition or state of the indoor built environment in which the building product is installed. Aspects of IEQ include: light quality, acoustic quality, and air quality.~~ —soil with a high percentage of organic material, particles are predominately silt size but range from clay size to sand size.

3.2.13.1 *Discussion*—Loams are usually good agricultural soils due to their nutritional organic content and their ability to hold water. Loams should be avoided in earthen construction, as the organic content is subject to biological decay and volume change. Note that the word " loam" derives from the German "lehm." In Europe, "loam" and "lehm" usually have an opposite meaning; that is, they connote earth with a very low organic content, ideal for building but not for agriculture.

3.2.14 ~~*loam*~~material (product feedstock), *n*~~—soil with a high percentage of organic material, particles are predominately silt size but range from clay size to sand size.~~ —refers to the substances that are required for the manufacture or fabrication, or both, of a building product.

3.2.14.1 *Discussion*~~—Loams are usually good agricultural soils due to their nutritional organic content and their ability to hold water.~~ —Material resources include raw materials and recycled content materials.

3.2.15 ~~*manufacturing process*, *n*—refers to the process of creating a building product and includes manufacturing, fabrication and distribution procedures.~~ moisture wicking—the capillary uptake of water from foundation soil or precipitation.

3.2.15.1 *Discussion*—Moisture wicking can result in saturation of adobe with an accompanying decrease in strength and durability.

3.2.16 ~~*materials (product feedstock)*~~operational performance, *n*~~—refers to the material resources that are required for the manufacture or fabrication, or both, of a building product.~~ —refers to the functionality of a product during its service life.

3.2.16.1 *Discussion*~~—Material resources include raw materials and recycled content materials.~~ —Specific measures of operational performance will vary depending upon the product. Aspects of operational performance include: structural strength, durability, energy efficiency, and water efficiency.

3.2.17 ~~*moisture wicking*—the capillary uptake of water from foundation soil, ambient humidity or precipitation. Moisture wicking can result in saturation of adobe with an accompanying decrease in strength and durability.~~ poured earth , *n*—see *cast earth.*

3.2.18 ~~*operational performance (product installed)*~~pressed block, *n*~~—refers to the functioning of a product during its service life. Specific measures of operational performance will vary depending upon the product. Aspects of operational performance include: durability, maintainability, energy efficiency, and water efficiency.~~ —a block (or brick, or the construction system using those blocks) that consists of earthen materials formed in a block mold by the mechanical compaction of lightly moistened earth into a dense mass (also called *compressed earth block, CEB*).

3.2.19 ~~*pressed-block*~~rammed earth, *n*~~—a construction system that consists of walls made from earthen materials formed in a block mold by the compacting of lightly moistened earth into a hardened mass.~~ —a construction system that consists of walls made from moist, sandy soil, or chemically stabilized soil, which is tamped into forms (mechanically stabilized).

3.2.20 ~~*rammed earth*~~sand, *n*~~—a construction system that consists of walls made from moist, sandy soil, or stabilized soil, which is tamped into forms.~~

~~3.2.20.1*Discussion*—Walls of unstabilized soil are usually a minimum of 300 mm (12 in.) thick for load bearing purposes. Soils for rammed earth construction usually contain about 30% clay and 70% sand.~~ —inorganic soil with particle sizes ranging from 0.75 to 4.75 mm (0.03 to 0.19 in.).

3.2.21 ~~*sand*~~silt, *n*~~—inorganic soil with particle sizes ranging from 0.05 to 2.0 mm (0.002 to 0.079 in.).~~ —inorganic soil with particle sizes ranging from 0.002 to 0.75 mm (0.00008 to 0.03 in.) having the characteristics of low dry strength, low plasticity, and little dilatancy.

3.2.22 ~~*silt*~~soil, *n*~~—inorganic soil with particle sizes ranging from 0.005 to 0.05 mm (0.0002 to 0.002 in.) having the characteristics of low dry strength, low plasticity, and rapid dilatancy.~~ —see *earth*,

3.2.23 ~~*straw*~~stabilization, *n*~~—an agricultural waste product that is the dry stems of cereal grains after the seed heads have been removed.~~ —modification of soils to limit water absorption, stabilize volume, increase strength, and increase durability, or some combination of these.

3.2.23.1 *Discussion*—For the purposes of this guide, reference to "stabilization" or "stabilized" means chemical stabilization or chemically stabilized. Chemical stabilization is achieved by the intermixture of cement, lime, gypsum, asphalt emulsion, or other materials with the soil before emplacement, and curing as appropriate for the stabilizer and chemical reaction. Mechanical stabilization is achieved by compacting or compressing a plastic earth mixture, or containing earth in permanent forms such as bags.

3.2.24 *straw, n*—an agricultural waste product that is the dry stems of cereal grains, or sometimes native grasses, after the seed heads have been removed.

3.2.25 *straw-clay, n*—a construction system that consists of clay slip ~~and~~ mixed with straw, of which straw makes up a high percentage by volume.

~~3.2.24.1~~3.2.25.1 *Discussion*~~—This system is well suited for manufacturing bricks, floor blocks, and insulating panels~~ —Other fibers such as wood shavings or paper are sometimes used. This system is well suited for manufacturing blocks and in situ insulating wall panels.

## 4. Summary of Practice

4.1 This guide identifies the principles of sustainability associated with earthen building systems. Additionally, it outlines technical issues associated with earthen building systems, identifying those that are similar to construction that is commonly used in the marketplace.

4.2 This guide is intended for use in framing decisions for individual projects.

4.3 This guide is intended for use in ~~framing decisions for~~ development of standards and building codes for earthen building systems.

## 5. Significance and Use

5.1 ~~*Historical Overview:* Earthen building systems have been used throughout the world for thousands of years. Adobe construction dates back to the walls of Jericho (now located in Israel) which was built around 8300 B.C. Many other earthen structures have been functioning for hundreds of years. However, with the development of newer building materials, earthen building systems have been largely abandoned in part of the world where they were once commonly used.~~ Historical Overview—Earthen building systems have been used throughout the world for thousands of years. Adobe construction dates back to the walls of Jericho which was built around 8300 B.C. Many extant earthen structures have been functioning for hundreds of years. However, with the development of newer building materials, earthen building systems have fallen into disfavor in parts of the world where they were once commonly used. At the same time, earthen construction is experiencing a revival in the industrialized world, driven by a number of factors.



5.2 *Sustainability*~~:~~—As world population continues to rise and people continue to address basic shelter requirements, it becomes increasingly necessary to promote construction techniques with less life cycle impact on the earth. Earthen building systems are one type of technique that may have a favorable life cycle impact.

5.3 ~~*Building Code Impact:* Earthen building systems have historically not been engineered. The first written standards for adobe were developed in the United States in the 1930s and were based on common construction practices. Only during the last 20 years have architects and engineers attempted to engineer adobe and rammed earth for use and compliance with contemporary building codes. Standards for the use of adobe were initially limited to local and state codes, predominantly in the southwestern United States. However, over time regional and national model building codes adopted provisions for adobe construction. For example, the International Building Code (IBC) provides empirical requirements allowing the use of adobe when the applicant follows specific procedures. New Mexico building code provides empirical requirements for the use of both adobe and rammed earth building systems. Where the building code does not specifically address earthen building systems, governing agencies frequently classify the construction as an alternative material, design, or method of construction. An alternative material, design, or method of construction will be approved when the code official finds that the proposed design is satisfactory and complies with the intent of the provisions of the code and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in the code in quality, strength, effectiveness, fire resistance, durability and safety. However, development of standards such as this can aid in the appropriate recognition and adoption of earthen building systems materials and methods by building codes and code enforcement agencies.~~ Building Code Impact—Earthen building systems have historically not been engineered, but as of the late 20th Century it is for the first time in history possible to reliably apply rational structural design methods to earthen construction. A large number of earthen building codes, guidelines and standards have appeared around the world over the past few decades, based upon a considerable amount of research and field observations regarding the seismic, thermal and moisture durability performance of earthen structures. Some of those standards are:

Australian Earth Building Handbook
California Historical Building Code
Chinese Building Standards
Ecuadorian Earthen Building Standards
German Earthen Building Standards
Indian Earthen Building Standards
International Building Code / provisions for adobe construction
New Mexico Earthen Building Materials Code
New Zealand Earthen Building Standards
Peruvian Earthen Building Standards

This guide draws from those documents and the global experience to date in providing guidance on earthen construction to engineers, building officials, and regulatory agencies.

5.4 ~~*Audience:* There are existing markets in the United States and internationally using adobe, rammed earth, and other earthen building systems. It is estimated that 40% of the world's population lives in earthen dwellings. Safety, functionality, and~~

~~sustainability of earthen building systems can greatly be improved through establishment of an international design standard. Intended users of this standard guide include: planners, developers, architects, engineers, interior designers, general contractors, subcontractors, owners, financial organizations related to building industry, building materials and product manufacturers, government agencies including building officials, and other building professionals.~~ Audience—There are two primary and sometimes overlapping markets for earthen construction and for this guide:

5.4.1 *Areas with Historical or Indigenous Earthen Building Traditions*—In places where earthen architecture is embedded in the culture, or there is little practical or economical access to other building systems, this guide can set a framework for increasing life safety and building durability.

5.4.2 *Areas with a Nascent or Reviving Interest in Earthen Architecture*—In places where earth is sometimes chosen over other options as the primary structural material, this guide provides a framework for codification and engineering design.

## 6. ~~Considerations for Sustainable Development~~ Considerations for Sustainable Development and Durability

6.1 ~~*Materials (Product Feedstock):* Materials of earthen building systems include a binder soil, typically clay, clay-silt mixture or loam; and inorganic or organic tempering materials, or both. Sand and gravel are commonly used inorganic tempers and straw, hair, and chaff are commonly used organic tempers. Soils may be stabilized, using such materials as cement, asphalt emulsion, calcined gypsum or cactus juice, or may be unstabilized. Adobe bricks may be held together by a variety of mortars. Systems may be finished with plaster or pigments, or both, or left unfinished.~~ Materials (Product Feedstock)—Materials of earthen building systems include clay soil and inorganic or organic tempering materials. Silt, sand, and gravel are commonly used inorganic tempers and straw, hair, and chaff are commonly used organic tempers. Soils may be stabilized, using such materials as cement, asphalt emulsion, calcined gypsum or cactus juice, or may be unstabilized. Systems may be finished with plaster or left unfinished.

6.1.1 ~~*Soil:* Soils for earthen building systems are a mixture of a binder soil, for example, clay, silt, clay-silt combination or loam, and temper soils of sand and gravel. These mixtures may be naturally occurring local soils or engineered by mixing different soils. Sources for the soils include on-site horizons, by-products of sand and gravel quarrying, and alluvial deposits.~~

~~Care should be taken to avoid adverse affects on the capacity for food production when considering the use of loams and other soils that are suitable for agricultural purposes.~~ Soil—Soils for earthen building systems are a mixture of a binder (clay), and temper soils of silt, sand, and gravel. These mixtures may be naturally occurring local soils or engineered by mixing different soils. Sources for the soils include on-site horizons, by-products of sand and gravel quarrying, and alluvial deposits. Some clays are highly expansive (montmorillonites) or moderately expansive (illites) when wetted, and thus problematic for earthen construction. Ideally, a non-expansive kaolinite clay should be used. The intermixture of small amounts of lime, bitumen, or cement will negate the expansive properties of swelling clays, but by the same chemical mechanism negate the binding and other beneficial properties of the clay. Stabilizing binders should thus generally be used only when there is no other viable strategy for meeting the project requirements. Care should be taken to avoid adverse affects on the capacity for food production when considering the use of loams and other soils that are suitable for agricultural purposes.

6.1.2 ~~*Straw:*~~*Straw*—Straw, being dry and having no seed heads is more durable in earthen building systems than hay ~~—which is a green, typically shorter, grass animal feed product containing stems and~~contains seed heads. Straw is an agricultural waste product that is typically not used for productive end use; therefore, it is considered an alternative agricultural product and a renewable resource when used in earthen building systems.

6.1.3 ~~*Plaster:* A material applied to the exposed surfaces of earthen building systems to improve durability, water resistance or modify its appearance, or both. Commonly used on adobe, pressed block, and straw clay systems to protect or conceal, or both, the joints between the units.~~ Plaster—"Plaster" is a material applied to the exposed surfaces of earthen building systems to improve durability and modify appearance.

6.1.3.1 ~~*Clay Plaster:* Clay plaster is a mixture of clay, sand and water. Tempering materials, such as straw, and pigments may be added.~~ Earth (or clay) Plaster—Earth plaster is a mixture of clay, silt, sand, and water. Fibrous tempering materials are typically added.

6.1.3.2 ~~*Cement-stabilized Clay Plaster:* Cement-stabilized clay plaster is similar to clay plaster except for the addition of Portland cement or some other hydraulic cement, which is added to improve durability or reduce dusting, or both. Tempering materials, other admixtures and pigments may also be added.~~ Cement Plaster—Cement plaster is a mixture of cement, sand and water; the mixture may also include pozzolans, lime, pigments, glass fibers, and proprietary admixtures. Cement plaster, which is considerably less vapor-permeable than earthen plaster, can trap moisture, resulting in saturation and deterioration of unstabilized earth wall systems. For this reason, the use of cement plaster over unstabilized earth is strongly discouraged.

6.1.3.3 ~~*Cement Plaster:* Cement plaster is a mixture of cement, sand and water; the mixture may also include pozzolans, lime, pigments, glass fibers and proprietary admixtures. Cement plaster, which is often less permeable than many of the structural materials used in earthen building systems, can be used to encapsulate the tops and bottoms of walls and around openings to prevent moisture wicking which can result in saturation and deterioration of unstabilized systems.~~ Lime Plaster—Lime plaster is a mixture of hydrated lime and sand that is much more compatible with unstabilized earth than cement plaster in terms of vapor permeability, coefficient of temperature change, and stiffness. Lime plaster has a long and successful history of use over indigenous earthen building systems in various cultures. Successful application of lime plaster over unstabilized earth does require some manner of mechanical locking, such as by scoring the earth surface, and careful application of the lime in progressive layers.

6.2 *Manufacturing Process:*