A CONCISE HISTORY OF THE USE OF THE RAMMED EARTH BUILDING TECHNIQUE INCLUDING INFORMATION ON METHODS OF PRESERVATION, REPAIR, AND MAINTENANCE

by

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THESIS ABSTRACT

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Pisé de terre or rammed earth is a building technique that has existed for over ten thousand years. Although this technique was first documented for Western Civilization by the Roman Pliny the Elder circa 79 AD, evidence of its use prior to his time is found in China, Europe, and elsewhere. Rammed earth achieved notoriety in the United States during three distinct periods in its history: the Jeffersonian era, the Great Depression, and the Back-to-Nature Movement of the 1970s. In the United States earth buildings are uncommon and usually deemed marginal or fringe. This is true even though at times the U.S. government has been a proponent of alternative building techniques, especially rammed earth. Intended for those interested in material culture, this thesis provides a brief history of rammed earth, articulates its importance to the building record of the United States, and describes methods for its preservation, repair, and maintenance.

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For Mom and Dad.

You always knew I could do it.

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CHAPTER I

INTRODUCTION

> *Have we not in Africa and in Spain walls of earth, known as "formocean" walls? From the fact that they are moulded, rather than built, by enclosing earth within a frame of boards, constructed on either side. These walls will last for centuries, are proof against rain, wind, and fire, and are superior in solidity to any cement. Even at this day Spain still holds watch-towers that were erected by Hannibal.*
>
> *– Pliny the Elder, "Natural History," Book XXXV, Chapter xlviii.*

> *"…the history of rammed-earth and the contemporary experience of the experimenters will hold a great value to the builder until the material enjoys the same commonplace security of the clay-fired brick, a building unit which no amateur questions but which is far more vulnerable to faulty manufacture and inexpert handling than rammed-earth could ever possibly be."*
>
> – *Anthony F. Merrill*, The Rammed-Earth House, *p. xvi.*

The building technique known as *pisé de terre* or rammed earth has been in existence for thousands of years. Its first documented use was by the Romans who later introduced it into France and England.[1,2,3] Rammed earth structures are formed by compacting moist earth layer by layer between temporary wooden forms. The forms are removed and the rammed earth dries to an extremely sturdy, long-lasting building.

Rammed earth has had minimal success as a building form in the United States. While achieving prominence at three distinct periods of U.S. history – in the Jeffersonian

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[1] Morris Cotgrave Betts and Thomas A. H. Miller, "Farmers' Bulletin No. 1500: Rammed Earth Walls for Buildings" (Washington, D.C.: U.S. Department of Agriculture, 1937), 1.

[2] Peter Walker et al., *Rammed Earth: design and construction guidelines* (Bracknell, United Kingdom: BRE Bookshop, 2005), 3.

[3] Anthony F Merrill, *The Rammed-Earth House* (New York: Harper & Brothers Publishers, 1947), 7.

Era, during the Great Depression, and in the late 1970s to early 1980s during the Back-to-Nature Movement – it has never been considered a mainstream building technique.[4] In reality, in the United States, dwellings composed of earth are uncommon and considered marginal or fringe. This is true even though at times in its history, the U.S. government has been a proponent of alternative building techniques including earth architecture and rammed earth in particular.[5] Even with the understanding that rammed earth buildings can appear as typical stick-frame buildings such as the residence shown in Figure 1, they have not been integrated into standard building practices.

Intended for those interested in material culture, this thesis provides an overview of rammed earth building techniques and explores the history of rammed earth as the commoner employed it in the U.S. with emphasis on the period from the 1930s through the 1950s. An examination of homes and buildings constructed during this period is included along with the motivations of their builders. In addition, the energy efficiency of rammed earth is described and an argument is made for the employment of this technique as a viable and acceptable building material based on analysis of the condition of these several buildings.

Figure 1. Rammed earth residence at 1814 Reservoir Road, Greeley, Colorado built in 1946. *Photograph by the author, 2011.*

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[4] Jennifer Lynn Carpenter, "Dirt Cheap: The Gardendale Experiment and Rammed Earth Home Construction in the United States" (Masters Final Project, University of Maryland, 2010), 5.

[5] The U.S. Department of Agriculture issued "Farmers' Bulletin No. 1500" in 1926 with a reissue in 1937. This bulletin specifically addressed how to use the rammed earth building technique to create cheap, long-lasting outbuildings on farms.

This thesis also strives to explain why rammed earth construction is uncommon or considered radical within the U.S. Rammed earth has been used for slave quarters, as an alternative housing construction type for the poor, and in farm outbuildings. This garners it a certain stigma and may explain its absence in definitive textbooks on American architecture.[6] Its use has also been influenced by politics and the special interests of certain industries. In addition, its need is not considered imperative, as U.S. resources in lumber and cross-country quick transport are the norm. Finally, using earth as a building material is generally considered the "old ways." When countries move into industrialization, steel and concrete are the measures of success.

While this thesis provides the historic context of rammed earth, an extensive description of the rammed earth building technique is also included. This topic was specifically incorporated as an aid in describing how to sensitively maintain and repair it – a topic exceedingly important for the preservation of the history of this building technique.

The Significance of Rammed Earth Construction

Although not common in the United States, rammed earth construction has been practiced at various points in our history. Shown in Figure 2, the Casa Grande National Monument in Coolidge, Arizona is home to the oldest existing remnants of rammed earth in the United States. Built circa 1350, the large, multi-storied structure was constructed

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[6] Rammed earth is not discussed in such texts as Leland M. Roth's excellent book *American Architecture: A History*, Virginia and Lee McAlester's *A Field Guide to American Houses* or *Common Places: Readings in American Vernacular Architecture* edited by Dell Upton and John Michael Vlach.

by the Hohokam, natives to the Sonoran Desert.[7] Its exact purpose is still unknown though the Hohokam had developed a sophisticated agricultural industry including a technologically advanced irrigation system. The Casa Grande area may have been its centerpiece.

Figure 2. Casa Grande rammed earth structure at Casa Grande Ruins National Monument, Coolidge, Arizona, built ca. 1350. *Photograph by the author, 2009.*

Frenchman François Cointereaux introduced the technique to Thomas Jefferson while Jefferson was living in Paris between 1784 and 1789. Subsequently, in 1806, S. W. Johnson[8] of New Brunswick, New Jersey, wrote a textbook on rural improvements that included a section on rammed earth construction. His book was based on the works of Cointereaux and an English translation by Henry Holland. Titled *Rural Economy: Containing a Treatise on Pisé Building; as Recommended by the Board of Agriculture in Great Britain, with Improvements by the Author; On Buildings in General; Particularly on the Arrangement of those belonging on Farms; On the Culture of the Vine; and on*

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[7] A. Berle Clemensen, *Casa Grande Ruins National Monument, Arizona: A Centennial History of the First Prehistoric Reserve 1892 – 1992,* An Adminstrative History (Washington, D.C.: United States Department of the Interior, National Park Service, March 1992), 7.

[8] Johnson is referred to in some literature as Samuel W. Johnson and in other literature as Stephan W. Johnson. In *Rural Economy*, he refers to himself as S. W. Johnson (Title, Dedication, 8, 11, 240, and Copyright).

Turnpike Roads, it was a discourse on how to improve rural life, devoting about one-third of the book to rammed earth. It also included a dedication to Jefferson.[9]

While Jefferson studied rammed earth, he never adopted it as a serious building technique.[10] He considered it inappropriate for the harsh North American climate and not necessary with the abundant natural resources found in the U.S.

Rammed earth did however enjoy a certain notoriety during this same time period. It was even used in the construction of slave quarters and other outbuildings at Mount Vernon. Supreme Court Justice Bushrod Washington, the nephew of George Washington inherited the estate after the death of Martha Washington in 1802. He constructed seven pisé buildings between 1810 and 1815 though none survived past 1875.[11]

Another early proponent and contemporary of Justice Washington was General John Hartwell Cocke. He constructed eighteen slave quarters and other buildings of rammed earth at Bremo Recess, his farm home along the James River in Fluvanna County, Virginia in 1815 and at Pea Hill Plantation in Brunswick County, Virginia.[12] Some of these structures, one of which is shown in Figure 3, are extant. These buildings aid in the understanding of rammed earth construction in the early 1800s and may

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[9] S. W. Johnson, *Rural Economy: Containing a Treatise on Pisé Building; as Recommended by the Board of Agriculture in Great Britain, with Improvements by the Author; On Buildings in General; Particularly on the Arrangement of those belonging on Farms; On the Culture of the Vine; and on Turnpike Roads* (New York: J. Riley & Co., 1806), Dedication.

[10] Merrill, *The Rammed-Earth House,* 10.

[11] Gardiner Hallock, “Pisé Construction in Early Nineteenth-Century Virginia,” *Perspectives in Vernacular Architecture* 11 (2004): 41.

[12] Ibid, 44-45.

provide insight into the similar works that had been constructed on the Mount Vernon estate.

Figure 3. Rammed earth slave quarters at Bremo Recess, Fork Union vicinity, Fluvanna County, Virginia. Built in 1815 by General John Hartwell Cocke. The HABS database cites this building as adobe not rammed earth. *Photograph from Library of Congress, Prints & Photographs Division, LC-DIG-csas-04761.*

Shown in Figure 4, the Church of the Holy Cross, near Sumter, South Carolina, was constructed in 1851. Made of rammed earth, the congregation agreed to its construction using this technique only because of the low construction price of 12,000 dollars.[13]

This church became significant to the future uses of rammed earth during the Great Depression era when the owners went to the U.S. government, specifically the Division of Agricultural Engineering of the U.S. Department of Agriculture, looking for information on how to repair forty-year-old damage to the structure caused by the 1886 Charleston Earthquake. This construction technique piqued the interest of agricultural engineer Thomas Arrington Huntington Miller who, along with architect Morris Cotgrave Betts, went on to author "Farmers' Bulletin No. 1500: Rammed Earth Walls for Buildings" first published in 1926.[14] This bulletin, published by the U.S. Department of Agriculture, reintroduced rammed earth to the vernacular community and lead to its resurgence.

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[13] Merrill, *The Rammed-Earth House*, 12.

[14] Ibid, 13.

Dr. Harry Baker Humphrey was the chief plant pathologist of the U.S. Department of Agriculture when Miller and Betts began their study of rammed earth.

He became so intrigued by it that he built his own home using the technique. His house was discussed in the November 1924 issue of *Popular Mechanics Magazine* in an article titled "Rammed Earth Lowers House Cost" by G. H. Dacy. Figure 5 provides an illustration of the front of the house as featured in the article. While not directly named, the caption to the illustration alludes to Humphrey as "a Washington Scientist."[15]

Figure 4. Church of the Holy Cross, Stateburg vicinity, near Sumter, South Carolina. Completed in 1851, the congregation agreed to the rammed earth building technique only because of its low cost. *Photograph from Library of Congress, Prints & Photographs Division, HABS SC,43-STATBU.V,1--20.*

Rammed earth construction was especially appealing during the Depression Era as labor was plentiful and because the main material needed for construction was dirt. Several communities were developed between 1930 and 1945 based on rammed earth. In 1932, rammed earth homes were constructed at Gardendale, Alabama under the direction of Thomas Hibben, an architectural engineer with the Resettlement Administration. Other experimenters and builders of rammed earth included Dr. Ralph Patty of the South

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[15] G. H. Dacy, "Rammed Earth Lowers House Cost," *Popular Mechanics Magazine* (November 1924), 839.

Dakota Agricultural Experiment Station and Elbert Hubbell, a vocational instructor at the Turtle Mountain Indian School in Belcourt, North Dakota.

"Patty conducted carefully monitored scientific experiments on test walls, farm buildings, and garden walls constructed with rammed earth."[16] These experiments on the integrity of rammed earth lent credibility to its use. Hubbell oversaw the construction of rammed earth buildings including barns, schoolhouses, and other dwellings at the Turtle Mountain Indian School and Pine Ridge Indian Reservation in North Dakota.[17]

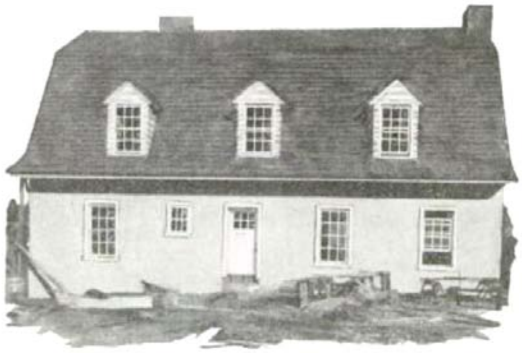

Figure 5. Illustration of Dr. Harry Baker Humphrey's rammed earth home in Washington, D.C. Built in 1924, it was featured in *Popular Mechanics*, a magazine for the do-it-yourselfer. *Drawing from "Popular Mechanics Magazine," November 1924, page 839.*

Rammed earth went out of fashion in the mid-1950s when Baby Boomers came along and mass construction of single-family homes became the norm. The post-World War II industrial transition from a wartime to a peacetime economy saw a boom in such industries as lumber, brick and transportation. Labor became expensive and materials cheap. This precluded the use of rammed earth.

Rammed earth resurfaced in the late 1970s and early 1980s as those who wished to form a new social ethic based on peace, love and back-to-nature philosophies

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[16] Robert G. Rosenberg, *North Casper Clubhouse National Register Nomination,* National Register of Historic Places Registration Form (Cheyenne, Wyoming: Rosenberg Historical Consultants, 1993), 17.

[17] Paul A. Jaquin, Charles Augarde and Christopher M. Gerrard, "A chronological description of the spatial development of rammed earth techniques," *International Journal of Architectural Heritage: Conservation, Analysis, and Restoration* 2, no. 4 (November 2008), 387.

employed rammed earth as a means to connect with the soil. Homes constructed by David and Lydia Miller in Greeley, Colorado were given national prominence by *Mother Earth News* magazine.[18] A story describing their rammed earth home originally built in the 1940s and featuring their pantry filled with produce from their own garden "generated such enormous interest among its readership that the Millers became instant folk heroes for thousands of young people exploring the back-to-the-land movement."[19] The Millers had made a hobby of rammed earth construction surveys and they wrote a manual on rammed earth construction that is still referred to today. The works produced by the Millers are archived at the University of Northern Colorado, James A. Michener Library.

In recent years rammed earth has been used in custom design-build architecture as a means of creating environmentally friendly buildings that require minimal heating and cooling. Mary C. Hardin and John Folan of the University of Arizona worked to perfect low-cost rammed earth construction in their Residence 1 single family home built by the Drachman Design-Build Coalition in 2006.[20] Others, such has Rick Joy have utilized rammed earth to create truly unique living spaces that embody the connection between earth, man and nature. A Rick Joy designed home is seen in Figure 6, while not cheap, these buildings are nonetheless aesthetically and environmentally beautiful.

Rammed earth is significant to historic preservation for three distinct reasons. First, it is a vernacular architecture type. While not regional, it is still an architectural

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[18] Mother Earth News. "Living in Rammed Earth Houses." *Mother Earth News: The Original Guide to Living Wisely*. January / February 1980. http://www.motherearthnews.com/green-homes/rammed-earth-houses-zmaz80jfzraw.aspx (accessed October 10, 2012).

[19] David Easton, *The Rammed Earth House* (White River Junction, Vermont: Chelsea Green Publishing Company, 2007), 20.

[20] Ronald Rael, *Earth Architecture* (New York: Princeton Architectual Press, 2009), 108.

style built by the common man that maintains the traditions and utilizes the resources of the people. Second, it is inherently environmentally suited. Rammed earth walls have a nominal twelve-hour temperature cycle – keeping them cool in the daytime and warm at night. This minimizes the need for artificial air conditioning with its associated costs. And third, as with the study of any architectural type, knowledge is gained from its challenges more than from its successes.

Figure 6. Tucson Mountain House designed by Rick Joy Architects. This rammed earth house near Tucson, Arizona was constructed in 2001. *Photograph from* Desert Works *by Rick Joy, page 134.*

Thesis Goals and Objectives

The goal of this thesis is to explain the importance of preserving the historic record of rammed earth as a means to articulate the value of this lesser known, not well understood building technique. This thesis provides an understanding of the rammed earth building technique, an overview of its history within the United States including the influences that brought it to North America, and its relevance to historic preservation.

Special consideration is given to its second renaissance. From the Depression Era until just after World War II, rammed earth became an “acceptable” alternative to traditional building materials. Though short-lived, rammed earth buildings constructed during this era have withstood the test of time and are a testament to its long-term viability.

The objectives of this thesis are: to describe what constitutes rammed earth and how it is mechanized; to give an overview of its use within the global community; to discuss its historic record within the United States; to specifically understand the dynamics that brought rammed earth back into the collective American conscious during the mid-twentieth century; and, to provide information on rammed earth repair techniques to aid in the understanding of how to preserve and maintain these robust structures. Each of these areas is included in the hopes of yielding a new appreciation of this building method.

Further Study

This thesis studies rammed earth as a single earthen architecture type. Often lumped in with other earthen building techniques such as adobe mud brick, compressed earth block, and molded earth cob, its singular attributes are rarely specifically defined. Rammed earth is of particular importance in this modern age where the need for sustainable building techniques has become an imperative. An historic perspective of this technique provides the necessary insights required to understand what has limited its use in the past.

While the forces that have stigmatized rammed earth are discussed, this thesis does not study the phenomenon in depth nor does it attempt to provide a roadmap for overcoming prejudices against it as a building technique. Also, although touched upon in the thesis, the latest resurgence of rammed earth is not studied in detail. Additionally, farm outbuildings built using rammed earth are mentioned only in the context of describing overall design and are not specifically addressed here. Rammed earth has been traditionally considered a rural construction type. There are undoubtedly numerous rammed earth outbuildings that have never been documented.[21] A more complete look at rammed earth use in rural farming areas would add significantly to the body of information on this topic. In particular, a study which catalogs rammed earth structures in rural settings may provide insight into the development of rammed earth technology within the U.S.

Structure of the Thesis

The thesis is organized in four major sections exclusive of the introduction and conclusion. Chapter II provides an overview of rammed earth construction. It describes how rammed earth construction is implemented. It includes a discussion of soil considerations, form construction, and tamping requirements. Design details including lintels, doors and windows, and roof and foundation attachments are described. The structural integrity and thermal characteristics of rammed earth are also described. This chapter provides insight into construction techniques and structural design requirements to aid the historic preservationist in understanding implementation methods so that

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[21] Alvar W. Carlson touches upon the use of rammed earth by German-Russian immigrant farmers who settled in the Great Plains region of the U.S. during the late 1700s and early 1800s in his article “German-Russian Houses in Western North Dakota.” [Citation: Alvar W. Carlson, “German-Russian Houses in Western North Dakota,” *Pioneer America* 13, no. 2 (September 1981): 51, 52, 55.]

responsible and thoughtful decisions can be made when considering preservation or adaptive reuse.

The second major section, Chapter III, gives a survey of rammed earth building from a global perspective. Far from unique to the United States, rammed earth is in use in a number of different regions and has been for a much longer period. The intent of this chapter is to survey the historic use of rammed earth from a global perspective to contextualize the building technique.

Chapter IV contains the third major section. This section discusses rammed earth building within the United States. A quick overview of its history prior to the mid-twentieth century is provided. A detailed description of its implementation during the Great Depression and post-World War II is given. The discussion includes specific examples of buildings constructed during this period and extant today. Political influences that have limited its use are described and the counter-culture stigma that has evolved around it is addressed.

The fourth section, Chapter V, discusses the importance of rammed earth from an historic preservation. Repair and maintenance are considered, along with reuse applicability. Included in this chapter is a discussion of the factors that cause deterioration of rammed earth structures. The determination of soil composition is described. Sensitive maintenance and repair methodologies applicable to maintaining context are also described.

Its vernacular origins, its environmental advantages and lessons learned from its implementation provide the justification for continued study and protection of this somewhat controversial and definitely unique building technique.

CHAPTER II

THE RAMMED EARTH PROCESS

As described in Chapter I, the building technique known as *pisé de terre* or rammed earth consists of tamping moist earth of the proper composition between temporary wooden forms. Layers of earth are compressed into an extremely hard packed state in sections of walls that are built a segment at a time. Once the compaction process is complete for a section, the formwork is removed and the earth is allowed to slowly dry to an extremely hard consistency. It is most commonly used for building walls, though it has also been used in the construction of floors, roofs, foundations, and even furniture and garden ornaments.[22] Although not common in the United States, rammed earth construction has been practiced at various points in U.S. history as described in Chapter I and detailed in Chapter III.

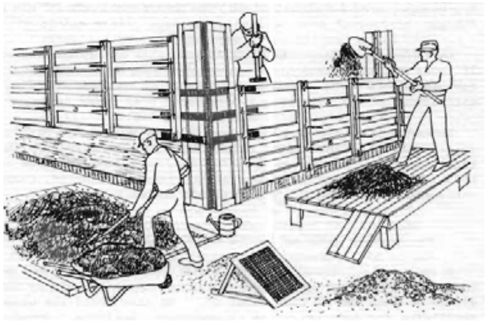

Figure 7. Rammed earth building construction process. *Drawing from* Manual for Building a Rammed Earth Wall *by Lydia A. and David J. Miller, University of Northern Colorado archives, page 5.*

Figure 7 is a pictorial of the rammed earth construction process as described by Lydia and David Miller in their book, *Manual for Building a Rammed Earth Wall*. Temporary formwork is usually constructed at the building site. Moist soil is shoveled into the form to a height of between four and six inches. It is then tamped down or rammed to a very tight compaction density – usually 50%

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[22] Walker et al., *Rammed Earth: design and construction guidelines*, 2.

of the original volume. More soil is layered on top of the compacted soil and this soil is then in turn compacted. This process is repeated until the structure reaches the desired design height. Rammed earth walls are usually between twelve and eighteen inches thick, though the actual widths vary based on the design and thermal requirements.[23] In the past, manual rammers, such as the one shown in use in Figure 7, were used to compact the soil. Today, however, there are electric hand-held, vibrating and pneumatically-powered dynamic rammers that make the job faster and produce better compaction ratios.

Figure 8 is a section cut of the rammed earth design process as implemented today. Originally created by Earth & Sun Construction, Inc., this drawing is used with permission. It should be noted that cement is added to the soil mixture, not concrete as the drawing indicates.

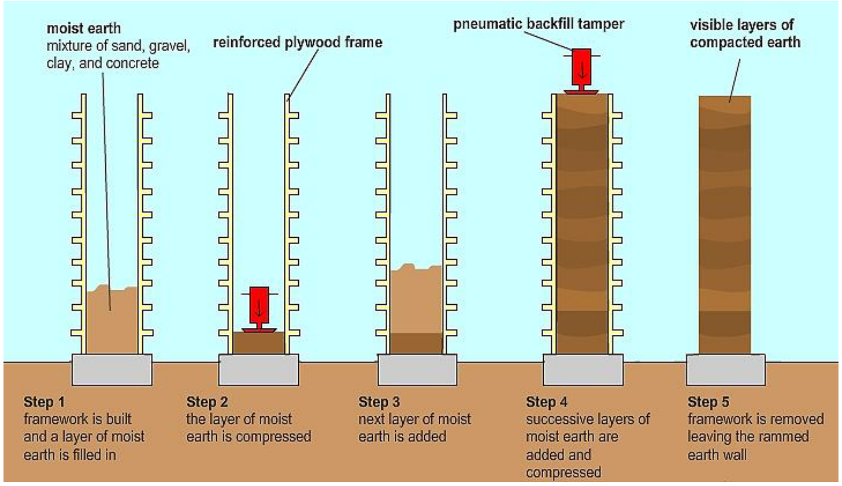

Figure 8. Section views of the compaction process for rammed earth construction. *Drawing from "How rammed earth works" by Earth & Sun Construction [http://earthandsun.com/index.php?p=1_3_About-Rammed-Earth]. Used with permission.*

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[23] Ibid.

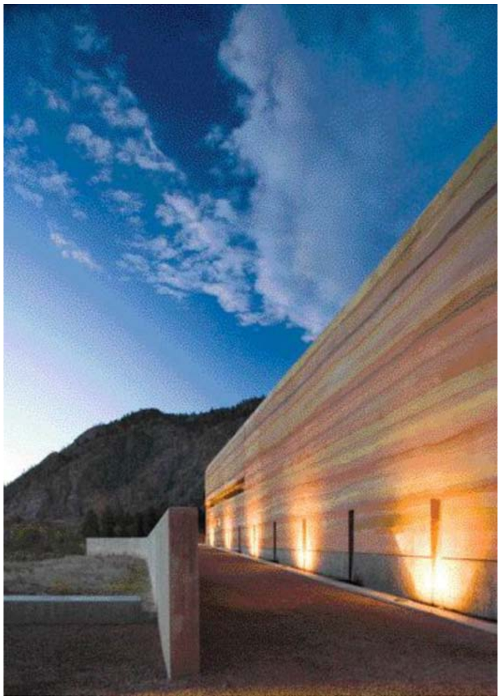

Figure 9. The Nk'Mip Desert Cultural Centre at the Osoyoos Indian Reserve in British Columbia, Canada was designed by Hotson Bakker Boniface Haden Architects. Completed in 2006, this 262-foot long, 18-foot high rammed earth wall shows the beauty of the successive layering seen in rammed earth construction. *Photograph from "Earth and Sky" by Peeroj Thakre, Canadian Architect, March 1, 2007.*

As seen in Figure 9, the rammed earth construction process usually results in walls that have a distinctive layered appearance that corresponds to the successive layers of soil compacted within the formwork. Not considered particularly desirable in the past, rammed earth walls were often covered with plaster or other coatings. Today the appearance is considered very attractive and is one of the appeals of rammed earth construction. In fact, the striation affect is often enhanced with color additives or by varying soil types. Rammed earth walls are often left without plaster or render because of their unique custom finish.[24] Thus, the display of the material is definitive of the time in which it was constructed and must be taken into consideration when repairing or preserving rammed earth structures.

Soil Considerations

The main material of rammed earth construction is the soil, specifically the inorganic subsoil found beneath the organic topsoil. The physical and chemical properties of subsoil are dependent on the original parent rock geology and subsequent

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[24] Ibid.

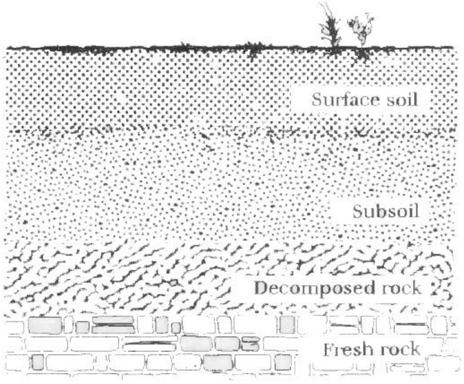

Figure 10. Soil profile. *Drawing from "Bulletin 5: Earth-Wall Construction" by G. F. Middleton with revisions by L. M. Schneider, page 13.*

weathering, including hydrological and hydrogeological processes, and other changes on exposure to the atmosphere.[25] Thus, the properties of subsoil are defined by the region in which the soil is found. Figure 10 shows the stratification of a notional soil sampling indicating the position of the subsoil.

Not all soil compositions are amenable to rammed earth construction and soil must be tested prior to use to verify its suitability. Additives may be required to construct long-term sustainable buildings in areas where earthen building is uncommon. They can be used to improve strength and water resistance. They can also be used to reduce shrinkage.[26]

Subsoil structure is made up of four main particle types. Classified according to size, they are gravel, sand, silt and clay.[27] Each particle type plays an important role in the structural integrity of rammed earth. Gravel is the skeleton that provides underlying structural stability. It, along with the sand, also enhances weathering resistance of exposed surfaces. The clay and silt are the binding agents that hold the material together. Clays are formed during chemical weathering. As such, they have very different

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[25] Ibid, 29.

[26] Ibid, 34.

[27] G. F. Middleton and L. M. Schneider, "Bulletin 5: Earth-Wall Construction, 4th Edition" (Division of Building, Construction and Engineering, CSIRO Australia, Australia: CSIRO, 1995), 12.

properties from the other particle types. They swell when wet and shrink as they dry.[28] The characteristics of clay are the most important factors in rammed earth construction and provide the cornerstone for its use as a viable building material.

Clay stabilizers can be added to soils where cohesion is lacking. Typical stabilizers include cement, bituminous emulsion, lime and adhesion chemicals. The addition of more clay to the soil is also an option. As a side note, elements such as cow-dung, rice husks and ant-beds have been used in the past.[29] Adding stabilizers requires thorough mixing and is generally very labor intensive. Rammed earth construction how-to books caution on the use of stabilizers emphasizing that they should only be added when absolutely necessary.

Other important soil characteristics to consider for use in rammed earth construction include plasticity, soluble salt content, organic material content, contaminates in the soil, color, grading and density. Each of these characteristics affects the performance of the rammed earth and is discussed in more detail below.

Plasticity is the ability of the soil to "undergo non-recoverable deformation at constant volume without crushing or cracking."[30] Soil plasticity is determined by its liquid and plastic limits. The limits are defined by the moisture content of the soil as it transitions states from liquid to plastic and from plastic to solid. The moisture content range over which soil acts plastically is defined by the difference between the liquid and plastic limits. This is the plasticity index. The characteristics of drying shrinkage,

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[28] Walker et al., *Rammed Earth: design and construction guidelines*, 29.

[29] Middleton and Schneider, "Bulletin 5: Earth-Wall Construction, 4th Edition," 12.

[30] Walker et al., *Rammed Earth: design and construction guidelines*, 32.

cohesion and rate of drying are related to the soil's plasticity index.[31] The clay type and content in the soil is the key component of the plasticity index of the soil.

Efflorescence can occur if the soil contains a high salt content. As the rammed earth dries, water-soluble chlorides, sulfates and carbonates leech from the soil leaving distinctive deposits on the surface of the design element. Normally these deposits can be cleaned off after the wall dries. However, if the salt content is particularly high, the efflorescence can cause surface damage such as discoloration, spalling and uneven weathering. In addition, some additives are less effective in high salt content soils.[32] Before construction begins, the salt content of the soil must be determined.

Organic material in the subsoil dramatically affects the structural integrity of rammed earth elements. Organics in the soil can decompose and decay over time. This can lead to deterioration of the fabric of the rammed earth. It also increases susceptibility to insect invasion with its inherent damage. And, as with salt, organics in the soil can alter the efficacy of some additives.[33] Sieving of soil prior to use aids in removing unwanted organic material.

Another consideration of soil composition is the presence of harmful contaminates in the soil such as arsenic or other carcinogens.[34] Although elements including arsenic naturally occur in soil, they are usually at levels too low to cause

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[31] Ibid, 33.

[32] Ibid, 30.

[33] Ibid.

[34] Ibid.

concern. However, in areas where mining or other heavy industry has taken place in the past, the level of harmful contaminates in the soil must be measured.

Table 1 provides a summary of soil composition requirements for use in rammed earth construction as defined by Peter Walker et al. in *Rammed Earth: Design and construction guidelines*. Conversions from metric to United States Customary Units are provided by the author.

Table 1. Soil Composition Requirements for Rammed Earth

Element / Characteristic	Requirement
Sand and Gravel Content	45 to 80% by mass
Silt Content	10 to 30% by mass
Clay Content	5 to 20% by mass
Plasticity Index	2 to 30 (liquid limit < 45)
Linear Shrinkage	Not more than 5%
Soluble Salt Content	Less than 2% by mass
Organic Matter Content	Less than 2% by mass
Toxic Carcinogens	Less than 10 to 20 mg (0.0003 to 0.0007 oz) per kilogram (2 lbs) of soil

Other characteristics to be considered with determining the usability of soil in rammed earth construction include color, grading and density. Since the 1990s one of the most coveted aspects of rammed earth is the stratification of colors that can appear watercolor-like in the finished product. Soil color varies across the color spectrum from blacks and browns to grays and whites with reds, yellows, greens, and blues in between. The color of the soil is determined by its mineral composition. For example, when iron is present, soil color is red, reddish-brown, yellow or yellowish-brown.[35] Though certainly not as important as strength and erosion resistance, color impacts the aesthetic of the

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[35] Ibid, 31.

building, so it must be considered as a part of the construction process. Binders, pigments and blending of different soils are techniques that can be used to affect the final outcome and builders often employ varying colored soils to enhance the stratification effect.[36] As stated in Chapter I, in past decades structural integrity concerns minimized the importance of the rammed earth design effect and structures were often covered with plaster or other surface protections. Enhancing the beauty of the soil was not a priority.

Grading is the process by which the composition of solid particles in the soil is described by particle size. Well-graded soil is soil "which has particles ranging from sand through fine sand and silt to clay" and is within the compositional matrix described in Table 1.[37] It is usually determined by sieving and sedimentation testing. While it is understood that grading greatly influences the finished texture and the friability of rammed earth structures, its effect on strength and durability has not been determined due to a lack of test data.[38]

Soil density is defined by the amount of air voids between particles in the soil. Less air in the soil means greater soil density. For rammed earth construction, high density is achieved by the expulsion of air voids through compaction. Higher density corresponds to better strength and durability. Ultimately, soil density is determined by moisture content, composition, grading and compaction. Soils with less desirable grading

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[36] Ibid.

[37] Middleton and Schneider, "Bulletin 5: Earth-Wall Construction, 4th Edition," 14.

[38] Walker et al., *Rammed Earth: design and construction guidelines*, 32.

can be improved by adding particles sizes that were lacking in the original soil composition.[39]

Simple field tests for acceptable soil composition are described in detail by Gernot Minke in his book *Earth Construction Handbook*.[40] These tests include smell, nibble, wash, cutting, sedimentation, ball dropping, consistency, cohesion or ribbon, and acid. Figure 11 illustrates the sedimentation and ribbon field tests as described by Minke.

Figure 11. Sedimentation Field Test and Ribbon Field Test. *Drawings from* Earth Construction Handbook *by Gernot Minke, pages 22 and 24.*

Table 2 provides a summary of the tests as outlined by Minke. The table includes information on indicators of good soil composition for use in rammed earth construction.

Prior to starting construction, soil test blocks should be produced and evaluated using, as much as possible, the tools and techniques planned for use at the building site. Typical evaluation criteria are listed in Table 3. This table is reproduced from “Bulletin 5: Earth-Wall Construction, 4th Edition” by G. F. Middleton with revisions by L. M. Schneider. Metric conversions to United States Customary Units were made by the author.

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[39] Ibid.

[40] Gernot Minke, *Earth Construction Handbook: The Building Material Earth in Modern Architecture* (Southhampton, U.K.: WIT Press, 2000), 22-25.

Table 2. Field Tests for Acceptable Soil Composition from *Earth Construction Handbook*

Field Test	Process	Description
Smell	Smell soil	Odorless; smells musty if deteriorating humus or organic matter is present.
Nibble	Taste soil	Sandy / gravelly soil; disagreeable sensation. Silt-based soil; not objectionable. Clay soil; sticky, smooth or flour sensation.
Wash	Rub moist soil between hands	Sandy / gravelly soil; grains clearly felt. Silt-based soil; sticky feel, hands can be rubbed clean when dry. Clay soil; sticky feel, water must be used to wash hands clean.
Cutting	Form moist soil sample into a ball and cut with a knife.	Shiny cut surface; high clay content. Dull cut surface; high silt content.
Sedimentation	Place soil sample in jar with large quantity of water. Allow sample to settle.	Stratification occurs with the largest particles settling to the bottom of the jar first. The proportion of the constituents of the soil can be estimated.
Ball Dropping	Form semi-moist soil into 1-inch diameter ball and drop onto a flat surface from a height of 5 feet.	High binding force / high clay content; ball flattens little and shows minimal cracking. Add sand to thin soil. Adequate binding force / average clay content; ball flattens, cracking and some crumbling occurs. Soil suitable for rammed earth construction. Low binding force / low clay content; ball falls apart, crumbling. Soil not suitable for rammed earth construction and should not be used.

Table 2. Continued

Field Test	Process	Description
Consistency	Form moist earth into 1-inch diameter ball. Roll ball into a 1/8th inch diameter rope. If rope breaks or develops large cracks before reaching 1/8th inch diameter, slowly moisten soil until robe breaks only when its diameter is 1/8th inch. Re-form soil into a ball.	If the soil cannot be re-formed, the sand content is too high and the clay content is too low. If the ball can only be crushed between the thumb and forefinger with a lot of force, the clay content is high and has to be thinned by adding sand. If the ball crumbles very easily, then the soil contains little clay.
Cohesion (Ribbon)	Roll a moist, not wet, soil sample into a 3 mm diameter robe without breaking. Form a ribbon that is approximately 6 mm thick and 20 mm wide. Hold it in the palm of the hand. Slid the ribbon along the palm allowing it to overhang until it breaks.	If the free length before breaking is more than 20 cm, the soil has a high binding force and the clay content may be too high for building purposes. If the ribbon breaks after only a few centimeters, the mixture has too little clay. This test is relatively inaccurate and is known to give errors of more than 200% if the soil under test is not well kneaded and/or the thickness and width of the ribbon is too varied.
Acid	Add one drop of a 20% solution of HCl to a soil sample.	When lime is present in the soil, CO_2 is produced according to the equation $CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$. Efflorescence results from the release of the CO_2.

Table 3. Evaluation Criteria for Rammed Earth Test Blocks

Evaluation Procedure	Test Limits
Specimen Preparation	No significant crumbling when form is stripped
Visual Inspection – Cracking	None longer than 75 mm (3 in), wider than 3 mm (0.1 in), or deeper than 5 mm (0.2 in)
Acceleration Erosion Test – Maximum Erosion Rate	1 mm / min (0.04 in/min)
Acceleration Erosion Test – Water Penetration	None
Compressive Strength	2 MPa (290 psi)

Middleton and Schneider recommend that three to five test specimens thirty-two inches long by twelve inches high and twelve inches deep be constructed for evaluation.[41] Figure 12 illustrates the soil test block construction process. In this example, through-bolts are used to hold the formwork rigid. They will be discussed in more detail in the following section.

The soil should be of optimum moisture content and the ramming equipment planned for use in the construction should be employed. After compaction, the specimen is removed from the mold and immediately evaluated for signs of crumbling. It is left to dry for one month after which it is checked for cracking.[42] Subsequent tests for erosion resistance, water penetration and compressive strength are performed.

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[41] Middleton and Schneider, “Bulletin 5: Earth-Wall Construction, 4th Edition,” 16.

[42] Ibid.

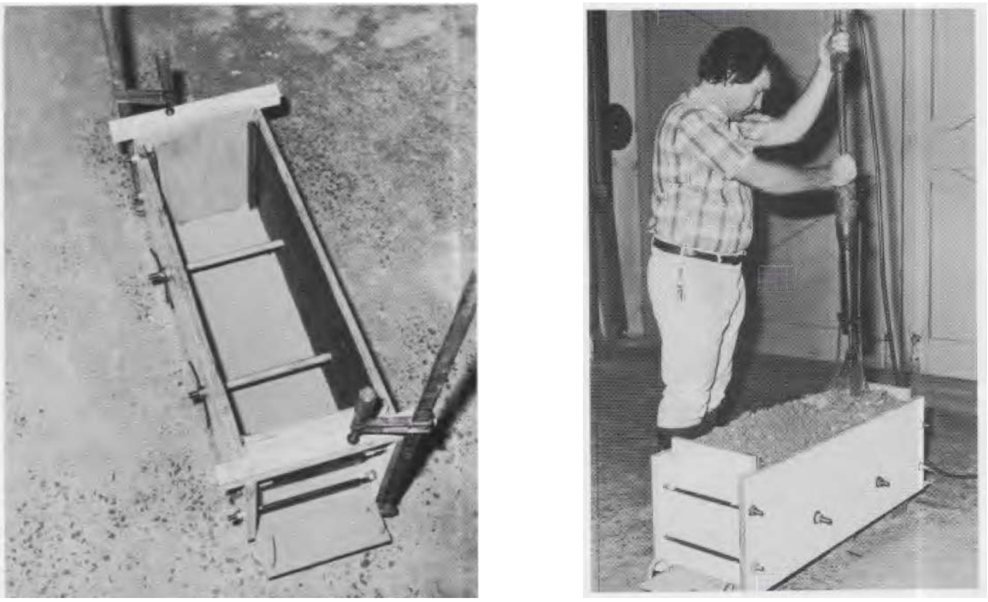

Figure 12. Specimen construction. A rammed earth specimen (left) with through-bolts visible in the formwork. Compaction of a rammed earth specimen (right). *Photographs from "Bulletin 5: Earth-Wall Construction," pages 16 and 17.*

Formwork Considerations

The formwork or shuttering used in rammed earth construction is a temporary support structure that holds the soil in place during the compaction process. While temporary by design, rammed earth formwork is nonetheless instrumental to the rammed earth building technique. Figure 13 is an illustration of a formwork concept as described by David and Lydia Miller.

Formwork re-use is inherent in rammed earth building because it is removed almost immediately after the compaction process is completed and moved to another section for further construction. Therefore, it must be sufficiently strong, stiff and stable to maintain integrity during the erection, placement and dismantling processes.[43] To aid

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[43] Walker et al., *Rammed Earth: design and construction guidelines*, 46.

efficiency, formwork should also be lightweight, easy to assemble and disassemble, and durable enough to withstand repeated on-site use.

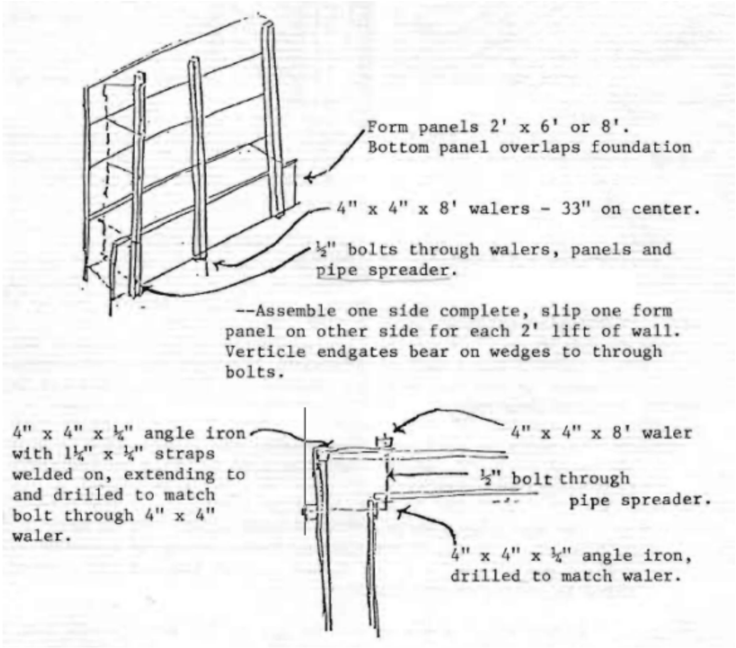

Figure 13. Formwork concept. *Drawing from* Manual for Building a Rammed Earth Wall manuscript *by Lydia A. and David J. Miller, University of Northern Colorado archives, page 21.*

The footings and foundation are completed before the rammed earth wall build-up begins. Foundations range from stone to concrete plinths. Special care is taken in the construction of the foundation for any rammed earth building as it carries a large structural load. The foundation must be level because the wall is built directly onto it and the foundation is used as the reference for vertical alignment.

There are two basic formwork design styles: moving and static. Both formwork systems use either through-bolt or cantilever designs with turnbuckles to provide the necessary structure to withstand the pressures generated by the compaction process.[44]

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[44] Ibid.

Examples of moving formwork with cantilever and through-bolt structure elements are shown in Figure 14.

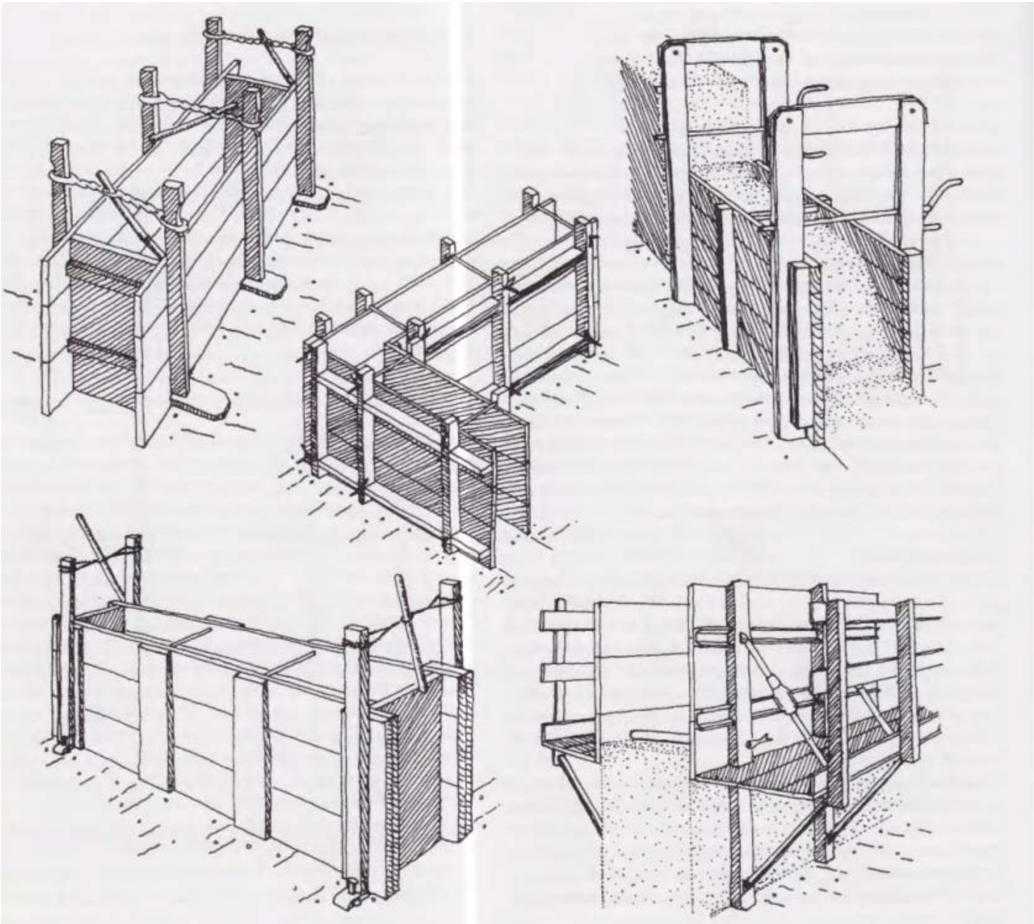

Figure 14. Examples of moving formwork with cantilever and through-bolts for structure. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 56.*

As illustrated in Figure 15, moving formwork systems require the set-up and build of wall sections horizontally a row at a time in a process similar to laying very large bricks. To minimize set-up and disassembly time, two identical forms are usually employed on site so that while one form is in use, the second is being disassembled and reassembled for the next unit. Moving formwork systems produce finished surfaces of lower quality than static formwork systems. However, if the final design incorporates plaster or other protective coatings, this is not a concern.

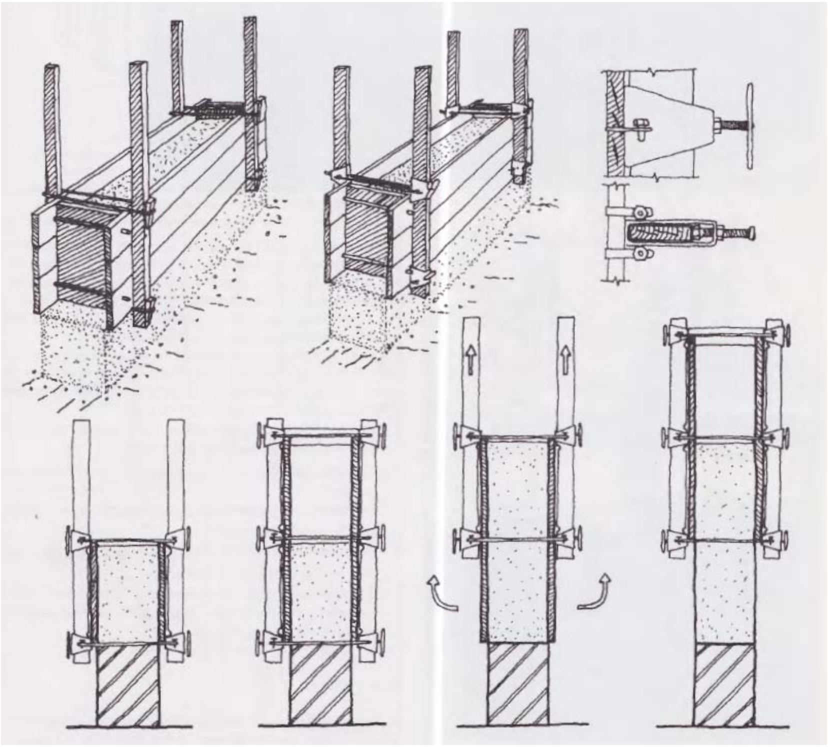

Figure 15. Perspective and section cuts of moving formwork showing how it is implemented. Through-bolts can be seen in the section drawings. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 57.*

Static formwork systems incorporate formwork processes similar to those developed for use with reinforced concrete. These systems have matured in the recent past and were not employed during the time period over which this paper is concentrated. Their use is discussed in this section to clarify modern developments in rammed earth technology that may not be appropriate for rehabilitation.

As opposed to moving formwork where the walls are built horizontally a section at a time, static formwork walls are built vertically a section at a time. As shown in Figure 16, a base formwork is constructed at ground level across the footing for the full wall section to be erected. This base is used for the compaction of the first layers of rammed earth. Modular panels are clipped onto the base with clamps, ties and supports that add strength to the formwork.[45] More panels are stacked vertically and clipped into place as the wall is built upward. No panels are removed until the section is completed. Thus, the walls are built up vertically in large sections. The panels are moved along the base formwork from section to section after the full wall height is reached.

Full-height static formwork systems with extended rammers have also been developed to minimize the time required for formwork erection.[46] This type of formwork is more costly because the base formwork is constructed on-site for one-time use only and is as labor intensive as building a second wall.

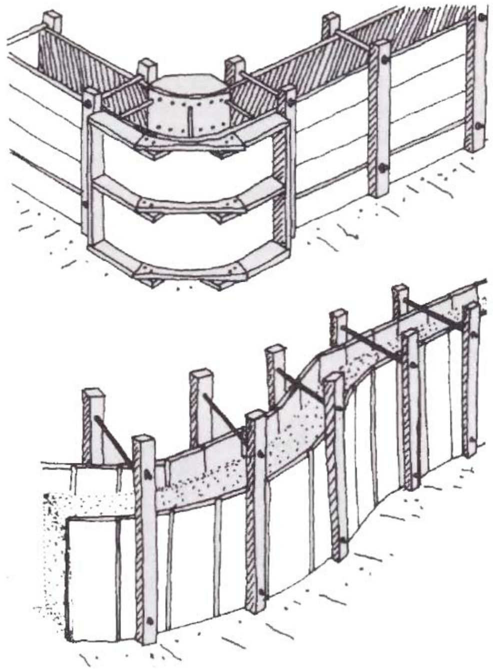

Figure 16. Examples of curved formwork. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 58.*

Prior to the development of modern mechanical rammers, rammed earth sections were layered in a trapezoidal fashion as depicted in Figure 17. This minimized horizontal

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[45] Walker et al., *Rammed Earth: design and construction guidelines*, 47.

[46] Ibid.

shrinkage cracks at vertical joints and improved the bonding between sections.[47] This technique has re-surfaced in recent years for the same purpose.[48]

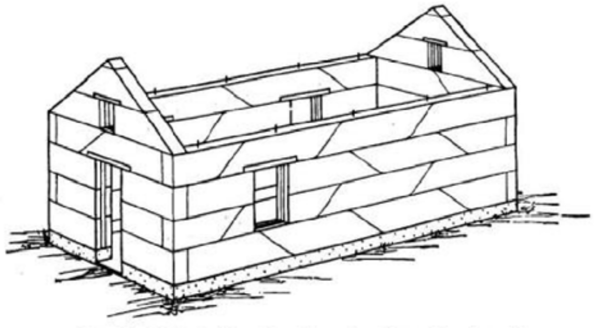

Figure 17. Trapezoidal sections with 45° angles were described by M. C. Betts and T. A. H. Miller as a means to improve bonding. *Drawing from "Farmers' Bulletin No. 1500," page 13.*

Timber or plywood-based formwork is used in both static and moving formwork systems. Timber or plywood sheathing is combined with either timber or metal strong backs (walers and soldiers) to provide added flexibility for curved forms.[49] With added flexibility comes the price of lower efficiency as timber formwork is generally more labor intensive, as well.

Through-bolts are often used in rammed earth construction to limit formwork deflections during compaction. Bolts are placed from twenty inches to four feet apart as needed to limit deflections without hindering compaction. After the formwork is removed, bolt-holes are patched with matching earthen material. If the design aesthetic requires a clean wall without bolt-holes, form deformations are minimized by increasing the stiffness of the formwork with external ties and clamps, as well as external props.[50]

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[47] Betts, "Farmers' Bulletin No. 1500," 11.

[48] Minke, *Earth Construction Handbook*, 61.

[49] Ibid, 50.

[50] Ibid.

Tools Considerations

Different tools are needed to complete the various stages of the rammed earth building process from soil preparation to final tamping. Soil preparation mills or crushers are often used when the soil composition is not ideal and large particles must be crushed to a finer consistency. Loam mills such as the one shown in Figure 18 were used in Germany in the early 1900s.[51] The soil is loaded into the mill where it is broken down using horsepower to pulverize it.

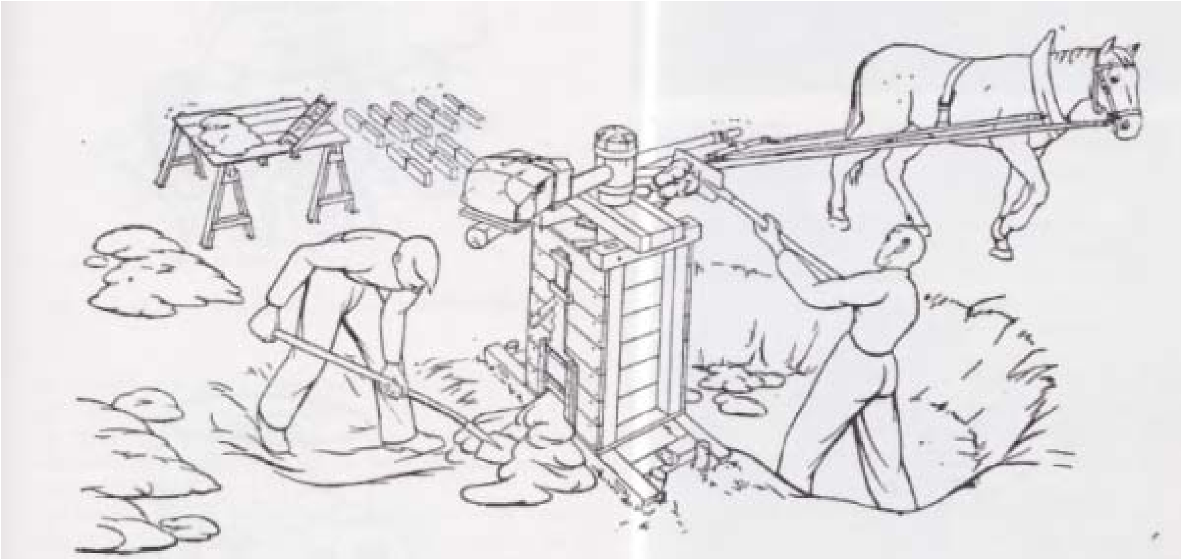

Figure 18. Early in the Twentieth Century, soil was crushed to the right consistency using a loam mill. The drawing shows one loam mill design commonly used in Germany during this time. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 39. Minke credits the drawing to Lydia and David Miller, 1947.*

Mechanical crushers are commonly used today. On-site crushers, such as those shown in Figure 19, incorporate various design styles including counter rotating cylinders and cutting blades mounted on a rotating horizontal plate similar to a kitchen blender in design. The crusher type depends on the job size. As indicated in the figure, even small-

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[51] Minke, *Earth Construction Handbook*, 40.

scale on-site crushers can process from about 90 ft^3 to 125 ft^3 of material per hour, with some more efficient than others. Also, all rammed earth how-to manuals that the author reviewed caution that mechanical crushers cannot be used if the soil is wet.

Figure 19. The counter rotating drums crusher (left) is able to crush 20 m^3 (~700 ft^3) of clods in 8 hours. The blade crusher (right) can crush up to 30 m^3 (~1000 ft^3) in 8 hours. *Drawings from* Earth Construction Handbook *by Gernot Minke, page 42.*

Two other methods of crushing, water and freezing, are time consuming, but require no mechanics. In the water method, soil is layered into a large, flat container to a height of about six to ten inches. Enough water is added to the container to cover the soil. The mixture is left for two to four days. After this time (called maturation), the mix is of a soft, malleable consistency that allows for easy incorporation of additives such as sand or gravel.[52] In areas where freezing temperatures are common over the winter, the soil/water mixture is left to freeze. Disintegration of the soil occurs due to the expansion of the freezing water.[53]

Once crushing is complete, it may be necessary to remove organic materials or larger rocks by sieving the dry, crushed soil. Sieves can be simple wire mesh screens

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[52] Walker et al., *Rammed Earth: design and construction guidelines*, 51.

[53] Minke, *Earth Construction Handbook*, 40.

stretched across wooden or metal frames or, more effectively, cylindrical sieves such as the one shown in Figure 20.[54] They can be inclined and turned by hand or motorized.

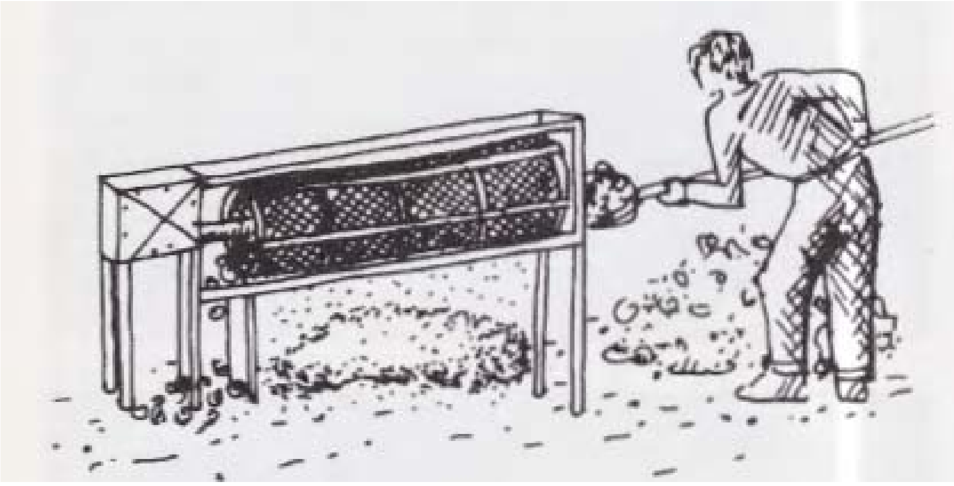

Figure 20. Sieving devices remove unwanted particles of organic matter or larger rocks. Sieves range from simple screens to hand-cranked or motor-driven mesh drums. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 42.*

After soil preparations are completed, the soil is mixed with any additives and water. Mixing breaks down aggregated lumps of soil and provides a uniform, consistent mixture of solids and water. The mixing method used in the construction process is defined by the job size. That is, mixing techniques range from hand mixing for small jobs and rammed earth repair to concrete drum mixers for large-scale jobs.[55]

In the past, horse drawn wheel carts, such as the one illustrated in Figure 21, were often used to mix the soil near the building site. Mechanical mixers, such as the ones shown in Figure 22, are most commonly used today. Care is needed to avoid balling of the soil. Mechanical mixtures best suited to rammed earth construction include forced-

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[54] Ibid, 42.

[55] Walker et al., *Rammed Earth: design and construction guidelines*, 52.

action or screed mixers and pan concrete mixers. Rotating drum mixers tend to ball the soil and are not generally recommended.

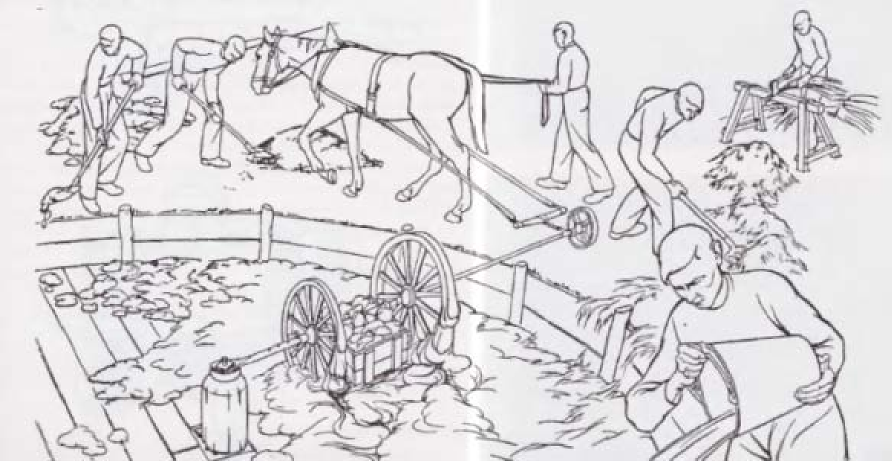

Figure 21. Mixing soil using a wheel cart. This technique, like the loam mill, was common practice in Germany at the beginning of the twentieth century. *Drawing from* Earth Construction Handbook *by Gernot Minke, page 39. Minke credits the drawing to Lydia and David Miller, 1947.*

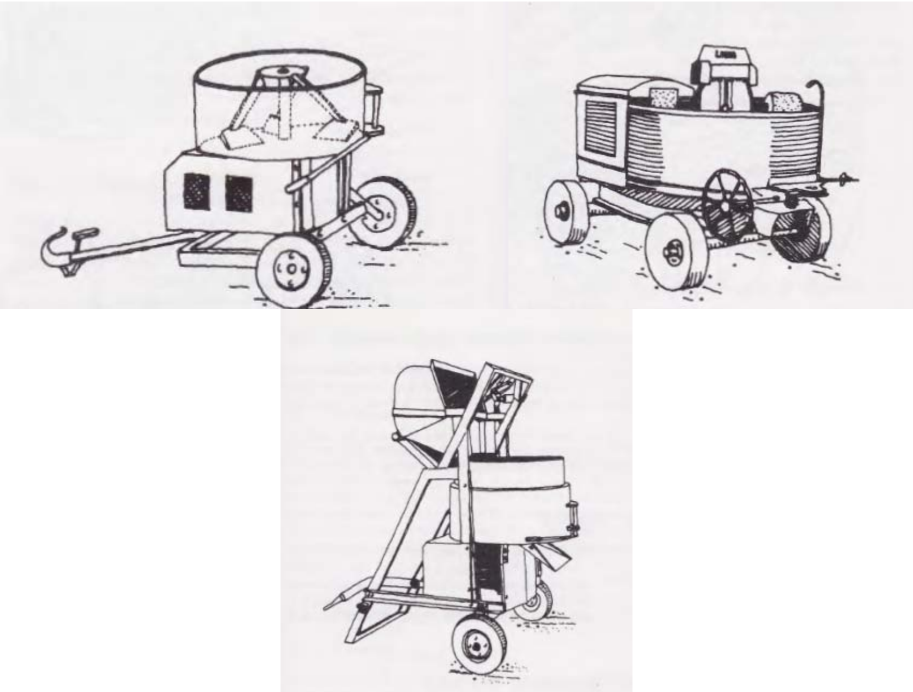

Figure 22. Types of mechanical mixers. Clockwise from top: forced mixer, forced mixer with loading device, and mortar mixer with rollers. *Drawings from* Earth Construction Handbook *by Gernot Minke, pages 40 and 41.*

Loaders are needed to lift the mixed soil into the formwork. As with crushers and mixers, job size determines loader requirements. Loading tools range from shovels to cranes. The most common are front-end loaders such as Bobcats.[56] Soil placement affects the final wall appearance. Often some manual smoothing for even depth and leveling is done before ramming.

The ramming process is either manual or automated based on project size. Hand-held electric or pneumatic rammers have flat, circular heads about six inches in diameter. Vibrating rammers have rectangular heads with rounded corners. They fit to the width of typical formwork (about eighteen inches) with handles on top for ease of placement inside the formwork.

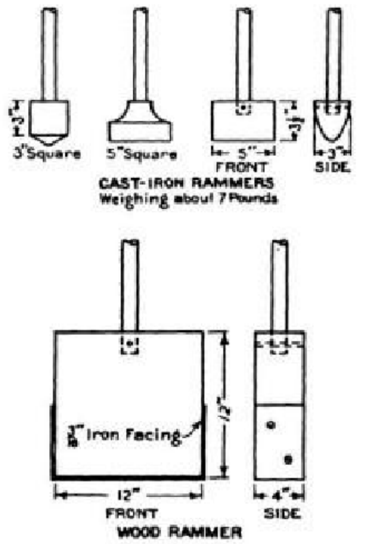

Figure 23. Different styles of manual rams. Conical or wedge-shaped rams are more effective at mixing the layers and aid in bonding. *Drawing from "Farmers' Bulletin No. 1500," page 7.*

Manual rammers, such as those shown in Figure 23, can be flat-headed or have conical, pointed or wedge-shaped bottom faces to improve the efficiency of the manual process. In the past, it was believed that the wedge-shaped head of manual rammers were more effective as they "compressed the earth in four directions and tended to knit it together…[while] a flat-faced rammer formed a crust that prevented the consolidation of the lower earth."[57] However, it was learned over time that flat-faced rammers were

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[56] Ibid.

[57] Betts, "Farmers' Bulletin No. 1500," 6.

better at compressing the earth along edges and in corners. In the end, both rammer types were typically used.

Design Details

Rammed earth is susceptible to water damage and abrasion. Thus, rammed earth structures should be designed to avoid standing water, excess moisture and wind. Also, unprotected rammed earth surfaces are soft enough to make them particularly vulnerable to vandalism. As a result, consideration must be given to the protection of rammed earth exteriors either by protective coatings or the addition of design elements that discourage defacement.

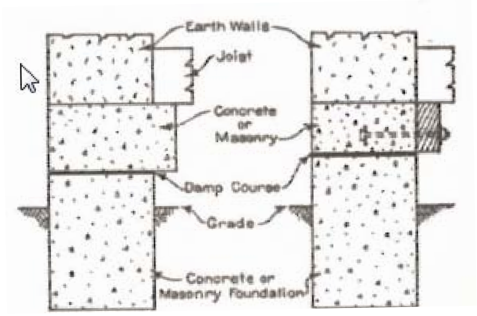

Figure 24. This drawing from page 15 of “Farmers’ Bulletin No. 1500” shows the placement of the rammed earth wall on top of a concrete or masonry footer with a damp-proof barrier.

As mentioned earlier, foundations or any surfaces that come in contact with the rammed earth must be of concrete, stone or other masonry. Also, it is common practice to incorporate some type of damp-proof barrier between the rammed earth wall and the footer as shown in Figures 24 and 25. Explained by Walker et al., “Protection from water damage, moisture ingress, and … radon gas, are the governing criteria for wall footing details.”[58] The type of material used for damp-proofing aids historic preservationists in determining the timeframe in which a building was originally constructed.

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[58] Walker et al., *Rammed Earth: design and construction guidelines*, 61.

In “Farmers’ Bulletin No. 1500,” Betts and Miller specified that “footings should be below the frost line to prevent heaving, and the masonry should be carried up at least 12 inches above the surface of the ground, so that rain will not splash on the earth walls.”[59] They also specified that the foundation be formed to the same thickness as the superstructure and that a damp-proof course be incorporated between the footing and the rammed earth “to prevent moisture from rising by capillary attraction into the rammed earth.”[60]

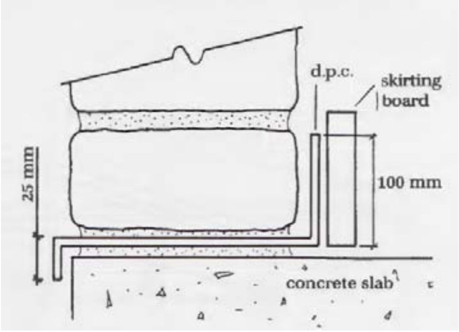

Figure 25. This section cut from page 3 of “Earth-Wall Construction” shows the placement of the rammed earth wall on top of a concrete slab with damp-proof barrier indicated.

They provided two options for moisture barriers: slate or tar. If choosing slate, they suggested topping it with two brick courses to protect the slate from breakage during the ramming process. If using tar paper, they recommended applying several thicknesses of tar paper embedded in hot tar.[61]

Damp-proofing is included in “Earth-Wall Construction” first published in 1952. In this bulletin, Middleton and Schneider state that the best materials for use as damp-proof courses are materials that maintain flexibility and will not fracture due to shrinkage in the wall or minor foundation movement. The materials they recommended include lead, copper and aluminum-cored bituminous.[62]

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[59] Betts, “Farmers' Bulletin No. 1500,” 8.

[60] Ibid.

[61] Ibid.

[62] Middleton and Schneider, “Bulletin 5: Earth-Wall Construction, 4th Edition,” 3.

Modern construction techniques for rammed earth utilize heavy-duty plastics-based damp-proof course materials.[63] As with materials used in the past, these materials must be strong enough to withstand the ramming process. Also, because they are made of impermeable materials, a two-row brick course or other permeable material is often incorporated between the footer and the rammed earth wall. Figure 26 shows two modern foundation designs.

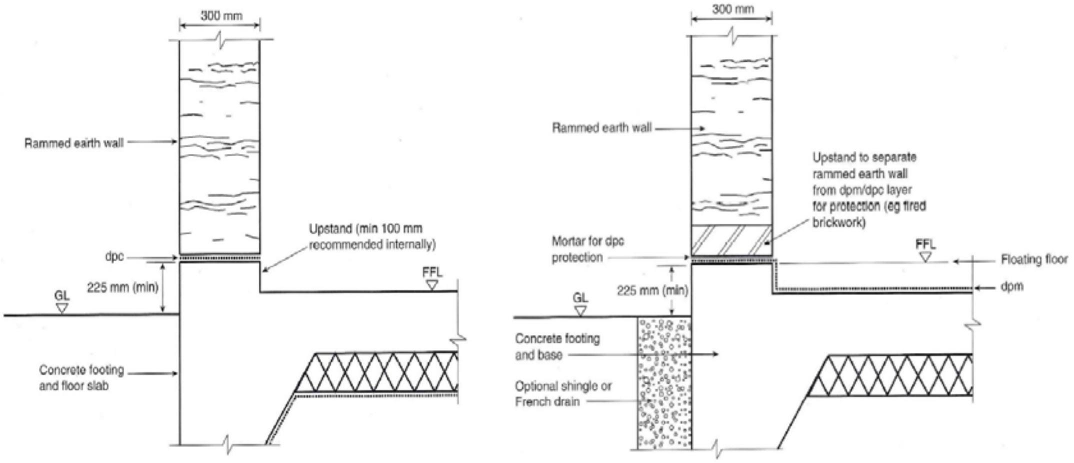

Figure 26. Section cuts of two modern foundation designs incorporating damp-proof barriers between the foundation and the rammed earth wall. *Drawings from* Rammed Earth: Design and construction guidelines *by Peter Walker et al, page 63.*

The high density and strength of rammed earth walls make it difficult to cut into built walls to create openings. Therefore, wall openings are usually preplanned. Openings are built or fashioned in one of three ways: full wall height openings, the incorporation of lintels during construction, or use of temporary block-outs.[64] Temporary block-outs are a more modern construction technique whereas lintels and full wall openings are more traditional.

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[63] Walker et al., *Rammed Earth: design and construction guidelines*, 62.

[64] Ibid, 51.

Wood and concrete lintel openings are described by Betts and Miller in “Farmer’s Bulletin No. 1500.” Figure 27 provides a detailed description for incorporating a double-hung window using a concert lintel and sill. Betts and Miller explain that while this is a more expensive design method, it produces a long lasting element. They also provide a lower cost alternative incorporating a wooden window frame design. This is also shown in Figure 27. Understanding the window design concepts described by Betts and Miller is of particular importance for historic preservation in that these methods were the methods most likely employed from the 1930s to 1960s.

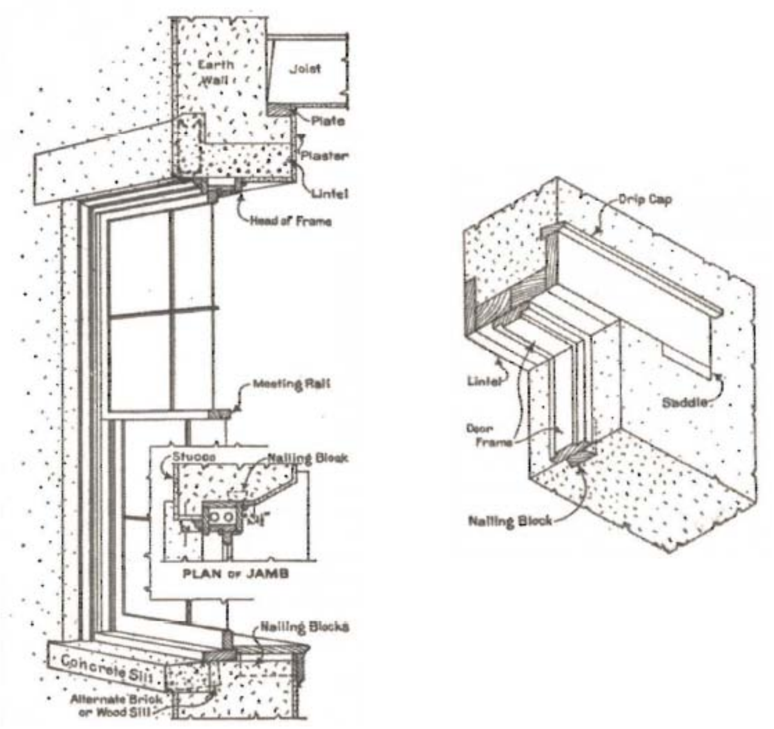

Figure 27. Detailed drawings of concrete (left) and wood (right) lintels and sills described in “Farmers’ Bulletin No. 1500,” pages 15 and 17. The L-shaped lintel in the concrete design not only provided a better architectural aesthetic, but also aided in preventing water from seeping behind the lintel. The wood lintel was a simplification of the standard practice of lintel design for rammed earth construction. Betts and Miller emphasized the use of a molded drip cap to prevent water from pooling above the wood lintel.

Modern lintel styles are shown in Figure 28. As the figure illustrates, timber, reinforced concrete, steel tee, steel angle or steel rods are used. They are much simpler in design owing to the availability of both steel and mobile heavy equipment that enables the easy placement of large concrete blocks.

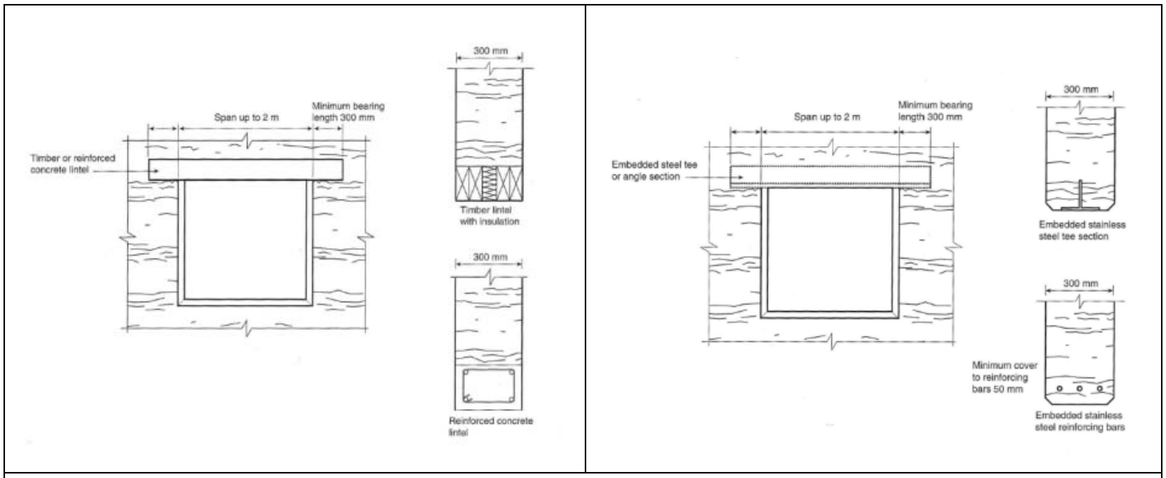

Figure 28. Different lintel techniques for window and door openings. *Drawings from* Rammed Earth: Design and construction guidelines *by Peter Walker et al., pages 66 and 67.*

The block-out technique is a modern method for creating window and door openings. It involves constructing plywood boxes of the required opening dimensions. The boxes are inserted into the formwork at the location where the opening is to be made. They are sufficiently strong to withstand the rammed earth compaction process. The block-out boxes are removed once the compaction process is complete leaving an opening of the desired size and shape. The block-out box technique allows for variations in window and door cut-outs. They do not have to be square as the term implies.

Betts and Miller do not discuss electrical and plumbing systems in “Farmers’ Bulletin No. 1500.” This may be attributed to the demographic to which the bulletin was aimed – rural farmers who most likely would have still been using outhouses and wells and would have had limited access to electricity.

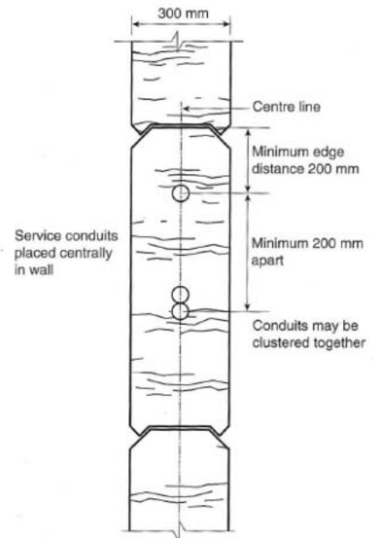

Figure 29. Section cut of rammed earth wall showing conduit placement. *Drawing from* Rammed Earth: Design and construction guidelines *by Peter Walker et al., page 74.*

Today, however, as with door and window openings, all inter-wall services for electrical, low-voltage lighting or other in-wall access points must be preplanned. Illustrated in Figure 29, conduits are run horizontally as much as possible to minimize any hampering of the rammed earth process. [65] While rammed earth walls can be easily chased to allow access post-production, it is generally not recommended as the patching process often leaves surface discontinuities or color variations in the face. This must be considered when adaptive reuse is planned for rammed earth buildings.

It should be noted that even today water pipes are usually not incorporated into rammed earth walls because of the code requirements defined by New Mexico, the only state with building codes that address rammed earth specifically. So, plumbing is generally routed through the foundation.

Betts and Miller included a brief discussion on the use of protective coatings in the Farmers' Bulletin though they did not include any specific recommendations for types of coating or particular sealing properties. They highlighted their importance especially

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[65] Ibid, 74.

to prevent water infiltration when sub-optimal soil is used.[66] Figure 30 is a photograph from the Library of Congress archives showing workers applying a mud coat over an earth walled structure circa 1930.

Figure 30. Coating of an earth house with mud, near Santa Fe, New Mexico, ca. 1930. *Photograph by Russell Lee, Library of Congress.*

Ralph L. Patty of the South Dakota Agricultural Experiment Station experimented extensively with coatings for rammed earth. He documented a detailed analysis of a 10-year study on the effects of various rammed earth wall coatings. He studied both interior and exterior coatings, as well as the use of admixtures to increase the life expectancy of rammed earth walls. In "Bulletin 336: Paints and Plasters for Rammed Earth Walls," published in May, 1940, Patty concluded that if high-quality soil is used, the wall need

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[66] Betts, "Farmers' Bulletin No. 1500," 19.

not be protected. If, however, the soil is less than ideal, use of ordinary stucco was the best choice for exterior walls and good quality paint was sufficient for indoor use. [67]

Though fashionable at the time, Patty recognized that stucco was expensive and not necessarily aesthetically pleasing. He explained, however, that exterior paints generally failed within a few years:

> Paints have been tried persistently with the hope of finding a successful paint covering for earth walls, and especially with the hope of finding a successful transparent paint. Paints will protect the surface of earth walls from violent driving rains, and at the same time do not completely hide the identity of the material. This is of particular value in dwelling house construction, where the owner is not only interested in the high thermal efficiency and air conditioning value of this type of wall, but is also interested in having a wall that is unique and different.[68]

Patty studied twelve types of stucco mixtures applied to panels between 1932 and 1934. He ultimately recommended a stucco mixture of one part Portland cement, three and one-half parts of high-quality sand, and one-third part cem-mix (a commercial filler) or hydrated lime. He emphasized that at least nine months should pass after the wall is constructed before applying any coatings. He also explained that while rammed earth does have a rough surface texture, some sort of bonding process is still necessary.[69]

Patty experimented with forty-four different bonding methods during the same time period. The methods ranged from light wire mesh to heavy metal lath to simple

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[67] Ralph L. Patty, *Bulletin 336: Paints and Plasters for Rammed Earth Walls* (Brookings, South Dakota: South Dakota State College, 1940), 4 - 5.

[68] Ibid, 6.

[69] Ibid, 6-8.

nails. He studied various jointing methods for use with the different wire types. He also studied various nail sizes, nail placement and separation distances between nails.[70]

Patty concluded that there was no distinct advantage of heavy metal lath over light wire, at least not over the period of the study. However, lapping the wire mesh had a definite advantage over just butting the wire panels together. The mesh strips were lapped by two to three inches and were wired together every eighteen inches using 16-gauge wire. The mesh was nailed to the wall at the lap joints as well as at the corners. This resulted in minimal checks. He found that butting the mesh strips together without any overlap resulted in checks at more than one half of the vertical joints.[71] Thus, while wire size was not important, overlapping the mesh made a big difference. Patty also determined that driving the nails straight into the rammed earth and then hooking them over the mesh was more effective that driving the nails in at a slant as was the practice when attaching mesh to wood frame buildings. His team developed a tool to bend the nails efficiently.

Today, rammed earth is celebrated for its visual impact, thus exterior and interior walls are left exposed as much as possible. Stucco is rarely used. Even with the advances that have been made with transparent paints and applicators, coatings are still not recommended unless the soil is not of high quality or the building is located in an area where water damage is likely. The exception is mainly with interior walls which are sometimes coated to minimize dusting. If coatings are used, reapplication is required

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[70] Ibid, 8 -11.

[71] Ibid, 9.

every one to five years depending on the building location and coating type.[72] Also, only breathable coatings must be used.

As seen in Figure 31, Betts and Miller discuss the importance of incorporating damp-proofing in the roof-to-wall connection in the Farmers' Bulletin. They explain "[o]verhanging eaves, tight flashings, and drip grooves on window sills, were found absolutely necessary to keep moisture from getting between the wall and the [interior plaster] coating."[73]

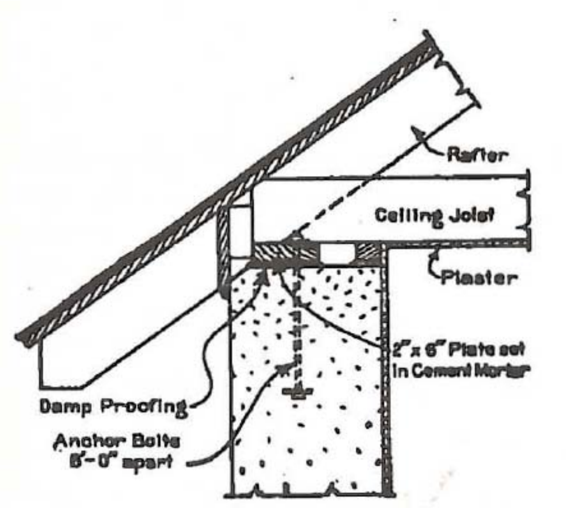

Figure 31. Roof-to-wall connection as described by Betts and Miller. Damp-proofing is indicated. *Drawing from "Farmers' Bulletin No. 1500," page 19.*

The use of eaves or overhangs to aid in protecting rammed earth walls is specifically discussed by Walker et al., in *Rammed Earth: design and construction guidelines*. They also describe using a stem wall to protect the base of the wall. Figure 32 provides a section cut of the roof connection as described by Walker, et al.

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[72] Walker et al., *Rammed Earth: design and construction guidelines,* 70.

[73] Betts, "Farmers' Bulletin No. 1500," 19.

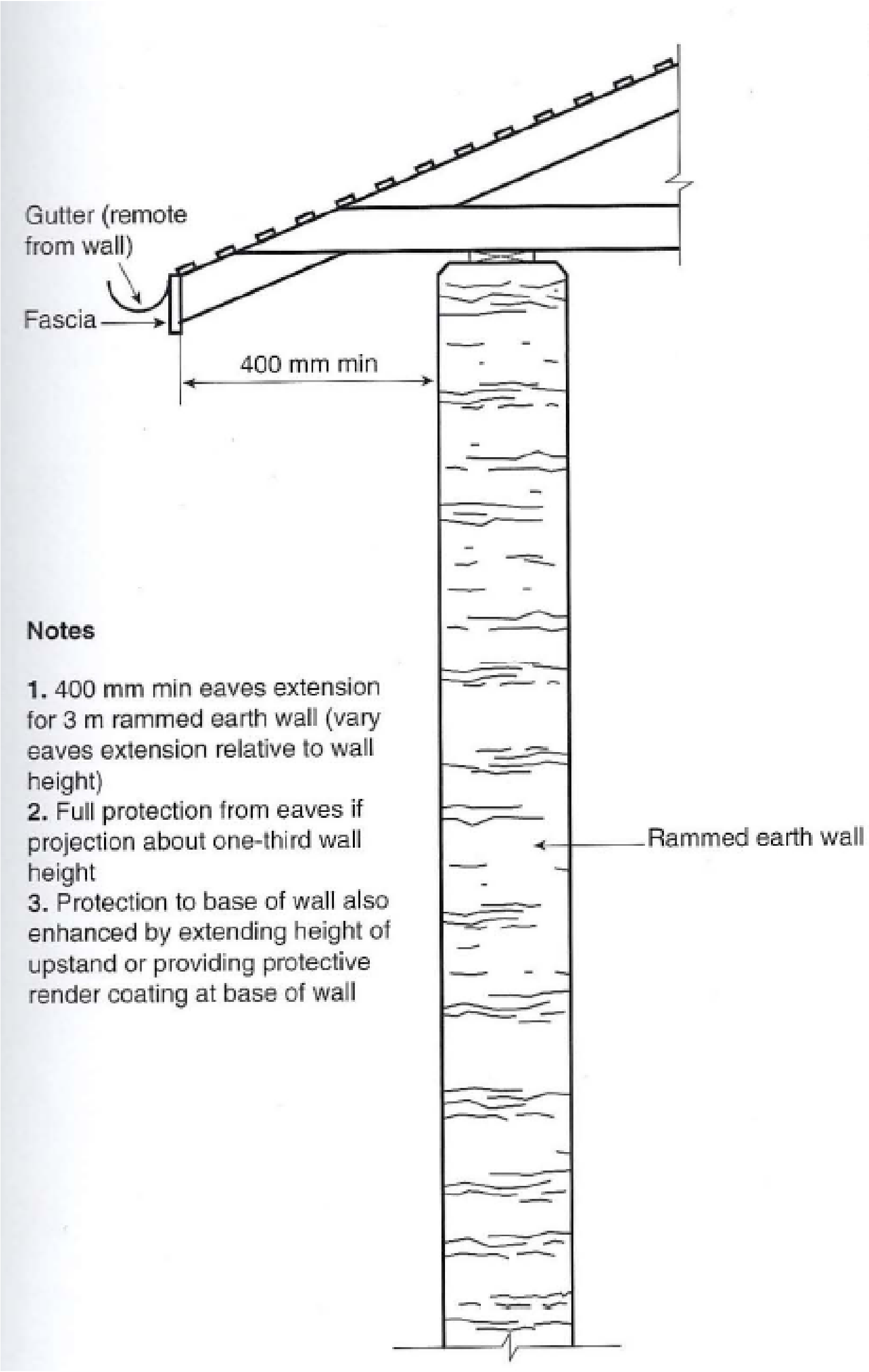

Figure 32. Section cut showing the eave as the protection for the rammed earth wall. Notes in drawing indicate eave projection to wall height estimate and describe use of stem wall and coatings as added means of protection. *Drawing from* Rammed Earth: Design and construction guidelines *by Peter Walker et al., page 69.*

Thermal Considerations

The insulation requirements for mass wall designs are specified in the *International Residential Code* based on climate zone. Figure 33 is the climate zone map for the United States.[74] Table 4 is extracted from the 2009 edition of the Code. The R-factors range from 3 to 19 ft²·°F·h/Btu and 4 to 21 ft²·°F·h/Btu depending on the fraction of the insulation that is on the interior of the building.[75]

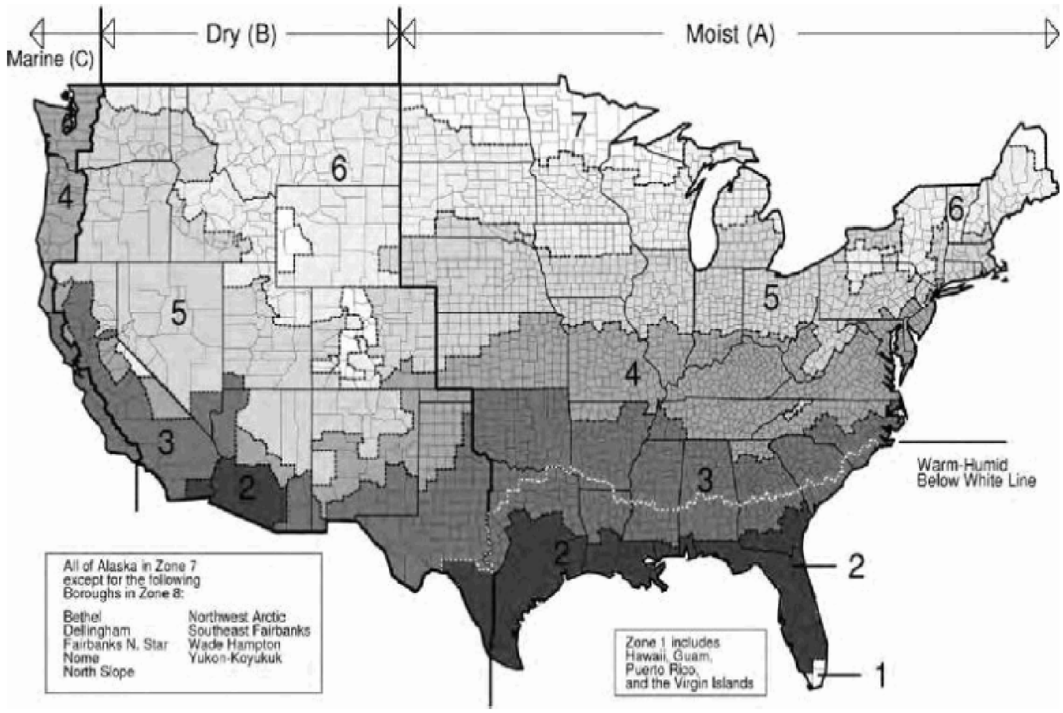

Figure 33. Climate Zone Map for the United States. *Illustration from* 2009 International Residential Code, Figure N1101.2, page 456.

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[74] International Code Council, Inc., *International Residential Code for One- and Two-Family Dwellings* (Country Club Hills, Illinois: International Code Council, 2009), 456.

[75] Ibid, 468.

Table 4. Insulation and Fenestration Requirements by Component[a] from *2009 International Residential Code* (Table N1102.1)

Climate Zone	Fenestration U-Factor	Skylight[b] U-Factor	Glazed Fenestration SHGC	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value[k]	Floor R-Value	Basement Wall R-Value	Slab[d] R-Value and Depth	Crawl Space Wall R-Value
1	1.20	0.75	0.35[j]	30	13	3/4	13	0	0	0
2	0.65[i]	0.75	0.35[j]	30	13	4/6	13	0	0	0
3	0.50[i]	0.65	0.35[e, j]	30	13	5/8	19	5/13[f]	0	5/13
4 except Marine	0.35	0.60	NR	38	13	5/10	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.35	0.60	NR	38	20 or 13 + 5[h]	13/17	30[f]	10/13	10, 2 ft	10/13
6	0.35	0.60	NR	49	20 or 13 + 5[h]	15/19	30[g]	10/13	10, 4 ft	10/13
7 and 8	0.35	0.60	NR	49	21	19/21	30[g]	10/13	10, 4 ft	10/13

a. R-values are minimums. U-factors and solar heat gain coefficient (SHGC) are maximums. R-19 batts compressed in to nominal 2 x 6 framing cavity such that the R-value is reduced by R-l or more shall be marked with the compressed batt R-value in addition to the full thickness R-value.

b. The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration.

c. The first R-value applies to continuous insulation, the second to framing cavity insulation; either insulation meets the requirement.

d. R-5 shall be added to the required slab edge R-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less, in zones 1 through 3 for heated slabs.

e. There are no SHGC requirements in the Marine Zone.

f. Basement wall insulation is not required in warm-humid locations as defined by Figure N1101.2 and Table N1101.2.

g. Or insulation sufficient to fill the framing cavity, R-19 minimum.

h. “13+5” means R-13 cavity insulation plus R-5 insulated sheathing. If structural sheathing covers 25% or less of the exterior, R-5 sheathing is not required where structural sheathing is used. If structural sheathing covers more than 25% of exterior, structural sheathing shall be supplemented with insulated sheathing of at least R-2.

i. For impact-rated fenestration complying with Section R301.2.1.2, the maximum U-factor shall be 0.75 in zone 2 and 0.65 in zone 3.

j. For impact-resistant fenestration complying with Section R301.2.1.2 of the International Residential Code, the maximum SHGC shall be 0.40.

k. The second R-value applies when more than half the insulation is on the interior.

Mass walls are defined by the *International Residential Code* as any masonry or concrete wall having a mass greater than or equal to 30 pounds per square foot, solid wood walls having a mass greater than or equal to 20 pounds per square foot, and any other walls having a heat capacity greater than or equal to 6 Btu per square foot.[76]

Wall conductivity is directly related to material density, which, in turn, is reciprocally related to steady state thermal resistance. For rammed earth walls, this has the effect of lowering the overall steady state thermal performance of the building making it appear undesirable for energy-conscious design. Therefore, it is generally understood by architects and structural engineers working with rammed earth that steady state thermal properties should not be the measure for massive wall thermal performance as they do not reflect reality.

Kevan Heathcote formally of the University of Technology in Sydney, Australia conducted a study to model the true thermal performance of earth buildings. Table 5, reprinted from his journal article "The thermal performance of earth buildings," describes the results of his research. It shows that rammed earth walls are extremely dense and have the largest conductivity value of the three major forms of earth construction. The author added the United States Customary Units conversion for density and conductivity.

Table 5. Values of Density and Conductivity for Earth Wall Constructions

Material	Density (kg/m^3)	Density (lb/ft^3)	Conductivity (W/m°K)	Conductivity (Btu/h ft °F)
Cob	1450	91	0.60	0.35
Adobe	1650	103	0.82	0.47
Rammed Earth	2000	125	1.20	0.69

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[76] Ibid, 17.

Heathcote explains that the relationship between steady state thermal resistance and conductivity can be described by Equation 1.

$$\boldsymbol{R_{wall}} = \frac{\boldsymbol{Wall\ Thickness\ (m)}}{\boldsymbol{Wall\ Conductivity}\left(\frac{\boldsymbol{W}}{\boldsymbol{m\,^{\circ}K}}\right)} \qquad \textbf{Equation 1}$$

From the table and equation, it can be seen that the steady state performance of rammed earth is very low.[77] That is, for a rammed earth wall to achieve the same steady state R-value as a brick veneered wall with R1.5 insulation (having a cavity resistance, i.e., R_{wall}, of 2.02 $m^{2\,\circ}K/W$), the wall would have to be about 2.4 meters or 7 feet, 10 inches thick.

However, experience with earthen buildings and rammed earth buildings in particular, have shown that their thermal performance is actually very good. Many occupants of earth homes describe that their home is warm in the winter and cool in the summer.[78] To appreciate this phenomenon when considering rammed earth thermal performance, Heathcote contends that the cyclic nature of earth properties must be understood.

To this end, Heathcote modeled the effects of time lag to define thermal performance. Unlike an insulated wall that resists the transfer of energy from the outside to the interior, a mass wall stores heat energy. It takes time for the heat to build and transfer into the building. The time lag plays an important role. Heathcote explains,

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[77] Kevan Heathcote, "The thermal performance of earth buildings," *Informes de la Construcción*, Vol. 63, No. 523, 119.

[78] Easton, *The Rammed Earth House*, 43.

“Whilst the steady state thermal resistance is linear in relation to wall thickness the cyclic thermal resistance increases exponentially with wall thickness.”[79]

Figure 34, from Heathcote’s analysis, graphically illustrates the effect of wall thickness on cyclic thermal resistance, steady state resistance and time lag for an adobe wall. As the graph shows, the Cyclic R value behaves as an exponential function, and for earthen walls with a thickness greater than 450 millimeters (~18 inches), the cyclic resistance increases rapidly.

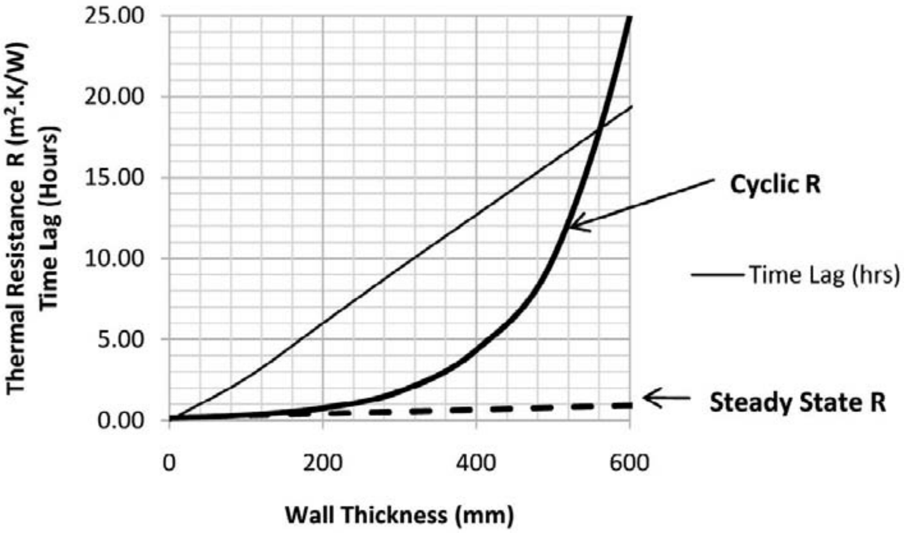

Figure 34. Thermal resistance and time lag as related to wall thickness for an adobe wall. *Graph from “The thermal performance of earth buildings” by Kevan Heathcote, page 121.*

Heathcote shows that the heat flow through an earthen wall can be modeled by Equation 2 on the following page. $Temp\_Out_{lag}$ represents the outside temperature at time t_{lag} hours prior to the inside temperature at the time under consideration, $Temp\_In_{current}$.

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[79] Heathcote, “The thermal performance of earth buildings,” 121.

$$\boldsymbol{Heat\ Flow = \frac{Surface\ Area\ of\ the\ Wall\ (m^2) \times (Temp\_Out_{lag}\ (^\circ K) - Temp\_In_{current} (^\circ K))}{R_{cyclic}\ (m^2\ ^\circ K/W)}} \qquad \textbf{Equation 2}$$

From his analysis of this equation, Heathcote concluded that when the exponential Cyclic R value is coupled with a time lag greater than 12 hours, such as for an 18-inch thick wall, heat flow through the wall becomes negligible “almost totally leveling out external temperature swings.”[80]

Heathcote cautions that the thermal performance of the earthen walls is only part of the story when determining the thermal properties of an earth building. Other factors, such as the gains and losses in conduction heating as a result of the glazing, roof and floor designs, and solar heat gains through the glazing design, contribute to the overall internal temperature.[81] After adding these factors to his model, Heathcote concluded that better thermal performance in the winter requires the addition of large areas of glazing (north-facing for Australia), large internal thermal mass areas, or walls greater than 450 millimeters (~18 inches) thick. In lieu of any of these concessions, Heathcote had one more recommendation:

> One other option to improve the thermal performance of thinner walls that is worth considering is to place a layer of polystyrene in the centre [sic] of the wall. A 250 mm thick wall with a layer of 50 mm of polystyrene in the middle has a steady state thermal resistance equivalent to a brick veneer wall with R 1.5 insulation in the cavity. It also has a very high cyclic thermal resistance.[82]

Walker et al. provide two options, shown in Figure 35, for thermal insulation for modern rammed earth construction. They explain that any insulation materials must be

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[80] Ibid, 125.

[81] Ibid, 122.

[82] Ibid, 126.

vapor permeable, or if not, a 25 – 50 millimeter (1 – 2 inch) ventilation cavity should be incorporated into the wall design to prevent the build-up of condensation.[83]

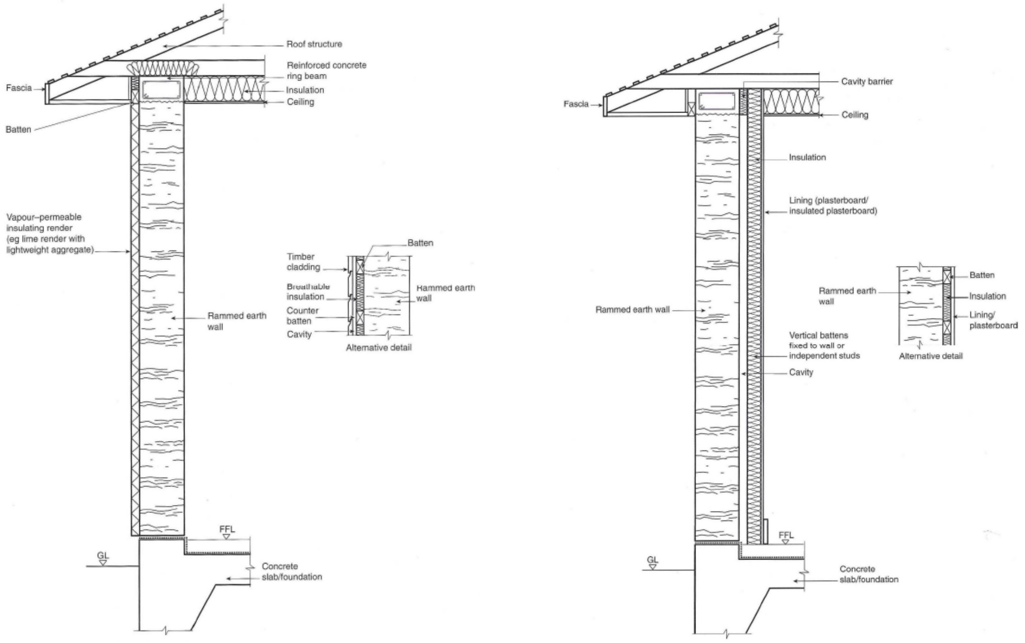

Figure 35. Different insulation techniques for new construction. *Drawings from* Rammed Earth: Design and construction guidelines *by Peter Walker et al., pages 76 and 77.*

Heathcote's study aids historic preservationists in determining the best methods for improving the thermal performance of rammed earth structures to meet modern building requirements for energy efficiency. While Walker et al. provide additional guidance in the incorporation of insulation into rammed earth design. Modeling of the unique design of a particular building based on Heathcote's work could also be used by preservationists to determine whether or not a building should be preserved, adaptively reused, or removed. That is, the long-term energy efficiency and upgrade costs can be compared to the embodied energy of removal and replacement.

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[83] Walker et al., *Rammed Earth: design and construction guidelines*, 75.

Structural Integrity Factors

Paul McHenry, Jr. explains in *Adobe and Rammed Earth Buildings: design and construction* that the principal criteria for rammed earth wall design are governed by the same guidelines that are used for masonry or formed-concrete wall systems while at the same time taking into consideration the lower strength factors of earth walls. He further states that the international vernacular standard for a rammed earth wall height-to-thickness ratio is a minimum of 10/1 for bearing walls to insure stability.[84]

Walker et al. explain that the over-arching purpose of the design requirements for rammed earth are provided to meet the expectation that rammed earth buildings will "remain serviceable throughout their expected design life."[85] And, furthermore that they will not deteriorate unduly because of weather effects, accidental damage, animal infestation or from general use. They emphasize that the design intent can be met through "a programme [sic] of ongoing maintenance and repair" as well as through the adoption of design details including the specification of protective coatings and the use of techniques that minimize wall exposure to the elements.[86]

In addition, the authors identify six structural properties for rammed earth including dry density, compressive strength, flexural tensile strength, shear strength, elastic modulus, and drying shrinkage. [87] The authors provide overall guidance for these

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[84] Paul Graham McHenry, Jr., *Adobe and Rammed Earth Buildings: design and construction,*(New York: John Wiley & Sons, Inc., 1984), 105.

[85] Walker et al., *Rammed Earth: design and construction guidelines*, 79.

[86] Ibid.

[87] Ibid, 79 – 80.

properties in Chapter 6 of *Rammed Earth: design and construction guidelines*. Table 6 summarizes these guidelines.

Table 6. Structural Properties Guidelines

Property	Guideline
Dry Density	1750 kg/m^3 (109 lbs/ft^3) – beneficial, i.e., resistance to overturning 2250 kg/m^3 (140 lbs/ft^3) – unfavorable dead loading
Compressive Strength	1 N/mm^2 (144 psi) – minimum characteristic unconfined
Flexural Tensile Strength	Should not be relied on in design without testing
Shear Strength	Coefficient of friction (μ) between 0.2 and 0.3; should not be relied on in design without testing
Elastic Modulus	100 – 500 N/mm^2 (14.5k – 72.5k psi)
Drying Shrinkage	Sample testing to define

Walker et al. provide a comprehensive process for the analysis of the structural integrity of rammed earth designs in Appendix C of *Rammed Earth: design and construction guidelines*. They explain that the structural integrity of rammed earth walls are defined by their combined compression and bending strength, their concentrated compression load capability, their out-of-plane flexural load capability, and their ability to withstand shear forces. Each of these factors must be considered on the basis of the unique design. They emphasize that the shear strength of rammed earth should not be relied upon in the design as the coefficient of friction (μ) at between 0.2 and 0.3 is low. However, methods to shore up rammed earth wall shear strength including the use of external cross braces have been incorporated into modern rammed earth construction.

What follows is an explanation of how each of the structural integrity factors is calculated based on the process described by Walker et al. in Appendix C.

Compressive strength is used to determine the ability of a structural wall to withstand vertical forces and moments at the top and bottom of the wall. It is a function of wall slenderness ratio (S_r), load eccentricity (e), material compressive strength (f_c), and wall section dimensions of breadth (b) and thickness (t). The load eccentricity is considered statically equivalent at both the top and bottom of the wall. It is equal to the least favorable combined vertical forces and moments to which the wall may be subject.[88]

Wall slenderness ratio is determined by:

$$\boldsymbol{S_r = \frac{h_{ef}}{t}} \qquad \textbf{Equation 3}$$

where h_{ef} is the effective wall height as a function of lateral restraints at the base and top of the wall. h_{ef} is defined as follows:

h = clear wall height between restraints
h_{ef} = 0.75*h for a wall laterally supported and rotationally restrained both top and bottom
h_{ef} = 0.85*h for a wall laterally supported both top and bottom and rotationally restrained along at least one of these
h_{ef} = 1.00*h for a wall laterally supported but rotationally free both top and bottom
h_{ef} = 2.00*h for a wall laterally supported and rotationally restrained only along its bottom edge

To meet the compressive strength requirement, the rammed earth wall must satisfy

$$N_d \leq \frac{\varphi f_c b t}{\gamma_m} \qquad \textbf{Equation 4}$$

where: N_d = design compressive force

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[88] Ibid, 120.

φ = capacity reduction force which is dependent on S_r and load eccentricity and shown in Table 7
f_c = unconfined material compressive strength
γ_m = material partial safety factor shown in Table 8

Table 7. Slenderness and Eccentricity Reduction Factor, φ

Slenderness Ratio (S_r)	Reduction Factor (φ)			
	Ratio of maximum eccentricity to thickness (e_{max}/t):			
	≤ 0.05	0.10	0.20	0.30
6	1.00	0.78	0.56	0.32
8	0.94	0.73	0.54	0.29
10	0.88	0.67	0.49	0.25
12	0.82	0.62	0.45	0.22
14	0.76	0.56	0.40	0.18
16	0.70	0.51	0.35	0.15
18	0.64	0.45	0.31	0.11

Note: Slenderness ratios above 12 are not recommended for general construction

Table 8. Values for Material Partial Safety Factor, γ_m

Suggested Criteria	γ_m
Works carried out by experienced specialist contractor; tried and tested materials; materials from consistent supply or mix; materials tested fully in accordance with proper provisions; full program of compliance testing during construction; materials well within recommended limits of suitability criteria; materials property test results demonstrate consistent repeatable performance	3.0 – 4.0
Works carried out by general contractor under supervision; untried material with limited laboratory test data; full program compliance testing during construction; materials within recommended limits of suitability criteria	4.0 – 5.0
Works carried out by inexperienced labor under some supervision; untried natural or quarry waste material with limited test data; limited program of compliance testing; materials marginally comply with recommended limits of suitability criteria; material property test results show some inconsistency	5.0 – 6.0

Compressive capacity can be increased by up to 50% in zones with concentrated loads. Concentrated loads are assumed to disperse through the rammed earth at an angle of 45° from the perimeter of the load bearing area. However, the dispersion cannot extend into the dispersion zone of an adjacent concentrated load, go beyond the physical end of the wall, or cross movement joints.

The wall must be designed to satisfy Equation 5 for each cross-section within the zone of dispersion of the concentrated load.

$$N_d \leq \frac{\varphi_b f_c A_b}{\gamma_m}$$ **Equation 5**

where:
N_d = design compressive force, including the concentrated load and portion of any other compressive forces acting on the cross-section under consideration
φ_b = contracted bearing factor
f_c = unconfined material compressive strength
A_b = area beneath bearing taking account of load distribution
γ_m = material partial safety factor shown in Table 8

The contracted bearing factor φ_b = 1.00 for cross-sections at a distance greater than 0.25*h below the level of the bearing. For cross-section distances within 0.25*h, φ_b is defined as either

$$\varphi_b = \frac{[0.55\left(1+\frac{0.5a_1}{L}\right)]}{(\frac{A_{ds}}{A_{de}})^{0.33}}$$ **Equation 6**

or

$$\varphi_b = 1.50 + \frac{a_1}{L}$$ **Equation 7**

whichever is less. However, φ_b cannot be less than 1.00 or greater than 1.50.

The variables for Equations 6 and 7 are defined as follows:

A_{ds} = bearing or dispersion area of the concentrated load at the design cross-section under consideration ($A_{ds} = Lt$)
A_{de} = effective area of dispersion of the concentrated load at mid-height ($A_{de} = L_e t$)

a_1 = distance from the end of the wall to the nearest end of the bearing area
L = clear length of the wall
L_e = effective length of the load dispersal at mid-height of the wall
t = section thickness

Out-of-plane flexural load capacity is defined as the amount of vertical bending moment that a rammed earth wall can withstand from short-term transient actions including out-of-plane wind loads or similar forces. The wall must satisfy Equation 5 or Equation 8 as defined below.

$$M_d \leq \left[\left(\frac{f_t}{\gamma_m}\right) + f_d\right] * Z \qquad \textbf{Equation 8}$$

where:
M_d = vertical design bending moment, including bending action from load eccentricities or bending moments applied at the ends of the wall
f_t = flexural tensile strength of rammed earth
f_d = design compressive stress at the cross-section
γ_m = material partial safety factor shown in Table 8
Z = section modulus

To withstand shear forces, the rammed earth wall design must satisfy:

$$V_d \leq \left[\left(\frac{v_0}{\gamma_m}\right) + \mu f_d\right] * A_v \qquad \textbf{Equation 9}$$

where:
V_d = design shear force for a given f_d
f_d = design compressive stress at the cross-section
v_0 = basic shear strength of the rammed earth as determined by testing
A_v = area of cross-section resisting shear
μ = shear factor
γ_m = material partial safety factor shown in Table 8

Construction tolerances for rammed earth are comparable to those of masonry design. Table 9 is reproduced from *Rammed Earth: Design and construction guidelines*. It provides "recommended and reasonable tolerances for newly built rammed earth construction."[89] Metric conversions to United States Customary Units were made by the author. The United States Customary Units were rounded to meet typical construction tool measurement increments.

Table 9. Construction Tolerances for Rammed Earth Construction

Description of Deviation	Allowable Tolerance mm	Allowable Tolerance in
Horizontal position of any rammed earth element specified or shown at its base or at each story level	±10	± 0.25
Deviation within a story from a vertical line through the base of the member	±10 per 3 m of height	±0.5 per 10 ft of height
Deviation from vertical in total height of building (from base)	±15 per 7 m of height	±0.5 per 23 ft of height
Deviation (bow) from line in plan in any length up to 10 m (~33 ft)	±10 per 5 m of height	±0.25 per 16.5 ft of height
Deviation from vertical at surface against which joinery is to be fitted	±10	± 0.25
Deviation from design wall thickness	±10	± 0.25
Position of individual rammed earth formwork panels	±5	± 0.125

This chapter provided an understanding of the process of rammed earth construction. Its purpose was to familiarize historic preservationists with rammed earth and to describe how rammed earth design has evolved over time. Emphasis was placed on the building techniques that were employed during the early part of the twentieth century as this thesis is focused on buildings constructed from the 1930s to 1960s. This

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[89] Ibid, 78.

chapter provided historic preservationists with information to help date buildings, as well as construction considerations for use in repair and adaptive reuse.

This chapter discussed the importance of proper soil composition and how it is tested. It included a section about the tools needed to build a rammed earth wall from formwork to soil mix to tamping devices. Tools used in the past and modern tools were described. Rammed earth wall design details were discussed. The need for a damp proof course between the base of the rammed earth wall and the footer, as well as the roof-to-wall connection, was described.

Damp proof design techniques were discussed in detail as damp proofing has changed the most over time. The construction period of a rammed earth wall can be determined or verified by examination of the damp proof design used at the base or top of the wall. Also, door and window lintel design and roof-to-wall connection details were described for the same reason. These design details are important for the historic preservationist as they not only help in dating the building, but also are needed for repair and maintenance considerations.

The thermal performance and structural integrity of rammed earth walls were described. The disadvantage of the use of static R-value was explained and an alternative method for determining thermal performance of a rammed earth building was described. A description of the requirements for structural integrity and construction tolerances was included. A detailed equation review was incorporated to aid historic preservationists in understanding how structural integrity is determined. Both thermal performance calculations and structural integrity determination is important to understand especially for repair and reuse.

The following chapter views the use of rammed earth construction from a global perspective. Far from unique to the United States, the rammed earth building technique has been utilized in a number of different regions of the world and for a much longer period of time. Samples of rammed earth buildings constructed through time are described. As with this chapter, emphasis is placed on buildings constructed in the early part of the twentieth century for comparison purposes.

CHAPTER III

CIVILIZATION AND RAMMED EARTH

In his article “Earth as a Building Material Today,” author Paul Oliver describes a 1981 exhibition held at the Centre Pompidou in Paris, France. Organized by Jean Dethier and entitled “Des Architectures de Terre ou L’Avenir d'une Tradition Millenairé,” the exhibition was on the global use of earth architecture over time. The history of earth architecture was visualized from ancient times to modern day. Over two hundred images were displayed and the ten thousand year history of earth architecture was documented including descriptions of the buildings of Jericho and the Tower of Babel. “Stunning examples of earth building in the Sahara, the Middle East, Latin America, China and India…Europe and North America underlined the universality of the employment of the material.”[90] Figure 36 shows a detail of a poster for the event with rammed earth construction depicted in the scene.

Figure 36. Detail of a poster from the 1981 earth architecture exhibition in Paris, France. Eighteenth-century French, traditional Yemen and modern buildings are combined to illustrate the historic and global perspective of earth architecture. Notice the rammed earth formwork in the forefront of the image. *Artwork from “Earth as a Building Material Today” by Paul Oliver, page 31.*

Figure 37 is a sketch map of the major areas where earth building is found throughout the world today. As will be described in the following section, earth

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[90] Paul Oliver, “Earth as a Building Material Today,” *Oxford Art Journal* (vol. 5, no. 2, 1983), 31.

architecture is more than rammed earth. It includes a number of building techniques that use earth as the principal material.

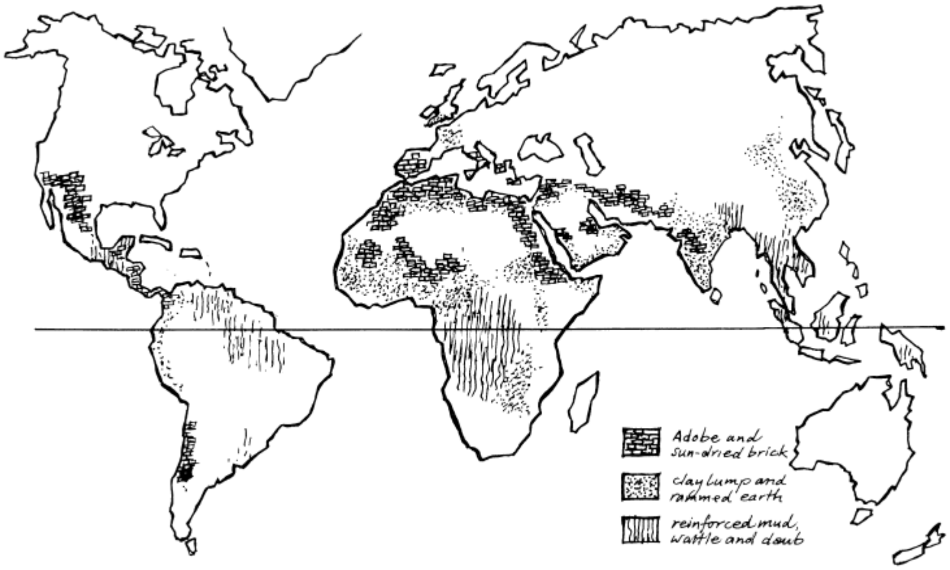

Figure 37. Areas of the world where earth-building is the principal building technique. *Drawing from "Earth as a Building Material Today" by Paul Oliver, page 35.*

This chapter provides an overview of different earth construction techniques and their use over time. It puts rammed earth into context within the construct of earth architecture. It provides early examples of rammed earth buildings and discusses its use in Asia, Spain and South America. It describes the re-discovery and adaptive reuse of the rammed earth technique into a new building style by François Cointereaux in the late eighteenth century and explains how his promotion of the nouveau pisé technique brought about its widespread use in Europe, Russia, Australia and New Zealand during the nineteenth century. The chapter ends with a description of the efforts of English architect Sir Clough Williams-Ellis at the beginning of the twentieth century to promote the use of rammed earth and nouveau pisé as a means to mitigate the tremendous housing shortages in the United Kingdom after both World War I and World War II.

A Global Perspective on Earth Architecture

In his book *Earth Architecture*, Ronald Rael divides the techniques used in earth architecture into four main categories: rammed earth, mud brick, compressed earth block, and molded earth. He explains that these categories are broad and emphasizes that the flexibility of earth as a building material is such that there are approximately twenty different methods within these categories for using it in the construction of walls, floors, and roofs.[91]

Rael describes rammed earth as "the man-made equivalent to sedimentary rock."[92] He continues with an historic sketch of its use through time:

> For thousands of years builders throughout the world have compacted soil to create rock-hard structures using only simple tools and manpower, resulting in some of the most beautiful and well-known wonders of the built environment. The Alhambra in Spain, the great kasbahs of Morocco, and long stretches of China's Great Wall, begun in the fifth century B.C.E., are only a few of examples of rammed earth's historic global heritage.[93]

Mud brick construction, Rael explains, is any technique that incorporates mud, straw and water. The mixture is poured into brick forms and allowed to dry in the sun. He describes mud brick as "a building module so versatile and durable it has been used

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[91] Rael, *Earth Architecture* (New York: Princeton Architectual Press, 2009), 9.

[92] Ibid, 17.

[93] Ibid.

for floors, walls, and roofs throughout the world for thousands of years."[94] Adobe is one form of mud brick.

In explaining compressed earth block, Rael states that it is similar to rammed earth except that the earth is placed into brick-like forms and compacted using a press. Unlike rammed earth, it does not require on-site building. The technique was developed and perfected by Cointereaux at the turn of the nineteenth century. Having been born and raised in the wine country of Lyons, France, Cointereaux designed a rammed earth press, called a crécise, based on the traditional wine presses of the day.[95] His use of earth as the basic building material was in keeping with the political atmosphere of France at the time. For pre-Revolutionary France, building with earth exemplified the common man. Earth was a material that was inexpensive and readily available. It was fireproof and did not require the use of timber – a precious and expensive material that was considered a lavish commodity. Rael describes compressed block as "a building component that has the versatility of a brick but the social, economic, and environmental potential of rammed earth."[96]

Rael describes four earth architecture methods under the category of molded earth: wattle and daub, cob, poured earth, and extruded earth. Wattle and daub consists of building a framework, weaving a grid within the framework and filling the grid with daub or mud. Excavations of some of the oldest known settlements including Jericho and Çatahöyük have shown that wattle and daub structures found at these sites predate more

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[94] Ibid, 113.

[95] Ibid, 157.

[96] Ibid.

permanent structures.[97] Wattle and daub has been modified and changed over time, but it is still the predominate building technique used today. The modern day wattle is the metal lath used to hold the daub which is stucco in place.

In describing cob, Rael explains that it is the simplest method of earth architecture as it consists of piling and molding mud to create walls. It requires few tools. And, no formwork or internal structures are needed. The mud mixture used in cob contains a high amount of straw as a binder and stiffener. A wall is built by piling the cob and molding it into shape using hands and sometimes a trowel. The wall is formed on top of a pre-laid foundation.[98]

Rael describes poured earth as a combination of wattle and daub, rammed earth, mud brick and cob. A wattle and daub framework structure is used to form the inner and outer walls in a manner similar to the formwork used in rammed earth construction. The gap between the walls is filled with mud. The mud is patted in place by hand in a manner similar to cob. Finally, the mud is allowed to dry within the framework as mud bricks dry in the sun. Once the poured earth structure is dry, the wattle and daub framework can be removed or left in place.[99]

Rael equates the extruded earth technique to traditional clay brick making with a twist. Extruded earth bricks are not fired in a kiln. Precise amounts of clay, shale and other soils are mixed with water. The soil mixture is placed in a hopper and then mechanically pushed through a die where it is extruded into a ribbon. The still-moist mud ribbon is cut into bricks of predetermined length by a precision wire cutting

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[97] Ibid.

[98] Ibid.

[99] Ibid, 180.

machine. The bricks are left for several days to dry out. Rael explains that the unfired bricks are called “green bricks” and that “increasingly, architects are considering these as building modules because the precision inherent in the process makes the production of large quantities of high-quality earthen building units possible.”[100] The mixing process ensures batch consistency as do the mixing and cutting processes. The bricks can be cut to size for custom installations and because they are not kiln fired, fossil fuels are not wasted.

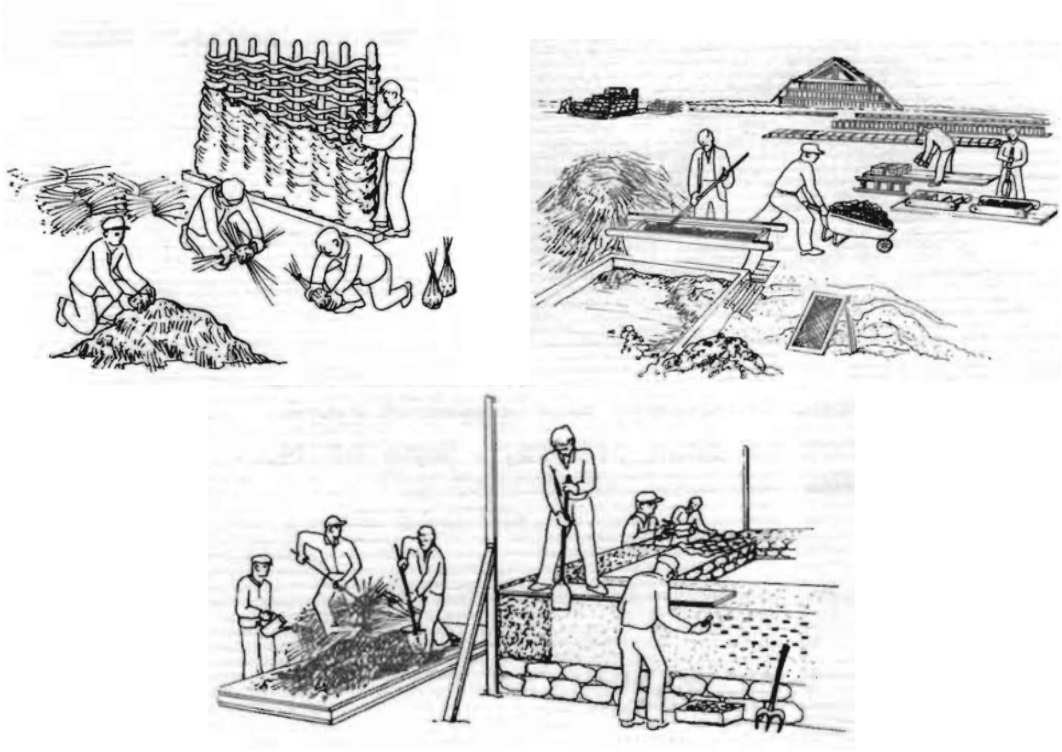

Figure 38. Different types of earth architecture other than rammed earth. Clockwise from the top: wattle and daub, mud brick, and cob. *Drawings from the manuscript of* Manual for Building a Rammed Earth Wall *by Lydia A. and David J. Miller, page 4. Drawings by Ruth Savig. University of Northern Colorado Archives.*

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[100] Ibid.

Examples of Centuries-Old Extant Rammed Earth Buildings

In China, evidence of the use of rammed earth construction techniques in buildings dates back to the Tang Dynasty during the reign of the Emperor Zhongzong.[101] The smaller of the two Wild Goose Pagodas in Xi'an, the capital city of the Shaanxi providence in central China, was built between 707 and 709 AD. Shown in Figure 39, the building was originally a fifteen-story structure that stood almost 148 feet tall. It is currently thirteen stories and stands 141 feet in height.

Figure 39. The Small Wild Goose Pagoda in Xi'an, Shaanxi, China is built of rammed earth walls with set-in brick pillars. It was originally constructed between 707 and 709 AD. *Photograph from "Research on 3D Reality-based Modeling and Virtual Exhibition for Cultural Sites -Taking the Small Wild Goose Pagoda in Tang-Dynasty as the Case" by Jun Liu and Guo-hua Geng, page 307.*

The rammed earth walls of the building were faced with bricks set in relatively soft lime mortar. Pillars of brick set into the rammed earth walls were used to bear the

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[101] The old Han wall, built as the perimeter defensive wall for the city of Xi'an, was constructed around the start of the Common Era about 2000 year ago. It was built of rammed earth and its remains still stand today. Also, as cited earlier, large portions of the Great Wall were built of rammed earth. In the context of this discussion, "buildings" is used to refer to spaces that people can occupy.

structural weight of the building in a manner similar to steel reinforced concrete construction today. In addition, the foundation was designed in a hemispherical shape and the soil under the foundation was pre-compacted.[102] This building survived the great earthquake of 1556, estimated to have killed 830,000 people in the region, and considered the largest earthquake in recorded history.[103] The building sustained minimal damage that remains unrepaired. This is attributed to the strength of the embedded pillar design, the foundation design and the soil compaction prior to the laying of the foundation.

The original citadel of the Alhambra in Granada, Spain was constructed during the ninth century. However, most of the palace structures and grounds were built during the fourteenth and fifteenth centuries by the descendants of Mohammed I ibn Nasr (1191 – 1273) including Muhammad III (1256 – 1309), Ismail I (1279 – 1325), Yusuf I (1318 – 1354) and Muhammad V (1338 – 1391). Over about a 150-year time period, many Muslims in Spain immigrated to the Granada area as Christianity was expanding in the region. The architecture of the Alhambra was largely influenced by a desire to exert Muslim autonomy and as a display of Islamic strength. To that end, much of the architecture was a tribute to the great Córdoban caliphate.[104]

Though Moorish in design, the palaces and grounds also incorporated many western influences and ironically, the Alhambra has come to represent the Golden Age of

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[102] O.G. Ingles, "Impressions of a Civil Engineer in China," *The Australian Journal of Chinese Affairs*, No. 7 (January 1982), 144.

[103] Ibid.

[104] Michael Jacobs, *Alhambra* (London: Frances Lincoln Ltd., 2000), 28.

Emirs in Spain just before the re-conquest of the region by the Reyes Católicos (Catholic Monarchs) in 1492.[105]

Built in parts, the plan is not cohesive, and the materials used in its construction were not of the high quality normally associated with palaces "..but rather in the cheaper and more easily destructible materials of plaster, wood and tiles."[106] As pictured in Figure 40, rammed earth was commonly used in the construction of the Alhambra and is often included in examples of historic rammed earth structures.[107, 108]

Figure 40. Puerta de la Justicia, Alhambra, Granada, Spain. The main gateway into the Alhambra citadel was completed in June 1348 under Yusuf I. *This photograph is credited to Andrew Dunn, May 12, 2006.*

Rammed earth construction techniques have been used in Brazil for centuries.[109] Sixteenth and eighteenth century examples include the Igreja de

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[105] Ibid.

[106] Ibid, 6.

[107] Walker et al., *Rammed Earth: design and construction guidelines*, 4.

[108] Paul A. Jaquin, Charles Augarde and Christopher M. Gerrard, "Historic rammed earth structures in Spain: construction techniques and a preliminary classification," *International Symposium on Earthen Structures,* (Bangalore, India: Interline Publishing, 2007), 1.

[109] From lecture series by Dr. Marco Antônio Penido de Rezende at the University of Oregon, Fall session 2010.

Santo Antonio in Sâo Paulo and the Iglesia Matriz de Nossa Senhora do Rosário in Pirenópolis shown in Figure 41. The Igreja de Santo Antonio was built before 1592 and the cathedral in Pirenópolis was built between 1728 and 1732.

Figure 41. Igreja de Santo Antonio, Sâo Paulo, ca. 1590 (left) and Iglesia Matriz de Nossa Senhora do Rosário, Pirenópolis, 1732 (right) are two examples of Brazilian rammed earth architecture. *The photograph of Santo Antonio is credited to brazilmycountry.com. The photograph of the Pirenópolis cathedral to Jazzy Robban, December 28, 2007.*

Rammed Earth Becomes a Studied Construction Technique in the Nineteenth Century

François Cointereaux (1740 – 1830)[110] evolved the vernacular architecture of rammed earth into an international presence when he promoted its use in the late eighteenth and early nineteenth century. He was born and raised in Lyons in the Rhône valley of France where wine making was the stable industry and pisé was a common construction technique. Early in his career as architect, he learned that his passion was in the improvement of rural living conditions. He founded a school of rural architecture based on earth construction and, between 1790 and 1816, published a number of

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[110] Years of birth and death are given in this and the following chapter to aid in articulating the time period in which individuals lived and as illustration of the large amount of rammed earth work that was produced in a relatively short timeframe.

pamphlets and essays on its use.[111] A collection of his fascicles were published between 1790 and 1791 in Paris. The collected works, incorporated in a four-volume set, were titled *École d'Architecture Rurale*. Part, if not all, of his works in this collection were translated into German, Danish, Finnish, Russian, Italian and English over the next twenty years. His work "attracted the interest of major architects such as…Henry Holland … in England, David Gilly… in Germany, and Nicolai L'vov… in Russia."[112]

Cointereaux perfected the technique in rammed earth that he coined "nouveau pisé" in response to a competition offered by the Académie des Sciences, Belle-Lettres, et Arts d'Amiens (Academy of Sciences, Humanities, and Arts at Amiens) in 1784. The competition called for the development of the least costly and simplest construction method that would prevent fires while at the same time using materials appropriate to the area of Amiens.[113] His technique did not require the build of mass walls in situ, the technique he referred to as "ancien pisé." Instead, as illustrated in Figure 42, his method involved the creation of rammed earth blocks using a press that he designed.

The Amiens competition enabled Cointereaux to discover his passion and define his life's mission. It was during this time that he came to realize that his destiny was "to improve the peasant's lot by teaching him how to create his own affordable, dignified, and inflammable housing."[114]

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[111] Louis Cellauro and Gilbert Richaud, "Thomas Jefferson and François Cointereaux, Professor of Rural Architecture in Revolutionary Paris," *Architectural History*, Vol. 48 (2005), 173.

[112] Ibid, 177.

[113] Paula Young Lee, "Pisé and the Peasantry: François Cointeraux and the Rhetoric of Rural Housing in Revolutionary Paris," *Journal of the Society of Architectural Historians*, Vol. 67, no. 1 (March 2008), 59.

[114] Ibid.

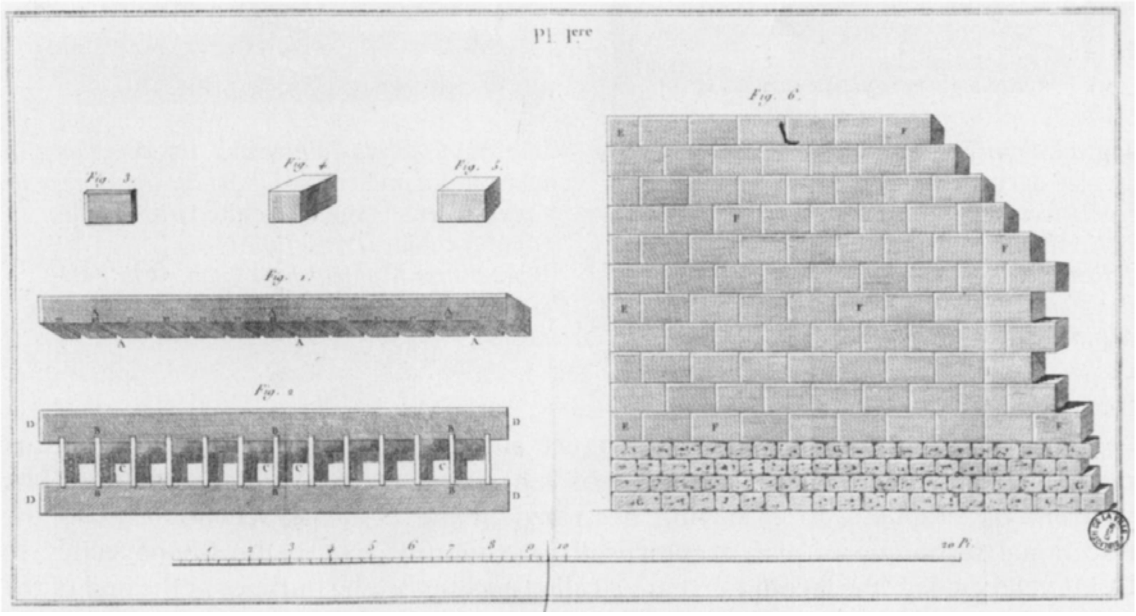

Figure 42. Drawing of a nouveau pisé wall by François Cointereaux from his *École d'Architecture Rurale Quatrieme cahier* (Paris, November 1791). *The photograph of the engraving is credited to Didier Nicole, Bibliothèque Municipale, Lyons and reprinted here from Louis Cellauro and Gilbert Richaud's article, "Thomas Jefferson and François Cointereaux, Professor of Rural Architecture in Revolutionary Paris," page 184.*

To reach his goal, he studied rammed earth techniques and trained other architects in its use as a means to spread his system throughout rural France. He experimented with the technique between 1785 and 1787 in Amiens at the Porte de Noyon. He built experimental models in Grenoble at the Atelier of the Porte de France between 1787 and 1788 that showcased the use of various earth block sizes enabling the build of "round or ogee arches, columns and the complete elimination of wood from buildings."[115] Examples of two concept home designs for both nouveau and ancien pisé are shown in Figure 43. Cointereaux was able to demonstrate how buildings could be made almost fireproof.

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[115] Cellauro and Richaud, "Thomas Jefferson and François Cointereaux," 178.

Cointereaux established an École d'Architecture Rurale (School of Rural Architecture) in 1789 in Paris.[116] And, in shameless promotion of the rammed earth construction technique, Cointereaux exploited the fashion of day. He stressed that pisé was first introduced to the French by the Romans, a calculated move “which conferred social acceptability upon a vernacular material in the age of Neoclassicism.”[117]

Figure 43. Example of house designed of nouveau pisé (left) and ancien pisé (right) by François Cointereaux. The building on the left was painted with frescos. *The photographs of the engravings are credited to Didier Nicole, Bibliothèque Municipale, Lyons and are reprinted here from Louis Cellauro and Gilbert Richaud’s article, “Thomas Jefferson and François Cointereaux, Professor of Rural Architecture in Revolutionary Paris,” page 183.*

He also emphasized its relative cheapness as a construction style as the main building material was earth. His mantel was picked up by French Revolutionary committees prior to the start of the French Revolution and pisé became a symbol of freedom from oppression and tyranny. The French Revolution began in earnest in 1789.

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[116] Ibid, 173.

[117] Ibid, 174.

What followed was a series of wars in Europe that included the Napoleonic Wars (from 1803 to 1815). Thus, for twenty-five years the people of France and Europe lived with food and fuel shortages. “From a political perspective, pisé was an attractive process because the buildings required no wood…not only [ameliorating] the crisis of deforestation that was driving up the cost of food and housing, but…[relieving] the scourge of fire that was devastating the countryside.”[118]

As shown in Figure **44**, Cointereaux designed economical homes that resembled conventional homes made of brick or stone. However, because they were constructed of earth, they were disassociated from any ties to class or privilege making them the ideal symbol of Revolutionary France.

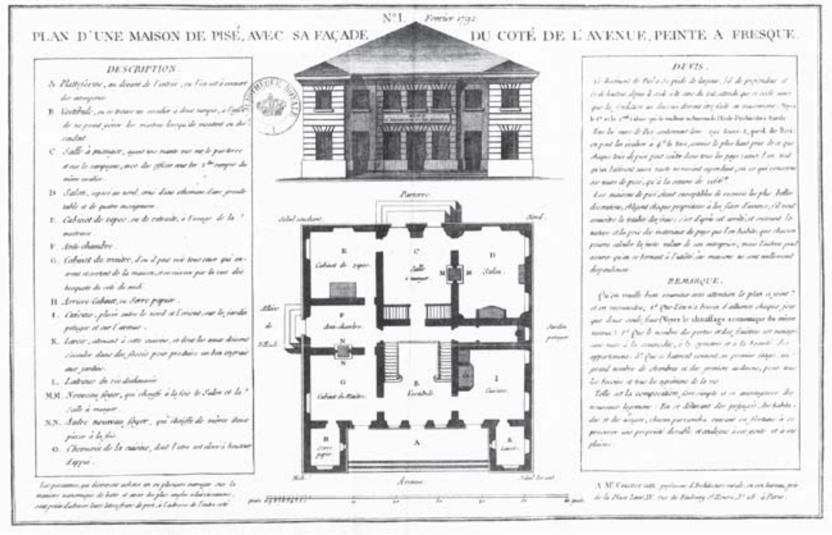

Figure 44. Elevation and plan for a pisé house by François Cointereaux “with the facade facing the avenue, painted in fresco.” Published in *Conférences a la suite d’une découverte* in 1808. *This is reprinted from the article “Pisé and the Peasantry” by Paula Young Lee, page 72.*

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[118] Lee, “Pisé and the Peasantry,” 58.

Architect David Gilly (1748-1808) whose portrait is shown in Figure 45, promoted the use of pisé in Germany expanding on the work of Cointereaux. Gilly, who had previously founded an architectural school in Stettin that “combined French Rationalist theory with the realities of rural building construction,” went on to establish a *Bauschule* (school of architecture) in Berlin in 1793 modeled after Cointereaux’s schools. Later on, he re-established the school as a *Bauakademie* (academy of architecture) and it became one of the most influential architecture schools in Europe.[119]

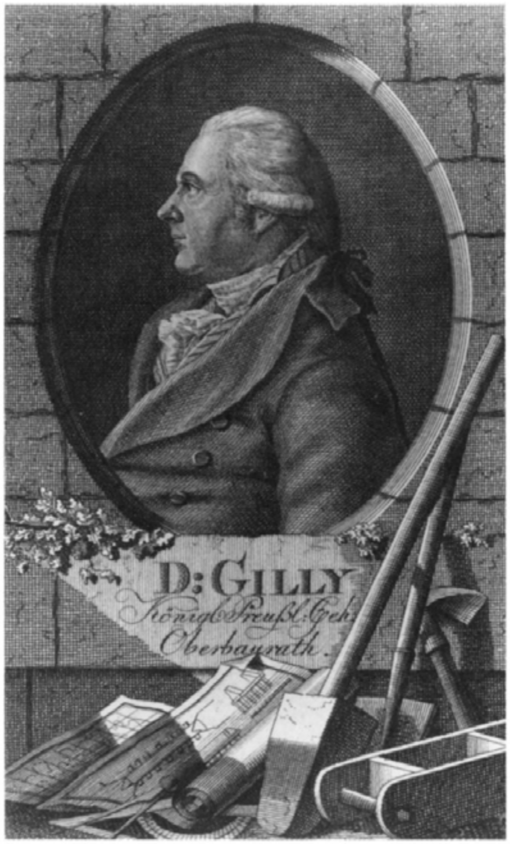

Figure 45. Engraved portrait of David Gilly with rammed earth construction tools in the foreground *Reprinted from “François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies,” by Louis Cellauro and Gilbert Richaud, page 131.*

Gilly’s commitment to rammed earth is exemplified in his engraved portrait in which the tools of rammed earth construction are prominently displayed. Also, Figure 46 provides a series of illustrations that Gilly drew to explain and expound upon the processes as defined by Cointereaux.

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[119] Louis Cellauro and Gilbert Richaud, “François Cointereaux's *École d'Architecture Rurale* (1790-91) and its Influence in Europe and the Colonies,” *Architectural History*, 49 (2006), 130.

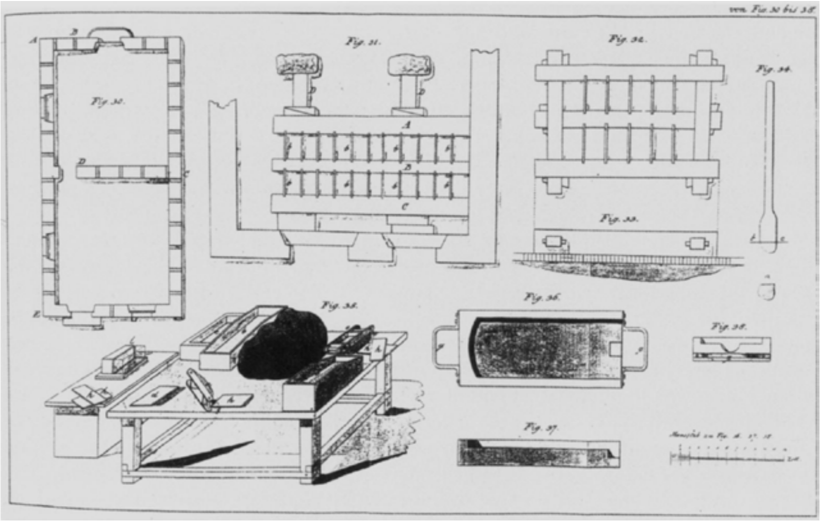

Figure 46. Drawings of nouveau pisé implements, molds and the build process by David Gilly. *Reprinted from "François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies," by Louis Cellauro and Gilbert Richaud, page 132.*

Gilly designed the Palace Kleinmachnow that was built in 1796-98 near Zehlendorf outside of Berlin. It was a large-scale two-story building constructed using the nouveau pisé technique. Figure 47 is a photograph of the Palace ca. 1920. Figure 48 provides the plan. Restored in 1919, it was mostly destroyed during World War II.

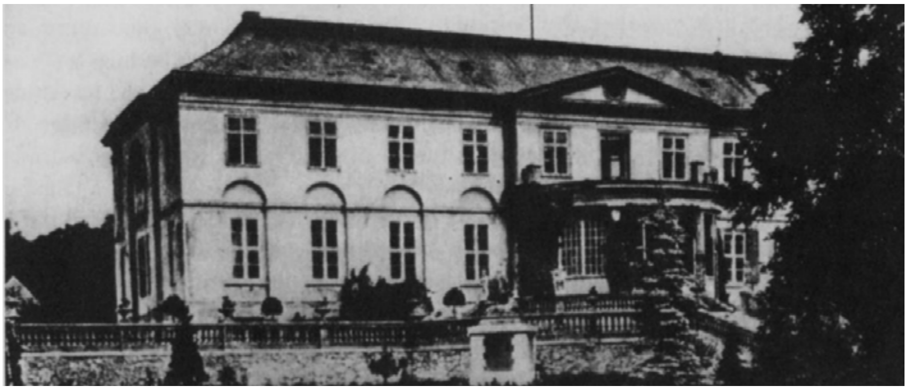

Figure 47. Palace Kleinmachnow, near Zehlendorf outside of Berlin, Germany, 1798. *Photograph reprinted from "François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies," by Louis Cellauro and Gilbert Richaud, page 133.*

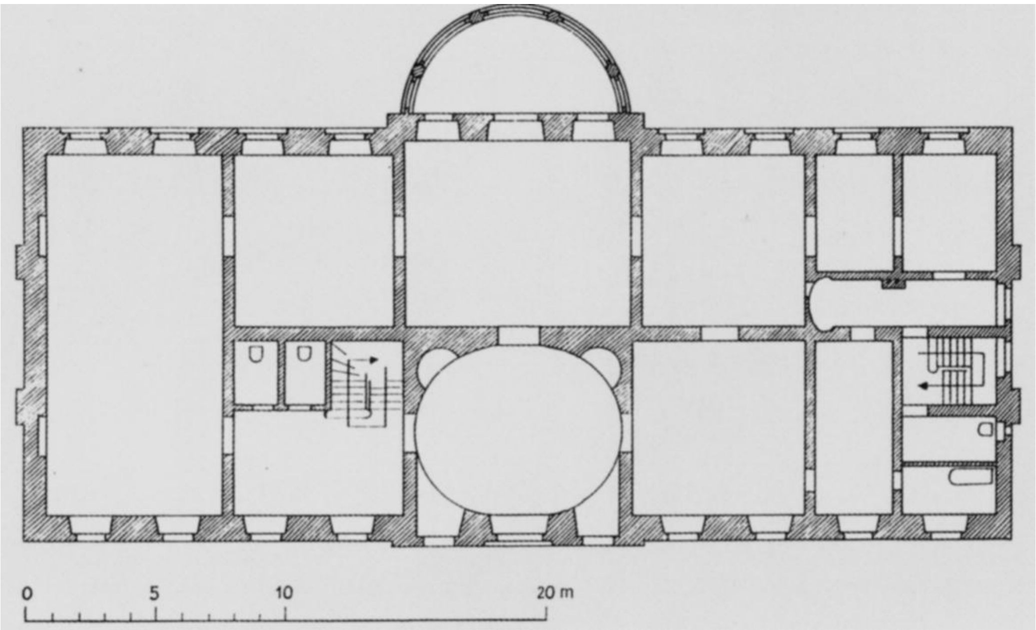

Figure 48. Plan of Palace Kleinmachnow. *Reprinted from “François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies,” by Louis Cellauro and Gilbert Richaud, page 133.*

Wilhelm Jacob Wimpf (1767-1839), also from Germany, followed after Gilly. He was a builder who designed most of his industrial buildings of pisé. He also built more than twenty residential buildings in the town of Weilburg an der Lahn that survive today.[120] Two of his buildings, seen in Figure 49, were used as examples of nineteenth century rammed earth construction documented by Lydia and David Miller in their manuscript “Manual for Building a Rammed Earth Wall.” The Millers noted that the buildings were originally constructed ca. 1820 but had been modified or renovated since

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[120] Ibid, 132.

that time.[121] The 2006 article by Louis Cellauro and Gilbert Richaud, "François Cointereaux's *École d'Architecture Rurale* (1790-91) and its Influence in Europe and the Colonies," established the construction of the seven-story apartment complex from 1825-28.[122]

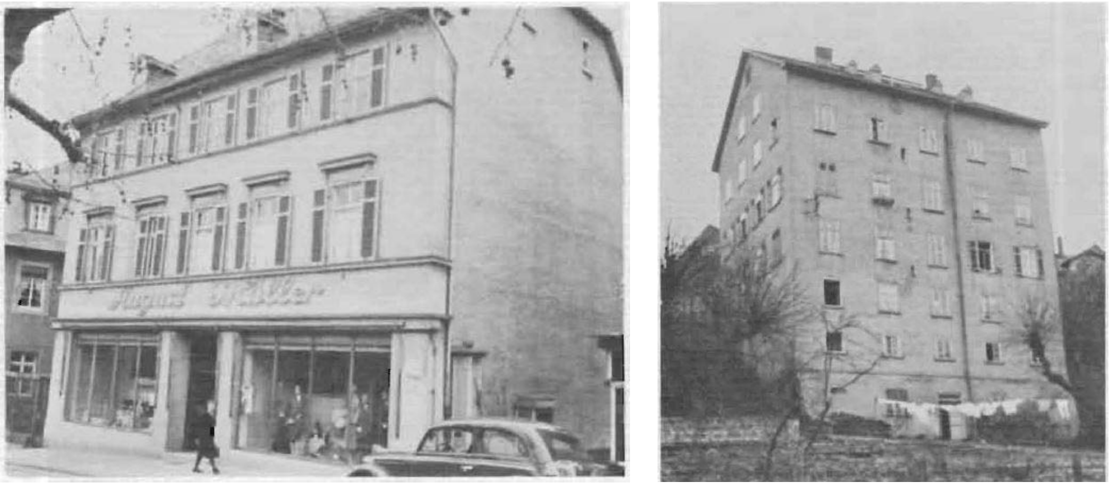

Figure 49. Two rammed earth buildings in Weilburg, Germany designed by Wilhem Jacob Wimpf. A home constructed ca. 1820 with a post-World War I commercial storefront conversion on the first floor (left) and a seven-story apartment complex constructed in 1828 (right) was renovated in 1978. *Photographs by Lydia A. and David J. Miller, 1949 from manuscript of* Manual for Building a Rammed Earth Wall, *page 50. University of Northern Colorado archives.*

Along with German architects, the Danish and Finnish also embraced Cointereaux's nouveau pisé construction technique. Klaus Henrik Seidelin (1761-1811) partially translated Cointereaux's *École d'Architecture Rurale* into Danish. His translation was published in Copenhagen in 1796. A Finnish edition based on Seidelin's work was published in 1798. These publications have been credited with the enormous

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[121] Lydia A. Miller and David J. Miller, *Manual for Building a Rammed Earth Wall* (Greeley, Colorado: Rammed Earth Institute International, 1982), 50.

[122] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 134.

impact the pisé style had on Scandinavian architecture during the nineteenth century. In fact, by 1871, over 4,000 houses were built in Denmark using nouveau pisé.[123]

Russia, too, was influenced by Cointereaux's work. All of his fascicles were translated into Russian by Aleksander Barsov and published in Moscow in 1796.[124] Nicolai L'vov (1751-1803) was a neo-Palladian architect who became intrigued with Cointereaux's ideas. He built his first set of earth houses in 1793 on his own estate near Torzhok, a city halfway between Moscow and St. Petersburg. Earlier in his career he had led a team of Scottish architects including Adam Menelaws (1749-1831) in the development of a large-scale pisé project.[125]

In 1798, L'vov obtained a commission from Tsar Paul I to build the Barracks in Torzhok. Menelaws was the architect for the design. The Barracks had earth walls and a thatch roof. L'vov stressed to the Tsar the advantages of rammed earth and emphasized that it "was ideal in regions devoid of timber and [its use] could also solve the problem of the preservation of the forests throughout Russia."[126] The Tsar was so impressed by the utility of rammed earth that he ultimately endorsed L'vov's development of two Schools of Earth Construction in Torzhok and Tiukhili (near Moscow).[127]

Along with granting a number of other commissions for pisé buildings, the Tsar also granted L'vov the Priory Palace (Priorat) in Gatchina, for the Order of the Knights of

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[123] Ibid, 135.

[124] Ibid.

[125] Alexei Makhrov, "Earth Construction in Russia: A Scottish Connexion." *Architectural History* 40 (1997), 171.

[126] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 135.

[127] Ibid.

Malta. It was built in 1798-99 and is the only earth structure designed by L’vov that is known to have survived.[128] Shown in Figure 50, the Palace was built using both traditional and nouveau pisé techniques.

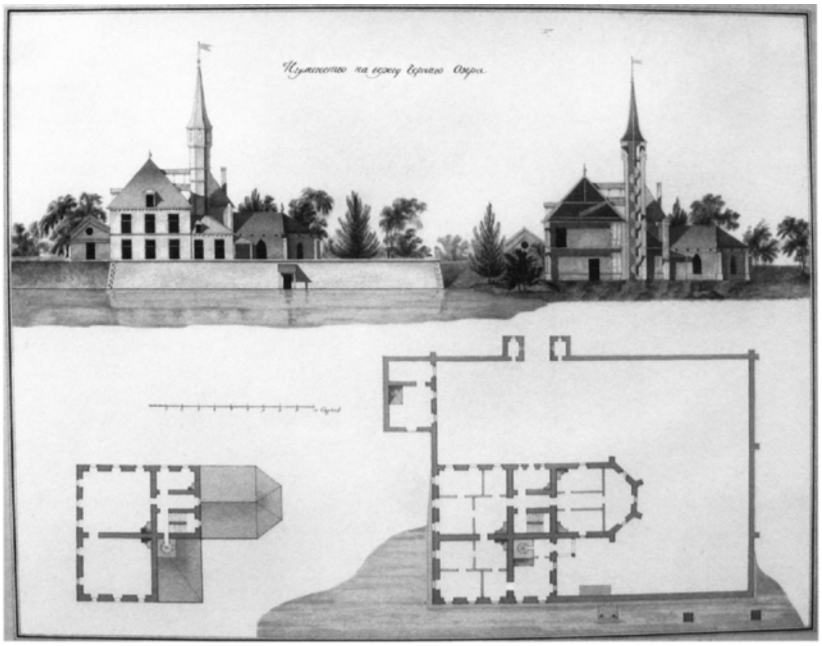

Figure 50. Drawing of the Palace of Priorat designed by Nicolai L'vov. *Drawing reprinted from “Earth Construction in Russia. A Scottish Connexion,” by Alexei Makhrov, page 175. Photograph credited to the Gatchina Palace Museum.*

During the same period, L’vov and Menelaws designed the main building of the School of Practical Farming and Agriculture, near Pavlovsk and close to St. Petersburg. Figure 51 provides an elevation and plan of the design. The layout and design of the school was greatly influenced by the work of Andrea Palladio, specifically the Villa Pisani which Palladio had published in *The Four Books on Architecture* in 1570. The school was devoted to teaching students the techniques of earth and clay building.[129]

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[128] Makhrov, “Earth Construction in Russia: A Scottish Connexion,” 174-75.

[129] Ibid, 176.

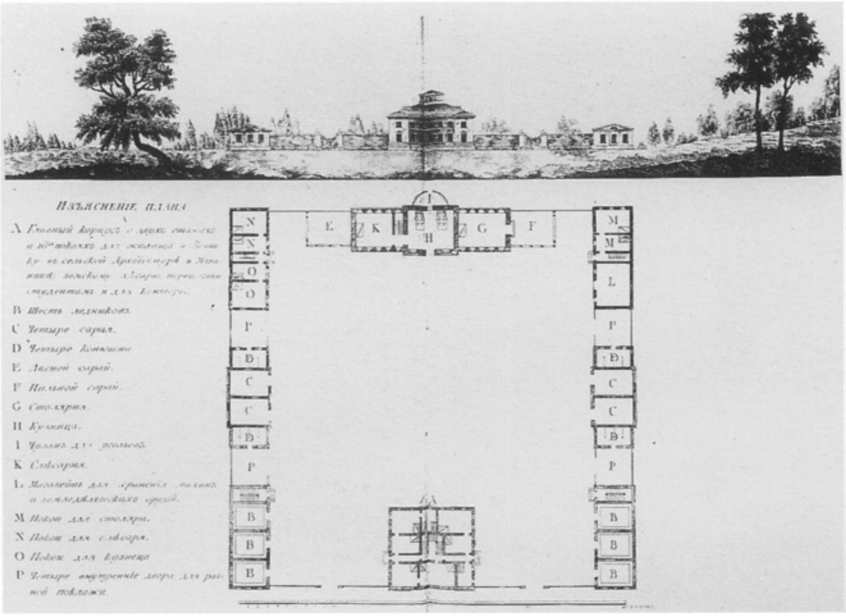

Figure 51. School of Practical Farming and Agriculture drawing by Adam Menelaws and Nicolai L'vov. *Drawing reprinted from "Earth Construction in Russia. A Scottish Connexion,"by Alexei Makhrov, page 178. Photograph credited to the Russian National Library, St. Petersburg.*

In 1799, L'vov convinced Menelaws to move to the School of Earth Construction in Tiukhili, near Moscow, where he had been made the director. The school was modeled on Cointereaux's schools in Paris. Its purpose was to introduce pisé to peasants for use in rural architecture.

Farmers from different regions of Russia were summoned to the school for an eighteen-month course of study. During their stay, the students built earth structures including a church, cottages, workshops, fences and a colonnade. They were also taught how to make stoves, build roads, make bridges from tree roots, dig canals and even make automatically closing gates.[130] The pisé technique was spread throughout the provinces of Russia by the many graduates of the school.

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[130] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 135.

The school produced *The Album of Earth Buildings* in 1801 to showcase forty-two buildings which had been erected in the various provinces of Russia by students of the school as a means to inform the Tsar about the schools accomplishments. A pise house and an earth barn are two examples of works from the album. They are shown in Figure 52 and Figure 53.

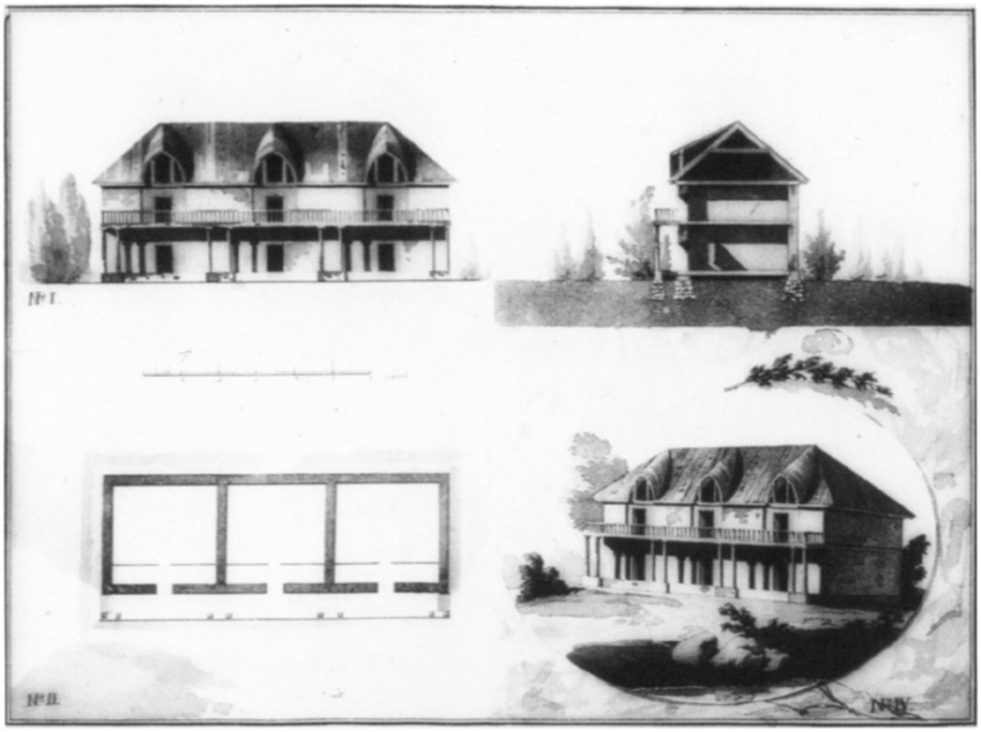

Figure 52. Pisé house from *The Album of Earth Buildings*. *Photograph reprinted from "François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies," by Louis Cellauro and Gilbert Richaud, page 139. Photograph credited to the Russian National Library, St. Petersburg.*

In the end, the school lost its official patronage when Tsar Paul I was assassinated in 1801. Skeptical about the usefulness of pisé, the new rulers considered the school just another whim of the late Emperor.[131] The school officially closed in 1803, the same year that L'vov passed away.

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[131] Ibid, 139.

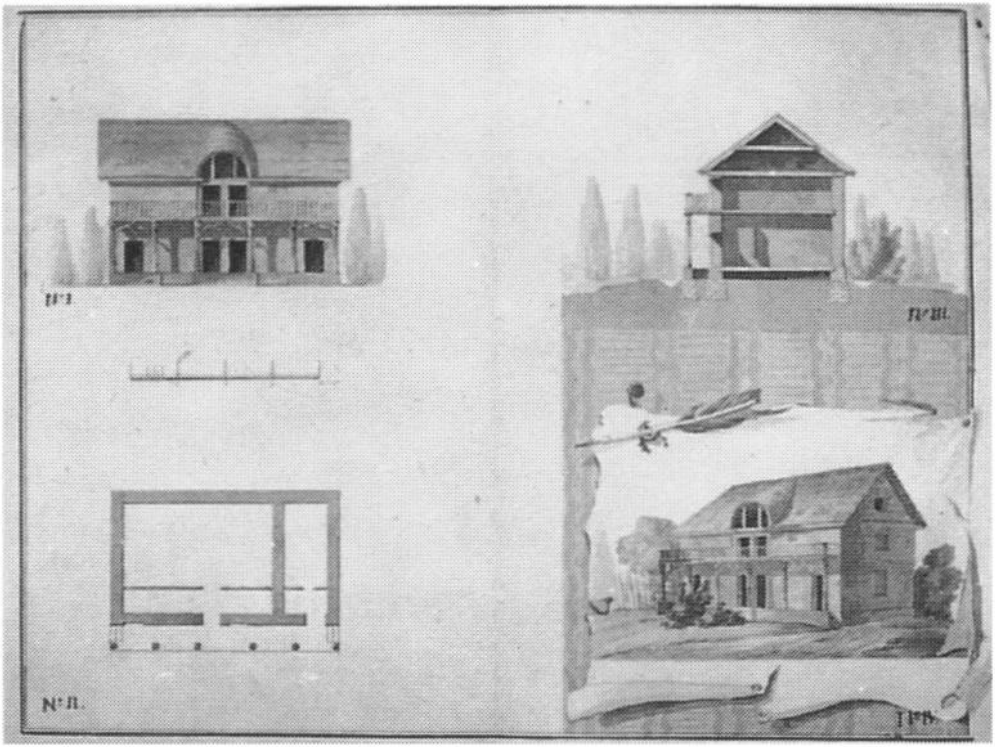

Figure 53. Earth barn from *The Album of Earth Buildings*. *Drawing reprinted from "Earth Construction in Russia. A Scottish Connexion," by Alexei Makhrov, page 181. Photograph credited to the Russian National Library, St. Petersburg.*

English architects developed an interest in Cointereaux's work and "the French vernacular technique of pisé" during the 1790s, as well.[132] In 1796, John Plaw (1745-1820) published *Ferme Ornée; or Rural Improvements* in which he referred to Cointereaux and illustrated a pisé lodge.[133] He explained that it was a much better method of earth construction than what was being practiced in Devonshire and Ireland at the time:

> In addition to the customary method of making Mud-Walls, as practised in Devonshire and the other countries of England, I beg to notice the new method of building Walls for Cottages, &c. as practised in France;

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[132] Ibid, 140.

[133] John Plaw, *Ferme Ornée; or Rural Improvements* (London: I. and J. Taylor, 1796), Advertisement.

> of which an account is given in a little work lately published at Paris, under the title of *Maison de Pisé*. The method there proposed and an experience recommended, is to construct the Walls of dry earth, well rammed, or beaten together in a mould, like a case; the advantage attending this method is by the author M. Cointeraux spoken of in the highest terms, and as applicable to building of considerable extent, with upper stories, &. That this method is practicable on a small scale, I am well assured by some gentlemen, who have really built with success in this manner. It certainly is cheap, for the mould or case once formed, is easily shifted, and the whole process may be performed by common labourers. It may be proper to observe, the several pieces of the mould must be made to fit properly, and the whole must be well braced or tied together, to resist the percussion of the beating. This method has some advantages over that usually practised; for, being, worked dry, the building is habitable as soon as formed, no danger being likely to arise to the inhabitants from damp walls.[134]

While John Plaw did not directly translate Cointereaux's fascicles to English, Henry Holland (1745-1806) provided an abstract of Cointereaux's first and second fascicles in an appendix to Volume 1 of the *Communications to the Board of Agriculture* in 1797. Entitled "Pisé, or the art of building strong and durable walls, to the height of several stories, with nothing but earth, or the most common materials. Drawn up and presented to the Board of Agriculture," he began with a brief history and bibliography of the subject. He followed with descriptions of the tools required, windows and doors construction techniques, advice on how to select the best earth and how to work with the soil, and even exterior and interior finishing options.[135,136]

Holland's writings on pisé were cited and restated in a number of agricultural documents over the next forty years. In particular, his work was cited in Peter Nicholson's *Architectural and Engineering Dictionary*, published in London in 1819 and

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[134] Ibid.

[135] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 140.

[136] Building Research Board, Department of Scientific and Industrial Research, *Building in Cob and Pisé de Terre,* Report (London: His Majesty's Stationery Office, 1922), 29.

1835. Nicholson “noted in his entry ‘Pisé’ that ‘different kinds of buildings of these earthy materials may be seen in England at Woburn Abbey ... and in other places.’”[137] The dissemination of Holland’s work is of particular importance because it brought pisé to the attention of people in other English-speaking countries such as Australia (*Hobart Town Gazette*, 3 May 1823; *The Sydney Gazette and New South Wales Advertiser*, 29 May 1823, 12 June 1823 and 19 June 1823), New Zealand and North America (*American Farmer*, 1821).[138,139]

Walker et al. discuss rammed earth and rammed chalk buildings erected in southern England during the nineteenth century. Examples, pictured in Figure 54, include five-story rammed chalk townhouses and a country estate both built ca. 1840.[140] As the name suggests, the distinction between rammed earth and rammed chalk is defined by the amount of chalk in the soil. The use of chalky soil requires careful mincing of the soil to insure the chalk is thoroughly pulverized. Any pockets of chalk hazard the possibility of explosion of the wall in a severe frost as described by British architect Sir Clough Williams-Ellis in *Cottage Building in Cob, Pisé, Chalk & Clay: A Renaissance*.[141]

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[137] Peter Nicholson, 'Pise', *Architectural and Engineering Dictionary*, II (London, 1835), 534-37 quoted in Cellauro and Richaud, “François Cointereaux's *École d'Architecture Rurale*,” 140.

[138] Cellauro and Richaud, “François Cointereaux's *École d'Architecture Rurale*,” 140.

[139] Jeffrey William Cody, “Earthen Wall Construction in the Eastern United States” (master’s thesis, Cornell University, 1985), 132.

[140] Walker et al., *Rammed Earth: design and construction guidelines*, 5.

[141] Clough Williams-Ellis, *Cottage Building in Cob, Pisé, Chalk & Clay: A Renaissance* (London: Country Life, 1919), 16.

Figure 54. Five-story Victorian rammed chalk houses in Winchester, Hampshire (top) and a rammed chalk country house in Andover, Hampshire (bottom) constructed ca. 1840. *Photographs from* Rammed Earth; Design and construction guidelines *and credited to Peter Walker, page 5.*

Though Abraham Rees (1743-1825) published *The Works of Cointereaux, on Rural and Economic Building* in Melbourne, in 1817, the May 3, 1823 article in *The Hobart Town Gazette* contained a much more detailed description of the rammed earth method. This article recorded what is believed to be the first pisé structure in Australia, a building on a farm at Coal River in Tasmania that was subsequently demolished.[142] *The Sydney Gazette and New South Wales Advertiser* published three articles on pisé on May 28, 1823, June 12, 1823 and June 19, 1823.[143] These articles included excerpts from Cointereaux's *École d'Architecture Rurale*, as well as, the works of Holland and Robert Salmon, an architect and surveyor for the Duke of Bedford who wrote on pisé.[144] The articles stressed the utility of rammed earth in areas with limited timber for building.[145]

In 1835, William Wilds, a surveyor from Hertford, United Kingdom published the impressively titled book, *Elementary and Practical Instructions on the Art of Building Cottages and Houses for the Humbler Classes: An Easy Method of Constructing Earthen Walls, Adapted to the Erection of Dwelling Houses, Agricultural and Other Buildings, Surpassing Those Built of Timber in Comfort and Stability*. The book was intended for those emigrating from England in reaction to the overpopulation the country was experiencing post the Napoleonic Wars and the distressed economic situation at the time.[146,147] Wilds described the nouveau pisé construction technique in detail. People were being encouraged to leave England for other countries including British North

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[142] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 141.

[143] Cody, "Earthen Wall Construction in the Eastern United States," 132.

[144] Ibid, 103-04.

[145] Ibid, 132.

[146] William Wilds, *Elementary and Practical Instructions on the Art of Building Cottages and Houses for the Humbler Classes: An Easy Method of Constructing Earthen Walls, Adapted to the Erection of Dwelling Houses, Agricultural and Other Buildings, Surpassing Those Built of Timber in Comfort and Stability (*London: John Weale, 1835) quoted in Jeffrey William Cody, "Earthen Wall Construction in the Eastern United States," 127.

[147] There had been a series of poor harvests and land prices were high. [Cody, "Earthen Wall Construction in the Eastern United States," 129.]

America, the Cape of Good Hope, New South Wales, and the United States.[148] As a result, settlers on the Western Plains of New South Wales used pisé to build small dwellings and farm buildings.[149]

During the 1860s and 1870s rammed earth construction came into its own in the Riverina district of New South Wales. Immigrants from Germany that settled at Walla Walla, along with those from other areas of Europe and England, built with pisé. Charles Hamilton McKnight, a Scottish immigrant, and his son are attributed with building several pisé houses in the region at the time. Today, ruins of pisé buildings constructed during this period are found along the roads that lead to the western Riverina and around Temora, Hay and Deniliquin.

A series of articles in the early 1870s spurred continued pisé construction in Australia into the twentieth century. In 1870, *Town and Country Journal* published an article on the use of pisé for rural construction in New South Wales. Other articles followed in 1871 and 1872 about pisé buildings constructed near Jugiong and at Harden. In addition, articles on pisé construction appeared in the *Sidney Morning Herald* in the early 1870s. “For small and large landholders alike, who had survived recessions and droughts, there were considerable advantages in constructing buildings that were cheap, durable, and which could be erected with one's own labour (sic) from a material available on one's own property.”[150]

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[148] Cody, “Earthen Wall Construction in the Eastern United States,” 130.

[149] Cellauro and Richaud, “François Cointereaux's *École d'Architecture Rurale*,” 141.

[150] Ibid.

Also during this time, rammed-earth construction occurred in the eastern and southern sections of Australia. This was because the best soils for use in pisé construction were found in these wheat-growing areas. From the 1870s to the 1930s, Australia had many small building teams that specialized in pisé construction. As the pisé process is very labor intensive, family members and friends often assisted with building. This further reduced overall costs of construction.[151]

Australia is still a prominent proponent of rammed earth construction today. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's national science agency. Until recently, the Building Code of Australia referred to the CSIRO publication "Bulletin 5: Earth Wall Construction" for the design and testing criteria for rammed earth construction. The CSIRO website description of rammed earth construction illustrates its significance:

> Earth-wall construction in Australia has a history dating from the earliest buildings of 'wattle and daub' and extending to two-storey contemporary dwellings and even to three-storey blocks of flats. Earth wall construction has now been used for large public constructions including visitor centres, hospitals and community facilities. There are earth-wall buildings here over 100 years old that can be expected to give many more years of service if adequate maintenance is continued. The strength of earth walls increases with their age.[152]

Bishop Pompallier's Printery (also known as Pompallier House) in Russell, North Island, New Zealand was originally constructed in 1841 as a publication facility for the French Marist Catholic mission established in 1839 under the leadership of Bishop Jean-

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[151] Ibid.

[152] CSIRO, "Earth-wall Construction: Building Technology File 06," CSIRO Publishing, http://www.publish.csiro.au/nid/22/pid/2981.htm (accessed April 15, 2012).

Baptiste François Pompallier, pictured in Figure 55. The purpose of the mission was to teach the native people, the Maori, to read and write to aid in their religious training.

The mission was poor and could not afford the timber needed to build a wooden structure that could house a printing press, bindery, tannery and paper storage facility. Louis Perret, French architect and lay missionary volunteer from Lyons, designed the printery building with a masonry base wall and a wide-eave roof to protect the walls from weathering.[153] Perret was well versed in rammed earth architecture and knew the work of Cointereaux, however he appears to have drawn a lot of inspiration for the printery design from the a description of pisé construction in a book written by Jean-Baptiste Rondelet entitled *Traité théorique et pratique de l'art de bâtir.*[154]

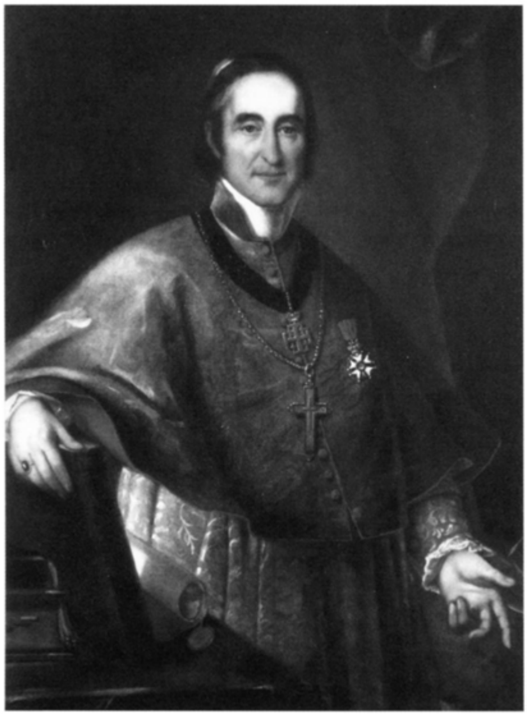

Figure 55. Portrait of Jean-Baptiste Pompallier by Marzochi de Belluci, 1848. *Reprinted from "François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies" by Louis Cellauro and Gilbert Richaud, page 142 . Photo credited to the Auckland Catholic Diocesan Archives.*

Figure 56 is an 1858 photograph showing the printery showing its location on the south side of the town complex. Figure 57 shows the front façade of the building.

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[153] Jeremy Salmond, "The Pompallier Project: Restoring a French Colonial Structure in New Zealand," *APT Bulletin* (Association for Preservation Technology International) Vol. 24, No. 1/2 (1992), 5.

[154] Cellauro and Richaud, "François Cointereaux's *École d'Architecture Rurale*," 141.

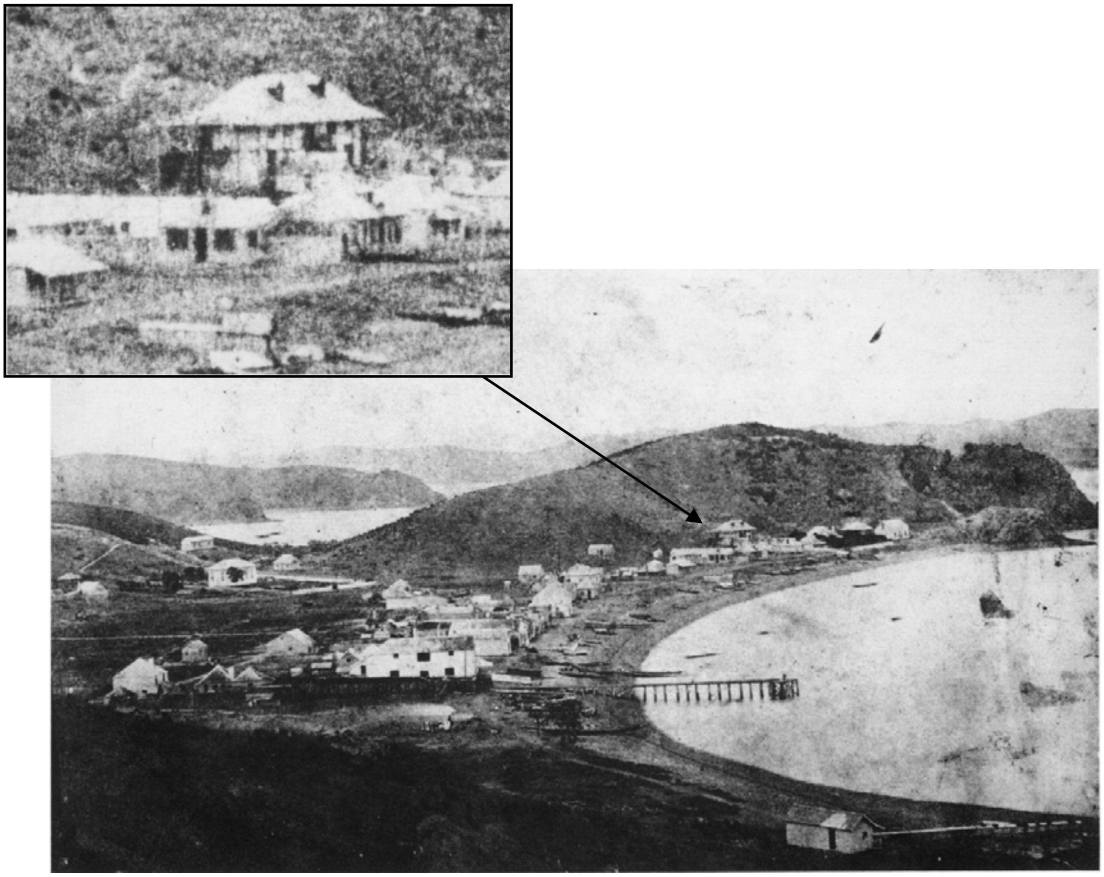


Figure 56. Panoramic view of Kororareka (now Russell township), North Island, New Zealand taken in 1858 from the north. The insert is a blow-up of the printery. *Reprinted from "The Pompallier Project: Restoring a French Colonial Structure in New Zealand" by Jeremy Salmond, pages 4 and 5. Photo credited to the Charlotte Ruck Album, Alexander Turnbull Library.*

The printery was restored in the early 1990s and the building has become a case study for historic preservationists. As-built drawings documented during the restoration project are seen in Figure 58.

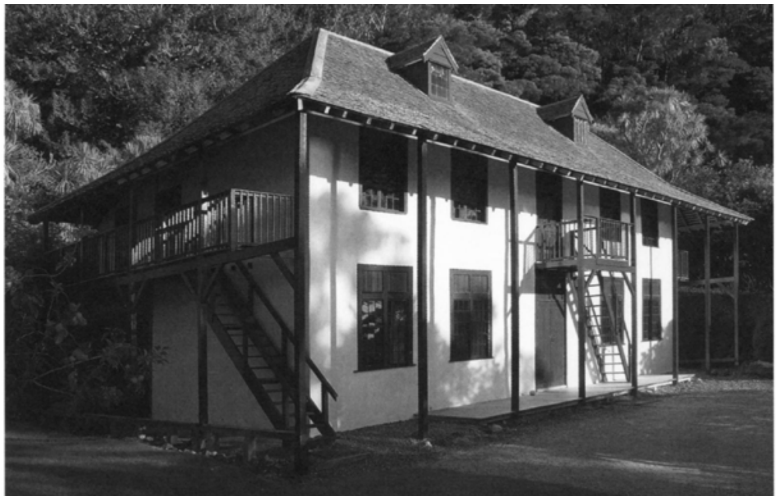
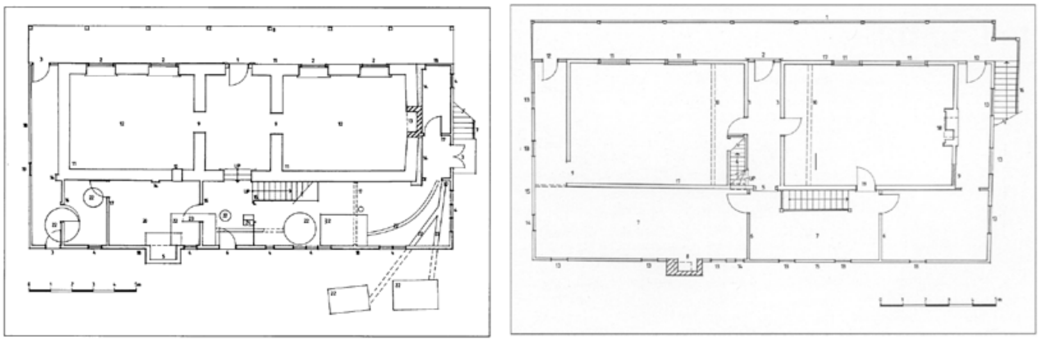


Figure 57. Main façade of the Bishop Pompallier's Printery, 1841. *Reprinted from "François Cointereaux's* École d'Architecture Rurale *(1790-91) and its Influence in Europe and the Colonies" by Louis Cellauro and Gilbert Richaud, page 142. Photo credited to the Pompallier Mission, New Zealand Historic Places Trust.*



Ground floor plan, existing condition, 1990.

First floor plan, existing condition, 1990.

West elevation.

South elevation.

Figure 58. Floor plans and as-is elevations for the printery from 1990. *Reprinted from "The Pompallier Project: Restoring a French Colonial Structure in New Zealand" by Jeremy Salmond, pages 12 and 13.*

The Rediscovery of Rammed Earth in the Twentieth Century

Rammed earth construction continued in the twentieth century, but it never became a mainstream building technique even though a number of housing problems could have been mitigated through its use. This is exemplified by the reception of Clough Williams-Ellis's writings on pisé. Originally published in 1919, Williams-Ellis wrote *Cottage Building in Cob, Pisé, Chalk & Clay: A Renaissance* as a meaningful answer to the chronic housing shortage in the United Kingdom at the close of World War I. In the introduction of the book, J. St. Loe Strachey, renowned editor and Ellis's father-in-law, cited the prediction of the committee appointed by the Ministry of Reconstruction in which it was projected that six billion bricks would be needed to build houses for the working class.[155] He discussed the lack of coal and quicklime for cement, and stressed the most critical shortage being that of timber. "Even worse is the shortage in timber — the material hitherto deemed essential for the making of roofs, doors, windows and floors. Raw timber is hardly obtainable, and seasoned timber does not exist."[156] In a second edition of the book published in 1920, Williams-Ellis described the demand he experienced as a result of the original printing. He attributed the books success to the popularity of pisé as a means to ameliorate the housing shortage:

> Any book that seemed to show a way of meeting the present building difficulties, however partially, was fairly assured of a welcome, but the somewhat unforeseen demand for my small contribution to the great volume of literature on cottage-building is, I think, to be attributed chiefly to its description of Pisé-building.
>
> Of the very large number of letters that reach me from readers of the book, quite ninety-nine out of every hundred are concerned with Pisé.[157]

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[155] Williams-Ellis, *Cottage Building in Cob, Pisé, Chalk & Clay,* 11.

[156] Ibid.

[157] Ibid, 5.

However, a report published in 1922 by the Building Research Board for the Committee of the Privy Council for Scientific and Industrial Research did not place rammed earth construction in a positive light. In fact, the Board's conclusion implied that those that supported rammed earth construction (including Williams-Ellis) were at a minimum naïve and more likely ill-informed:

> The fact remains that if the price of bricks, labor and transport settle to anything like the pre-war value, there will be no appreciable economy in using pisé except where the cost of walling bulks largely in the total cost of the building, or in particularly isolated situations.
>
> From time immemorial "raw earth" construction, in various forms, has been the natural solution of the housing problem wherever the lack of other material, or the skill necessary to employ such material when at hand, occurred. There are some who contend, in the light of recent experience, that once a better understanding of the true factor of strength and the best surface treatment of the various usable earths is obtained, building with "raw earth" will stand comparison with other construction even where no saving accrues, and where alternative material and the skilled labour to use it are available.[158]

Williams-Ellis revised and reprinted his book in 1947 after the close of World War II. Now titled *Building in Cob, Pisé, and Stabilized Earth*, he strived once again to promote earth architecture as an alternative to more costly construction techniques. However, as Paul Oliver explains in his article "Earth as a Building Material Today," Williams-Ellis's recommendations continued to be ignored. "In neither case [i.e., either edition] were its sober and pragmatic recommendations acted upon, even though examples of buildings by Ernest Gimson and designs by Sir Edwin Lutyens were included."[159] Interestingly, there have been a number of reprints of his works since their inception. Moreover, the dates of reprints generally coincide with times of economic

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[158] Building Research Board, 30.

[159] Paul Oliver, "Earth as a Building Material Today," 34.

stress or resource limitation.[160] In a possible attempt to assuage the concerns of those uncomfortable with alternative building techniques, Williams-Ellis went so far as to include a design for a home that could be constructed using either conventional or unconventional means as shown in Figure 59.

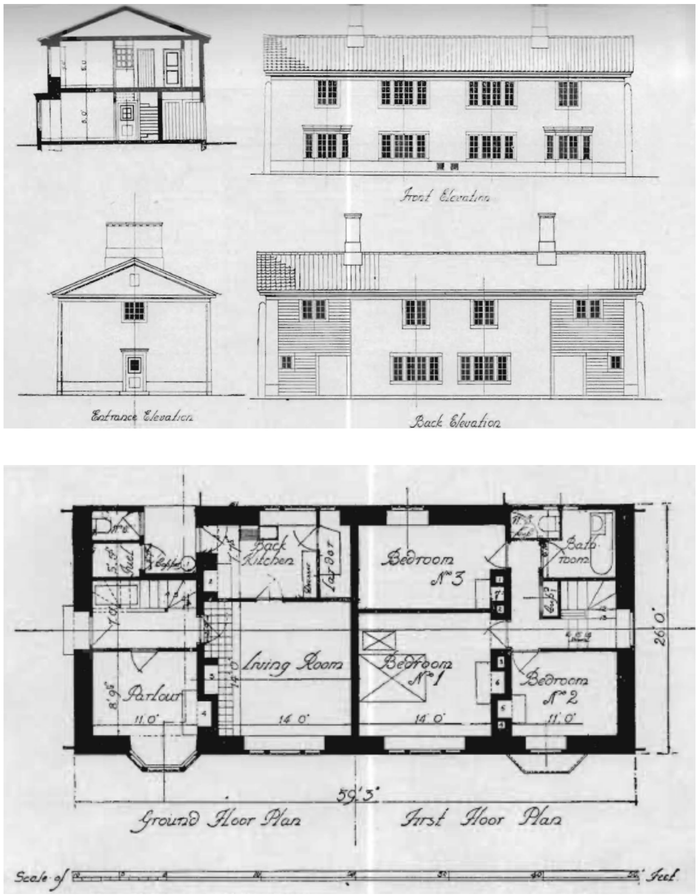

Figure 59. Section, elevations, and plan of a cottage designed by Sir Edwin Lutyens and Mr. Alban Scott included in Williams-Ellis's *Cottage Building in Cob, Pisé, Chalk & Clay*. The caption under the elevation read "This Cottage can be built in Cob, Pisé, Concrete, Stone, or Brick." *Drawings from* Cottage Building in Cob, Pisé, Chalk & Clay, *pages 27 and 28.*

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[160] The June, 1999 reprint of his book *Building in Cob, Pisé and Stabilized Earth*, includes an introduction by Gordon T. Pearson. Pearson states, "Upon reading the book again, its relevance to the late twentieth century soon becomes apparent. Emphasis has changed from experimenting with earth construction to conserving the national earthen heritage…The rapid rise in the 'green' or sustainable architecture movement has also helped to stimulate interest in constructing new earthen buildings and it is to be hoped that this interest will be maintained and developed to encourage [the United Kingdom] to return to its architectural roots."

As seen in Figures 60, 61, and 62, rammed earth construction occurred during the early part of the twentieth century. However, as stated above, it was an atypical building style.

Figure 60. Wayside station constructed of pisé, Simondium, South Africa, designed by Mr. Herbert Baker. Built 1919. *Photograph from* Cottage Building in Cob, Pisé, Chalk & Clay, *page 23.*

CHALK CONSTRUCTION AT AMESBURY, WILTS.

(From a sketch by W. R. Jaggard, F.R.I.B.A., the copyright of the Department of Scientific and Industrial Research.)

Figure 61. Anatomy of a rammed chalk house in Amesbury, Wiltshire. *Drawing from* Cottage Building in Cob, Pisé, Chalk & Clay, *page 96.*

Figure 62. Rammed chalk house in Amesbury, Wiltshire, United Kingdom built ca. 1920. *Photograph from* Rammed Earth; Design and construction guidelines, page 5. *The photo is credited to Peter Walker.*

Shown in Figure 63, the Hotel de L'Oasis Rouge (Red Oasis Hotel) was built about 1930 in the town of Timimoun in the Algerian Sahara.

Figure 63. The Hotel de L'Oasis Rouge (Red Oasis Hotel) in the town of Timimoun, Algeria was built about 1930. *Photograph from* Down to Earth *translated by Ruth Eaton, page 163. The photo is credited to Anne Rochette, 1981.*

While there is no evidence that Le Corbusier (1887 – 1965) used earth-building techniques, there is proof that he considered them as seen in Figure 64.

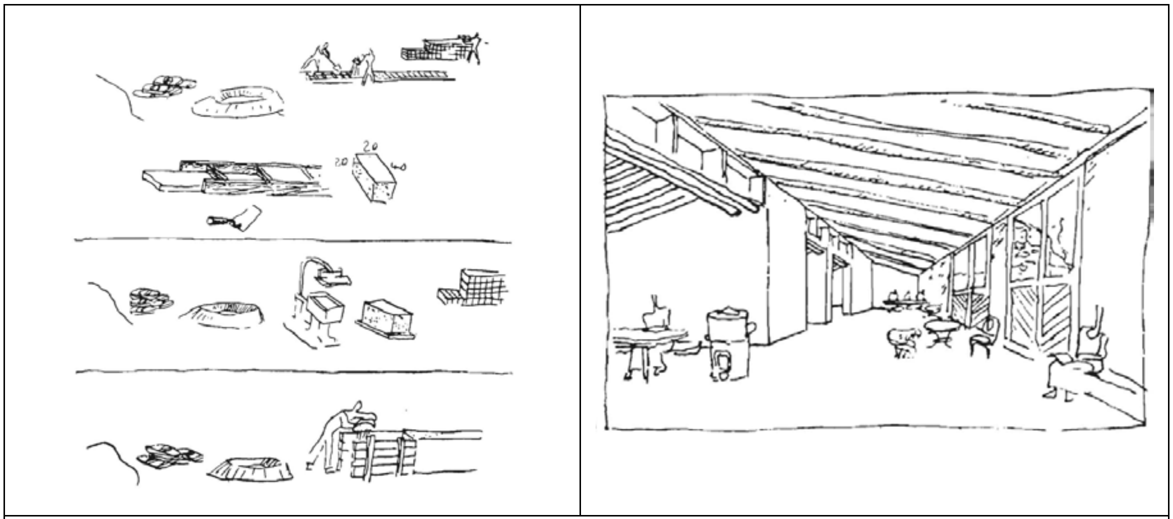

Figure 64. A series of sketches on earth construction methods by Le Corbusier in 1940 which appeared in *Les Murondins* in 1941. *Illustrations from* Down to Earth *translated by Ruth Eaton, page 153. The illustrations are courtesy of Fondation Le Corbusier.*

This chapter provided an overview of the use of earth construction techniques from a global historic perspective. The different earth construction techniques man has implemented were described based on the four main categories of earth construction as defined by Ronald Rael: rammed earth, mud brick, compressed earth block, and molded earth. These descriptions contextualized rammed earth within the construct of earth architecture. For illustration, early examples of rammed earth buildings were provided including the Small Wild Goose Pagoda in Xi'an, Shaanxi, China, the Alhambra in Spain, and the Igreja de Santo Antonio, Sâo Paulo and Iglesia Matriz de Nossa Senhora do Rosário, Pirenópolis, both in Brazil.

Next, the late eighteenth / early nineteenth century rediscovery and adaptive reuse of the rammed earth building technique by François Cointereaux was discussed. The new building style he coined “nouveau pisé” was described. An explanation was provided on the profound effect his promotion of the technique had in such countries as Denmark, Russia, Australia, and New Zealand. The works of various eighteenth century promoters of the pisé technique were discussed including David Gilly, Wilhelm Jacob Wimpf, Klaus Henrik Seidelin, Aleksander Barsov, Nicolai L'vov, Adam Menelaws, John Plaw, Henry Hollland, Abraham Rees, William Wilds, and Louis Perret. These architects and builders brought about the widespread use of pisé during the nineteenth century.

The next section of the chapter provided a description of the efforts of English architect Sir Clough Williams-Ellis at the beginning of the twentieth century. He promote the use of rammed earth and nouveau pisé as a means to mitigate the tremendous housing and building materials shortages faced by the citizens of the United Kingdom after both the first and second world wars. While pisé was never embraced as a panacea to the ills of the day, it was noted that each time there is an energy crisis, even to today, there is a resurgence of interest in his work and a reprinting of his books.

The chapter closed with a survey of some early twentieth century works in rammed earth including a wayside station in Simondium, South Africa, a rammed chalk house in Amesbury, Wiltshire and a hotel in Timimoun, Algeria. As a final note, sketch drawings from Le Corbusier were provided. These sketches were definitive proof that while he did not build with earth, he considered the techniques.

This chapter did not specifically touch upon the use of earth construction and rammed earth in particular within the historic context of the United States. This is covered in the next chapter along with an explanation of how rammed earth was promoted in the United States during the 1930s. Political and economic influences that have limited its use in the U.S. over time are also discussed.

CHAPTER IV

AN HISTORIC PERSPECTIVE OF RAMMED EARTH USE IN THE UNITED STATES

This chapter discusses rammed earth building within the United States with emphasis on the mid-twentieth century. The chapter begins with an overview of its early history within the U.S. A detailed description of its implementation during the Great Depression and post-World War II follows. The discussion includes specific examples of buildings constructed during this period and extant today. The chapter concludes with a discussion of how politics and the counter-culture stigma that has evolved around it have influenced its use as a viable building technique.

The Use of Rammed Earth in the Early Years of the United States

Thomas Jefferson (1743 – 1826) was Minister to the Court of Louis XVI from 1784 to 1789 as the representative of the newly formed United States following Benjamin Franklin's tenure in Paris and the signing of the Peace of Paris in 1783. Jefferson was living in France as the French Revolution was taking shape. As a self-made architect, he was always interested in new forms of architecture. He was also very much interested in architecture that brought new perspectives. As Leland Roth explains in *American Architecture: A History*, "The most radical architects [of the time], such as Ledoux in France, and Jefferson and Latrobe in the United States…suggested that architecture should be an instrument of social reform, a tool to instruct and reshape men's minds, and to enhance civil intercourse."[161]

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[161] Leland M. Roth, *American Architecture: A History* (Boulder: Westview Press, 2001), 107.

If Jefferson was familiar with pisé prior to living in France is unclear. However, correspondence with George Washington (1732 – 1799), in a letter dated 18 November 1792, provides evidence that while in France he visited Lyons, saw structures built of pisé and meet François Cointereaux:

> Th: Jefferson has the honor to inform the President that the papers from Monsr Cointeraux of Paris contain some general ideas on his method of building houses of mud, he adds that he has a method of making incombustible roofs and ceilings, that his process for building is auxiliary to agriculture, that France owes him 66,000 livres, for so much expended in experiments & models of his art, but that the city of Paris is unable to pay him 600. livres decreed to him as a premium, that he is 51. years old has a family of seven persons, and asks of Congress the expenses of their passage & a shop to work in.
>
> Th: Jefferson saw M. Cointeraux at Paris, went often to examine some specimens of mud walls which he erected there, and which appeared to be of the same kind generally built in the neighborhood of Lyons, which have stood perhaps for a century. Instead of moulding bricks, the whole wall is moulded at once, & suffered to dry in the sun, when it becomes like unburnt brick. This is the most serious view of his papers. He proceeds further to propose to build all our villages incombustible that the enemy may not be able to burn them, to fortify them all with his kind of walls impenetrable to their canon, to erect a like wall across our whole frontier to keep off the Indians, observing it will cost us nothing but the building, &c. &c. &c.
>
> The paper is not in the form of a petition, tho' evidently intended for Congress, & making a proposition to them. It does not however merit a departure from the President's rule of not becoming a channel of petitions to that body, nor does it seem entitled to any particular answer.[162]

Though Jefferson studied pisé, his interest appears to be purely academic. He had all of Coinetereaux's fascicles that had been compiled in a four-volume set, *École d'Architecture Rurale*, in his library along with S. W. Johnson's *Rural Economy*.[163] However, his disbelief that pisé was a viable building technique for the northeastern part

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[162] "Thomas Jefferson to George Washington, 18 November 1792," Library of Congress, Washington DC, Thomas Jefferson Papers Series 1, General Correspondence, 1651-1827 quoted in Cellauro and Richaud, "Thomas Jefferson and François Cointereaux," 197.

[163] Cellauro and Richaud, "Thomas Jefferson and François Cointereaux," 192.

of North America is clearly demonstrated in his response, while president, to a letter from Thomas J. Hewson of the American Philosophical Society. Jefferson's reply is found in a letter dated 29 October 1808:

> Sir,
>
> I have to thank you for the communication of Cointereaux's two pamphlets, which I now return you. At the moment of my receiving them I know that Mr. Fulton was building a wall of Pisé in the former manner [ancien pisé] and therefore sent them to him. He has made some moellons on the new method [nouveau pisé] and pronounces it infinitely superior to the former. But it may be questioned whether it is sensibly cheaper than stone, when stone is convenient. That it is not so durable must be admitted. I have seen houses in the South of France of earthen walls, which were said to have been built for more than one hundred years. But in that country they have but a few inches of rain in the year, and very rarely a frost to injure an olive tree. Here, we have between 3. and 4. feet of rain annually, and frosts which will make ice of a foot thickness. Its duration here then must be doubtful.[164]

In addition, at times, some have been under the mistaken belief that parts of Monticello are built of pisé. That idea, however, has been refuted. Jack McLaughlin documents the building of Monticello in detail in his book *Jefferson and Monticello: The Biography of a Builder*. In it, McLaughlin painstakingly describes the brickmaking process at Monticello. The bricks were made on-site using homemade kilns and slave labor. The results were uneven and inconsistent leading to walls of various sizes and depths.[165] The thickness of some of the walls may have misled people to believe they were made of pisé.

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[164] "Thomas Jefferson to Thomas J. Hewson, 29 October 1808," Library of Congress, Washington DC, Thomas Jefferson Papers Series 1, General Correspondence, 1657-1827 quoted in Cellauro and Richaud, "Thomas Jefferson and François Cointereaux," 199.

[165] Jack McLaughlin, *Jefferson and Monticello: The Biography of a Builder* (New York: Henry Holt and Company, 1988), 72-77.

To further refute the claim of pisé, McLaughlin is also quoted in the article “Is Thomas Jefferson's Monticello Constructed of Rammed Earth?” on the EarthArchitecture.org website:

> To my knowledge, Jefferson did not use rammed earth as a construction technique, certainly not at Monticello or Poplar Forest. These two buildings have been so thoroughly researched that any unusual materials would have turned up. Jefferson made his own bricks with slave labor so brick was readily available, as was stone rubble used for cellars. He did use rustication on the exterior of parts of Monticello, covering brick with stucco and sand and then scribing it to make it look like cut stone.[166]

While Jefferson did not employ rammed earth for his personal use, his knowledge of pisé may have contributed to its use by General John Hartwell Cocke (1780-1866) in the design of his estates and homesteads Bremo Recess (1803-1809), Upper Bremo (completed in 1820), and Lower Bremo (ca. 1844), all in the Fork Union vicinity of Fluvanna County, Virginia.[167] Jefferson advised Cocke on his Bremo residence. Indeed, he is often erroneously referred to as the architect for Bremo.[168]

Regardless of whether Jefferson discussed the pisé technique with him, Cocke learned the details of how to construct with pisé using S. W. Johnson’s book, *Rural Economy*.[169] Johnson’s book was essentially a re-write of Henry Holland’s

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[166] EarthArchitecture.org, “Is Thomas Jefferson's Monticello Constructed of Rammed Earth?” EarthArchitecture.org, March 12, 2006, http://www.eartharchitecture.org/index.php?/archives/772-Is-Thomas-Jeffersons-Monticello-Constructed-of-Rammed-Earth.html (accessed April 15, 2012).

[167] W. B. Morton, III, *Bremo Historic District National Register Nomination*, National Register of Historic Places Inventory - Nomination Form (Washington, D.C.: United States Department of the Interior, National Park Service, 1969), 6.

[168] Historic American Buildings Survey, “Bremo, State Route 656 vicinity, Bremo Bluff, Fluvanna County, VA.,” *Historic American Bulidings Survey*, after 1933, http://www.loc.gov/pictures/item/va0451/ (accessed April 15, 2012).

[169] Hallock, “Pisé Construction in Early Nineteenth-Century Virginia,” 45.

Communications to the Board of Agriculture with enhancements and refinements as determined by Johnson's own work with pisé.[170] Henry Holland's work, as stated in the previous chapter, was a translation of Cointereaux's *École d'Architecture Rurale*. Cocke built a school, a chapel, and multiple rammed earth living quarters for his slaves between 1815 and 1821 of which two are extant.[171,172] Figure 65 is a photograph of an extant slave quarters at Bremo Plantation.

Figure 65. Slave quarters at Bremo Plantation, Fluvanna County, Virginia, ca. 1820. The flared eaves, seen on the gable end, were designed to protect the rammed earth walls by diverting rainwater away from the structure.[173] *Photograph from Library of Congress, Prints & Photographs Division, HABS VA, 33-FORKU.V,1--22.*

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[170] Cody, "Earth Wall Construction in the Eastern United States," 143.

[171] Ibid, 44.

[172] Cellauro and Richaud, "Thomas Jefferson and François Cointereaux," 194.

[173] Ibid, 50.

St. George Tucker (1752-1827), member of the Virginia legislature, law professor at William and Mary College, and judge, likely introduced Cocke to Johnson's book.[174] Tucker, along with Bushrod Washington (1762-1829), was active in the American Colonization Society, which was an organization created to aid freed slaves in the establishment of new settlements on the west African coast.[175] Tucker, Cocke and Washington were dedicated to the betterment of the living conditions of slaves in the U.S.[176] This commitment drove all three gentlemen to learn and understand pisé. Its professed qualities of heat retention in winter and coolness in summer were far superior to the traditional log cabins that were normally used for cheap slave housing on the plantations of Virginia.[177]

Washington built eight pisé structures between 1810 and 1815: an overseer or slave quarters in 1810; two porter cottages and an above ground ice house in 1812; two barns, a cow food boiler, and a greenhouse in 1815.[178] Though none is extant, a drawing of the porter cottages survives and is shown in Figure 66.

Cocke also constructed up to sixteen pisé buildings at Pea Hill Plantation in Brunswick County, Virginia. The Overseer's quarters, shown in Figure 67, incorporated

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[174] From a letter to St. George Tucker from Bushrod Washington , 13 August 1814, Bushrod Washington Papers, Mount Vernon Ladies' Association Library as quoted in Gardiner Hallock, "Pisé Construction in Early Nineteenth-Century Virginia," 45.

[175] Hallock, "Pisé Construction in Early Nineteenth-Century Virginia," 41-42.

[176] Cocke had a long-standing business relationship with one of his slaves, Lucy Skipwith. She was the manager of his Hopewell plantation in Greene County, Alabama during the Civil War. [Ervin L. Jordan, Jr., *Black Confederates and Afro-Yankees in Civil War Virginia (*Charlottesville, VA: University of Virginia, 1995), 43-44.]

[177] Hallock, "Pisé Construction in Early Nineteenth-Century Virginia," 42.

[178] Ibid.

a roughcast finish commonly used in Virginia at the time. Pea Hill was a plantation Cocke managed for his deceased friend, John T. Bowdoin.[179] Cocke's son, Philip St. George Cocke, married Bowdoin's daughter and, in 1835, built slave quarters of pisé at his farm, Four Mile Tree Plantation. These slave quarters were the last documented pisé buildings constructed during the nineteenth century in Virginia.[180]

Figure 66. Porter Cottages, Mount Vernon, Virginia, 1812. *Reprinted from "Pisé Construction in Early Nineteenth-Century Virginia" by Gardiner Hallock,* Perspectives in Vernacular Architecture *11 (2004), page 42. Attributed to illustrator Benjamin Lossing and published in* Harper's Weekly, *ca. 1858. Provided to Mr. Hallock by the Mount Vernon Ladies' Association.*

Another example of the use of rammed earth construction techniques during the nineteenth century is the Borough House Plantation near Stateburg in Sumter County, South Carolina. In 1810, Dr. William Wallace Anderson, M.D. moved to South Carolina to begin practicing medicine. He was intrigued with pisé and owned a copy of *Rural Economy*.[181] Anderson designed the plantation complex in 1821. It consists of a main house with formal gardens and twenty-seven secondary structures. The plantation "contains the oldest and largest known

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[179] Hallock, "Pisé Construction in Early Nineteenth-Century Virginia," 45.

[180] Ibid, 48.

[181] William Wallace Childs, "From the Collections: Dr. William W. Anderson's Use of an Ancient Building Material in Stateburg," *The South Carolina Historical Magazine* (January 1984), 72.

collection of 'high-style' pisé buildings in the United States."[182] Sections of the main house and six of the outbuildings were constructed of rammed earth.

Figure 67. Overseer's quarters at Pea Hill Plantation, Brunswick County, Virginia, ca. 1820. Lime-based roughcast or lime-based stucco was used as the finish for rammed earth buildings constructed during the nineteenth century in Virginia.[183] *Photograph reprinted from "Pise Construction in Early Nineteenth-Century Virginia" by Gardiner Hallock,* Perspectives in Vernacular Architecture *11 (2004), page 46. Attributed to the Virginia Department of Historic Resources.*

The main house, shown in Figure 68, was constructed in the Greek Revival style and consists of a five-part Palladian design. The two wings on either side of the central block incorporate rammed earth.[184] Usually relegated to secondary structures and

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[182] Richard K. Anderson, Jr., "National Register of Historic Places Inventory - Nomination Form: Borough House Plantation," National Historic Landmark Nomination (Washington, D.C.: United States Department of the Interior, National Park Service, 1988), 3.

[183] Ibid, 41.

[184] Ibid, 2.

especially slave quarters, it is of particular significance that rammed earth was included in the main house construction. The six outbuildings served as utility buildings. They include an office, a schoolhouse, a weaving house, a dry well, a summer kitchen and storehouse, and a cook's house. The cook's house was originally slaves' quarters. Only the office and weaving house continued the Greek Revival style. All of these outbuildings, as well as the rammed earth elements of the main house, were finished with a yellow-tinted stucco coating. [185]

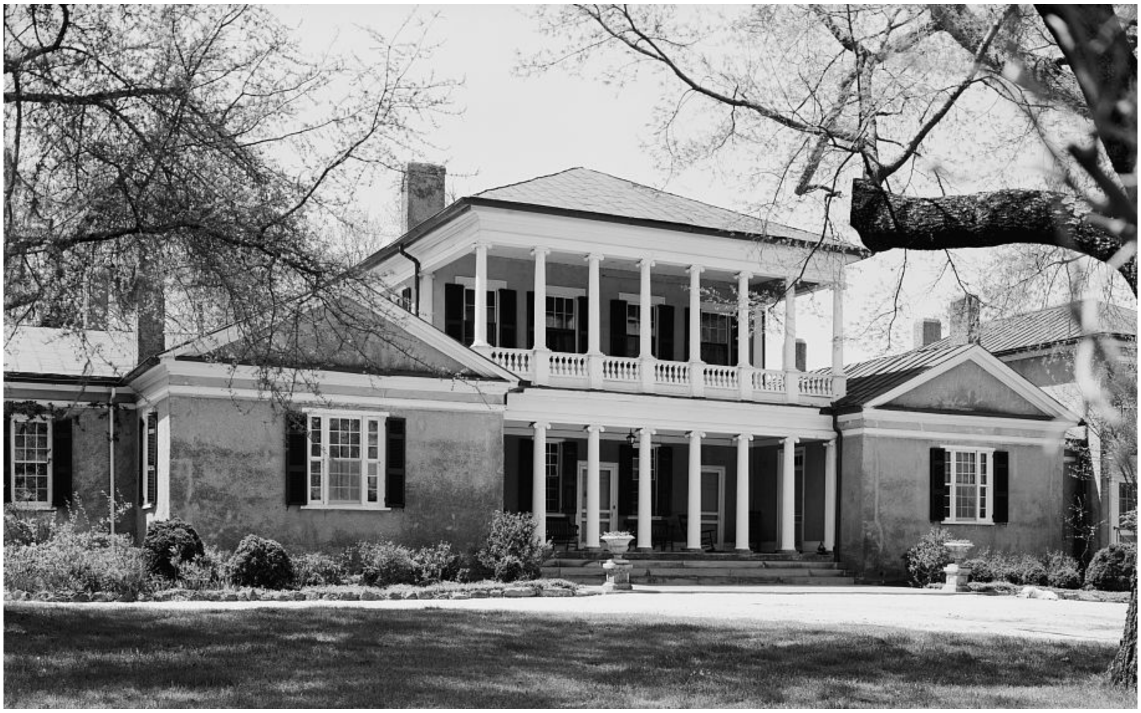

Figure 68. West (front façade) of main house, Borough House Plantation, Sumter County, South Carolina, 1821. *Photograph from Library of Congress, Prints & Photographs Division, HABS SC,43-STATBU,1--1.*

In addition to his own residence and plantation, Anderson was instrumental in the decision to build of the Church of the Holy Cross in Stateburg, Sumter, South Carolina of

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[185] Ibid, 6-9.

pisé. Constructed in 1850, the church name resulted from the architectural plan, seen in Figure 69.

In a December 3, 1923 letter to the editor of the *Washington Star*, William Wallace Childs, the grandson of Anderson, recounted the local story of how the decision was made to build the church of pisé. Anderson was a well-respected member of the local community and the largest contributor to the church. In an effort to refrain from influencing the decision on what material to use to build the church, he abstained from attending the church meeting in which the final material decision was to be made. A protracted argument ensued between members of the congregation who preferred stone and those who preferred brick. As Childs explains, Anderson soon grew impatient:

> The Doctor, sitting in his house on the hill [the planation overlooked the church site] impatiently waited for the vestry to adjourn, when he knew that most of the members would come up to tell him the result, and to refresh themselves after their arduous labors before the long ride home. But at last patience ceased to seem a virtue and the Doctor reached for his hat.
>
> "Now Doctor," said Mrs. Anderson, "don't you say anything about pisé."
>
> "O, not a word, not a word," replied the Doctor, "I'll just step down there and see what's keeping them so long."
>
> He found the vestry in the condition of a Congressional committee unable to function through a difference of opinion. It was in fact a deadlock between the advocates of brick and stone. When the members had finally exhausted argument, and a long pause ensued, the Doctor forgetting all about his promise, rose to his feet and impetuously exclaimed:_
>
> "Gentlemen, what do you say to pisé? What do you say to pisé?"
>
> And pisé it was.[186]

In the end, the congregation was pleased with decision because, as stated in Chapter I, the cost was low. This was in large part because the cost of importing

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[186] Childs, "From the Collections: Dr. William W. Anderson's Use of an Ancient Building Material in Stateburg," 74.

materials – either brick or stone – into the rural area that was Stateburg was very costly.[187] The photographs in Figure 70 show the wall construction for the church. The exterior and interior wall coatings are clearly shown.

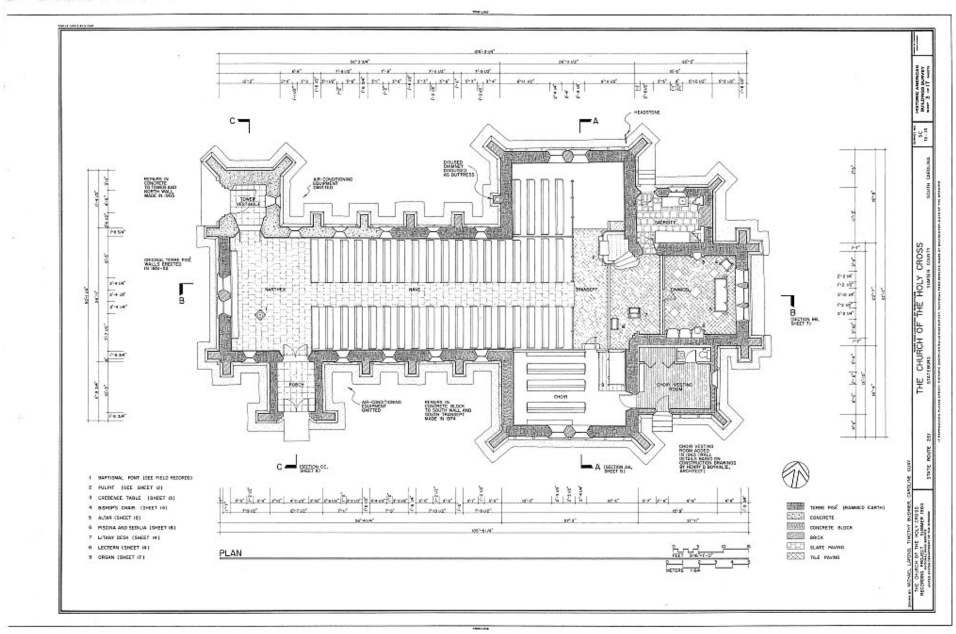

Figure 69. Plan of the Church of the Holy Cross, Sumter County, South Carolina, 1852. *Drawing from Library of Congress, Prints & Photographs Division, HABS SC,43-STATBU.V,1- (sheet 3 of 17).*

The Church also proved to be particularly robust surviving the Charleston earthquake of 1886, a "catastrophe which shook down the original tower of St. Michael's in Charleston and damaged an estimated 90 per cent of that city."[188] The structure survived a number of other natural disasters including a three-day hurricane in 1895. In 1903, however, a powerful cyclone caused the tower to collapse onto the roof necessitating a rebuild of the tower and some wall portions with cement. Nevertheless, as Anthony Merrill states in *The Rammed-Earth House*, "When one considers that the end

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[187] Ibid.

[188] Merrill, *The Rammed-Earth House*, 12.

wall which rise up to meet the roof are pierced with 16-foot Gothic windows, the survival properties of rammed-earth seem incredible."[189]

Figure 70. Section photographs of the south wall of the nave of the Church of the Holy Cross. The rammed earth wall is at the core of the section. A brick buttress is to the left and the lath, plaster and cornice interior is to the right. Henry D. Boykin, II, A.I.A., Photographer, 1974. *Photographs from Library of Congress, Prints & Photographs Division, HABS SC,43-STATBU.V, 1-11(left) and 1-12(right).*

Two other early examples of rammed earth use in the United States include the Ursuline Academy in San Antonio, Texas and the Michigan Lake Superior Power Company Hydroelectric Plant. The Ursuline Academy, the south elevation of which is shown in Figure 71, was founded by seven Ursuline sisters from New Orleans and Galveston. The head mistress, Sister St. Marie Trouard and six other nuns, arrived in San Antonio on September 14, 1851. Their mission was to start a girls school at the request of Bishop John Mary Odin who was striving to rekindle Catholicism in Texas. He was

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[189] Ibid, 13.

the first Roman Catholic Bishop of Texas. By November 3, Ursuline Academy was operational. Originally the second oldest girls school in Texas, it is now the oldest.[190]

Figure 71. South elevation of the Ursuline Academy, San Antonio, Texas. The original building was constructed before 1851. Arthur W. Stewart, Photographer, March 13, 1936. *Photograph from Library of Congress, Prints & Photographs Division, HABS TEX,15-SANT,7-1.*

The original academy building was the former home of Jules Poinsard. Measuring approximately 75-feet by 30-feet, it was made of rammed earth from native limestone. The exact date of the construction of the former Poinsard residence is unclear. This building was the basis for the rest of the school and is believed to be the oldest surviving example of pisé de terre work in Texas.[191, 192] The first floor plan is seen in

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[190] Sister Ignatius Miller, O.S.U., “URSULINE ACADEMY, SAN ANTONIO,” *Handbook of Texas Online*, Texas State Historical Association. n.d. http://www.tshaonline.org/handbook/online/articles/kbu04 (accessed April 3, 2012)

[191] Library of Congress, Prints & Photographs Division, HABS TEX, 15-SANT 7-Drawings, sheet 1 of 21.

[192] There is conflicting information on the legacy of the original building as the establishment of the academy is usually documented, not the build date of Poinsard’s residence. Poinsard, a Frenchman, built the house for his intended bride. She refused to join him in the “wild west” forcing him to sell the

Figure 72 and the second floor plan is in Figure 73. The original pisé de terre construction is indicated on the plans.

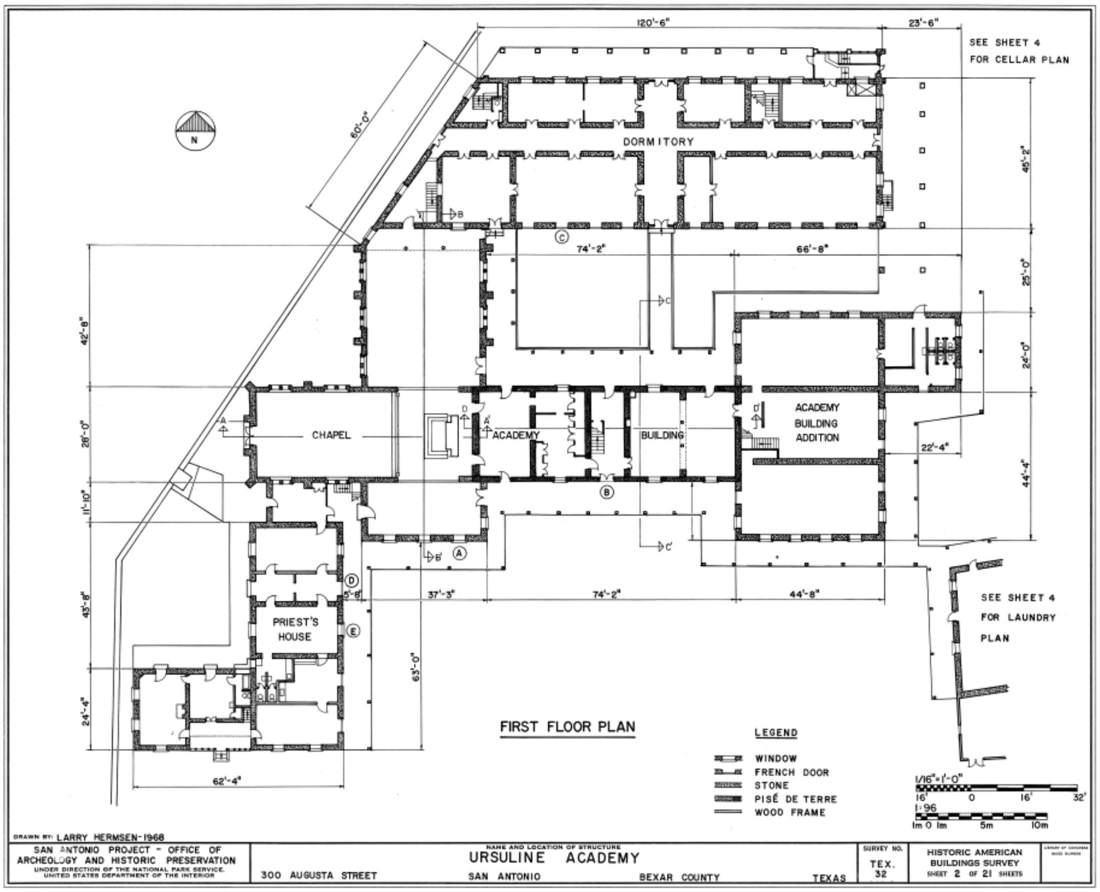

Figure 72. First floor plan of the Ursuline Academy. *Drawing from Library of Congress, Prints & Photographs Division, HABS TEX,15-SANT 7-Drawings (sheet 2 of 21).*

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home. He sold it for $600 to Bishop Odin. (Library of Congress, Prints & Photographs Division, HABS TEX, 15-SANT 7-Data Pages, "Photographs," 2.)

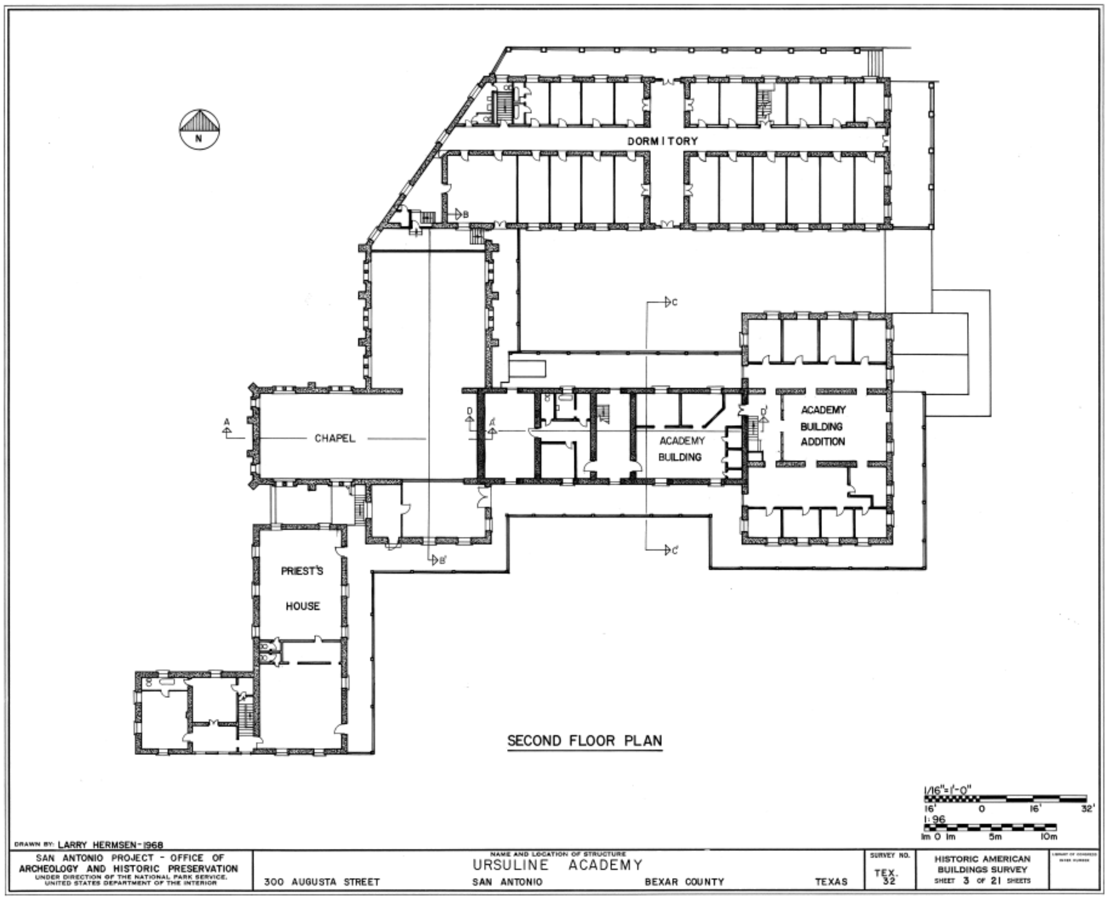

Figure 73. Second floor plan of the Ursuline Academy. *Drawing from Library of Congress, Prints & Photographs Division, HABS TEX,15-SANT 7-Drawings(sheet 3 of 21).*

The Michigan Lake Superior Power Company Hydroelectric Plant, Portage Street, Sault Ste. Marie, Chippewa, Michigan was completed in 1902. While not a rammed earth construction in the traditional sense, it did employ a unique adaptation of the rammed earth concept. Hans von Schon, chief engineer of the power plant project, developed an original design concept for the walls between the penstock units or turbine chambers. It was a cellular steel I-beam construction technique in which the skeleton of the walls were made by placing a number of vertical 12-inch thick I-beams into the concrete foundation. The spaces between the I-beams were filled with earth and the entire wall was then encased in concrete.[193] Figure 74 provides the north and south elevations of the power plant along with the floor plan for the Turbine 4 generator.

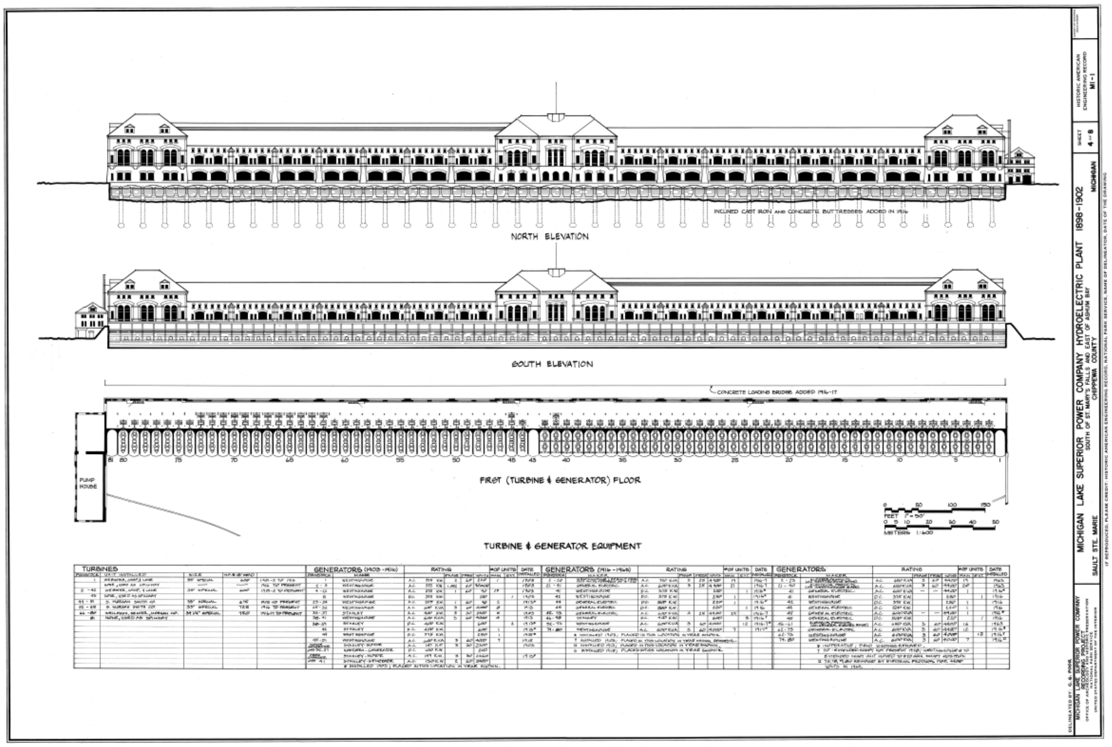

Figure 74. Elevations and floor plan of the Michigan Lake Superior Power Company Hydroelectric Plant, 1902. A variation of rammed earth construction was used in the walls between the turbine cells. *Drawing from Library of Congress, Prints & Photographs Division, HAER MICH,17-SAUMA 1-Drawings(sheets 4 of 8).*

Rammed Earth Is "Discovered" in the United States

As discussed in Chapter III, architect Clough Williams-Ellis and his father-in-law, J. St. Loe Strachey had campaigned for rammed-earth construction as a means to alleviate the housing crisis in post-World War I England in a cheap and efficient manner. Strachey, editor for the *London Spectator*, wrote extensively on rammed earth. His writings attracted the attention of the editors of the *Literary Digest* in the United

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[193] Library of Congress, Prints & Photographs Division, HAER MICH, 17-SAUMA 1- Data Pages, "Photographs: Written Historical and Descriptive Data," 74.

States.[194] They began to reprint his articles in the latter half of the 1920s. This brought earth building techniques to the consciousness of the American people. It also brought a number of inquiries into the U.S. Department of Agriculture regarding soil quality and the pisé technique.

Karl J. Ellington and his wife Inez Ellington published *Modern Pisé Building* in 1924. Living in Port Angeles, Washington, their how-to manual was designed as an aid to rural farmers and settlers in the use of rammed earth. The Ellington's expounded on the advantages of pisé, described the construction method and chronicaled its use in Sweden, Norway, Denmark, England, France, Germany and Australia. They included numerous photographs of pisé buildings along with many testimonials to the quality of rammed earth structures. They described both the monolithic and rammed block methods and even included a photograph of a pressed earth block making machine built by Concrete Equipment Co. of Holland, Michigan, a copy of which is seen in Figure 75. Their book included plans for cottages, barns and other outbuildings. [195]

During the same period, agricultural engineer T. A. H. Miller in the Division of Agricultural Engineering, U.S. Department of Agriculture (later the co-author of "Farmers' Bulletin No. 1500: Rammed Earth Walls for Buildings") was asked to evaluate the Church of the Holy Cross. He was also asked to aid in determining sympathetic repairs to the church from damage due to the Charleston Earthquake forty years early. Miller became intrigued with rammed earth as an alternative building technique especially for low-cost agriculture outbuildings.

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[194] Merrill, *The Rammed-Earth House*, 10.

[195] Ibid, 1-116.

Dr. Harry Baker Humphrey was the chief plant pathologist of the USDA when Miller "discovered" rammed earth. Humphrey decided to experiment with rammed earth in a grand style and built "a rather comfortably pretentious affair, quite in keeping with the architectural character of the better suburbs" of Washington D.C.[197] The Humphrey House, pictured in Figure 76, became the model for the construction techniques used in "Farmers' Bulletin No. 1500."

Another individual intrigued with rammed earth was R. C. Cook of Lanham, Maryland. In an effort to minimize construction costs as much as possible, Cook used rammed earth to build his home, seen in Figure 77, literally from bottom to top. Instead of making a concrete foundation and

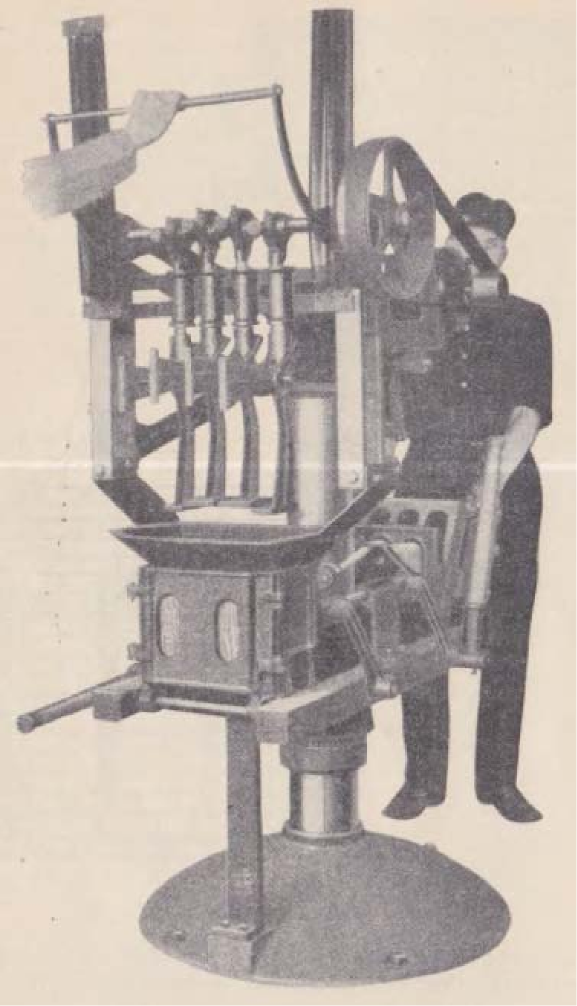

Figure 75. Concrete Equipment Co. block-making machine. Described in the Ellington's book as "a 'utility' power Block Machine, -which may be used in making Pise-Blocks." They warned it was not affordable to a lone settler, but "groups of farmers can use such in cooperation."[196] *Photograph from* Modern Pisé Building *by Karl and Inez Ellington, page 42.*

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[196] Karl J. and Inez Ellington, *Modern Pisé Building: House-Building with Compressed or Rammed Earth* (Port Angles: Karl J. and Inez Ellington, 1924), 42.

[197] Merrill, *The Rammed-Earth House,* 15.

incorporating a damp course, Cook chose to pack the foundation in a rammed-earth fashion. He built his first-floor walls of rammed earth directly on the packed earth floor.[198] He also used rammed earth for his chimneys and flues, an implementation of rammed earth expressly prohibited by even the most ardent of rammed earth proponents.[199]

Figure 76. The Humphrey House, Washington, D.C., 1924. Merrill notes that the first floor rammed earth walls must hold up the timber second floor, attic space, and massive tile roof. *Photograph from* The Rammed-Earth House *by Anthony Merrill, illustration insert.*

Cook originally planned to build his second floor of timber in a fashion similar to Humphrey. However, time ran short and materials were unavailable as winter was setting in. Therefore, Cook, whose second floor studding and roof were already in place, decided to use the rammed earth technique to fill in the walls between the studs. He

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[198] Ibid, 25.

[199] Francis Macdonald, *Terracrete: Building with Rammed Earth-Cement* (Research Paper, Chestertown, Maryland: Francis Macdonald, 1939), 12.

planned to remove the in-fill the following spring. In the end, however, he found that the walls were sound and did not require any modifications.[200]

As an interesting side note, to keep costs to a minimum, Cook used the rammed earth walls solely for load bearing and used the Flagg method for partition (non-loadbearing) walls inside the house. The Flagg method, named for Earnest Flagg, an architect who specialized in low-cost construction, involved forming walls by hanging a burlap curtain at the desired partition location and plastering the burlap on both sides simultaneously. Once the plastering is complete, the wall is attached to the baseboard. The Flagg method originated in Italy. Cook also incorporated a Flagg roof.[201]

Figure 77. R. C. Cook Residence, Lantham, Maryland, 1929. To keep costs to a minimum, Cook used rammed earth construction techniques uniquely. *Photograph from* The Rammed-Earth House *by Anthony Merrill, illustration insert.*

<u>Mitigating the Great Depression with Rammed Earth</u>

The United States government became an unwitting proponent of rammed earth construction methods during the 1930s. Rammed earth was viewed by many to be a low-cost and durable building technique during a time of limited economic resources – the

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[200] Merrill, *The Rammed-Earth House*, 25.

[201] Ibid.

Depression Era. The U.S. government support happened in the form of "Farmers' Bulletin No. 1500," the works of Dr. Ralph L. Patty of the South Dakota Agricultural Experiment Station, and the support of the U.S. Resettlement Administration, the Progress Works Administration, and the National Youth Administration – all agencies under the Roosevelt Administration's overarching New Deal program.

Miller and Betts wrote the "Farmers' Bulletin" as a means to answer questions from the public resulting from the *Literary Digest* articles and to alleviate the intrigue of the Humphrey House. Dr. Humphrey had had a legion of inquisitive citizens contact him for information on his home. The "Farmers' Bulletin" and the publication of Patty's testing led to a series of rammed earth experiments.

Most notable among the experiments was the low-cost Gardendale Resettlement Project near Birmingham, Alabama completed between 1933 and 1937. Pictured in Figure 78, this Resettlement Administration experiment encompassed the development of a housing project to aid distressed farmers in finding new livelihoods in an urban area.[202]

Figure 78. Rammed earth construction in-process photographs for Gardendale. Thomas Hibben and Arthur Rothstein, Photographers, 1937. *Photographs from Library of Congress: LC-USF347-015512-C, LC-USF347-015511-C, and LC-USF34-025290-D.*

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[202] Joseph L. Arnold, *The New Deal in the Suburbs: A History of the Greenbelt Town Program 1935-1954* (Columbus: Ohio State University Press, 1971), 29.

Architectural engineer Thomas Hibben used rammed earth for seven homes and outbuildings in Gardendale. The Gardendale experiment proved that the cost of rammed earth construction could be advantageous. Hibben's first house cost $2,700 to build and the last house cost $2,200 (in 1936 dollars). The houses included three-bedrooms, a large living / dining room combination, a kitchen, a bathroom and had large front and back porches. Built in the South, the homes incorporated no furnaces.[203] Figure 79 provides the plan of one of Hibben's Gardendale homes and includes exterior and interior photographs.

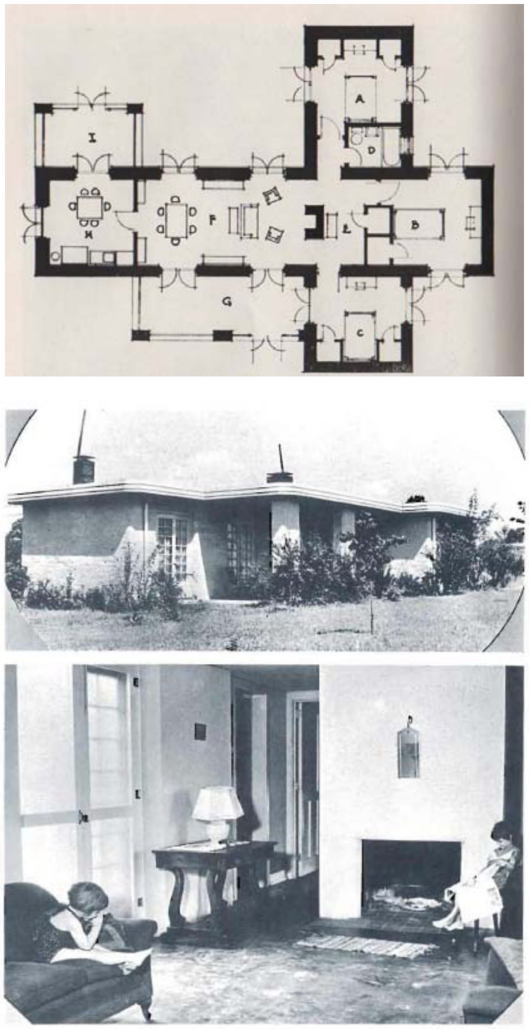

Figure 79. Gardendale rammed-earth house plan, and exterior and interior views. *Drawing from* The Rammed-Earth House *by Anthony Merrill, illustration insert. Photographs from* Historic Architecture in Alabama *by Robert Gamble, page 170.*

In extolling the virtues of rammed earth, Anthony Merrill wrote in *The Rammed-Earth House*, "The little Alabama community of Hibben-built earth houses…furnishes ample proof for the doubtful that a plain rammed-earth wall is a satisfactory building element; that it will stand the abuse of time and weather; that

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[203] Merrill, *The Rammed-Earth House*, 6.

there is nothing ugly or makeshift about its appearance; and that overall it is very, very cheap."[204] Also, in the epilogue to his book, *Historic Architecture in Alabama: A Guide to Styles and Types, 1810 – 1930*, Robert Gamble cited the innovation of the Gardendale project as a "hopeful experiment in low-cost housing."[205]

Elbert Hubbell was a vocational instructor at the Turtle Mountain Indian School in Belcourt, North Dakota during the 1930s. He became interested in rammed earth through the study of Patty's work and "not a little by his own surroundings."[206] He grew up the son of a trading post owner and was accustom to earth building. He built a number of rammed earth structures including barns, schoolhouses, and dwellings on the Pine Ridge Indian Reservation. One barn, shown in Figure 80, was very massive. Its walls consisted of a nine-foot tall rammed earth base topped with a six-foot soil-cement block header.

Figure 80. A massive rammed earth barn built on the Pine Ridge Indian Reservation in South Dakota ca. 1935 by Elbert Hubbell. *Photograph from* The Rammed-Earth House *by Anthony Merrill, illustration insert.*

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[204] Ibid, 5.

[205] Robert Gamble, *Historic Architecture in Alabama: A Guide to Styles and Types, 1810 - 1930* (Tuscaloosa: The University of Alabama Press, 1990), 169.

[206] Merrill, *The Rammed-Earth House*, 22.

The Indian School Building at Wanblee, South Dakota, also built by Hubbell, was constructed in 1938. Seen in Figure 81, it was one-hundred and eight feet long by sixty-eight feet wide and was considered the largest rammed earth structure in the U.S. at the time of the publication of Merrill's book in 1947.[207] It contained four classrooms and an auditorium, as well as a kitchen, restrooms and closets.

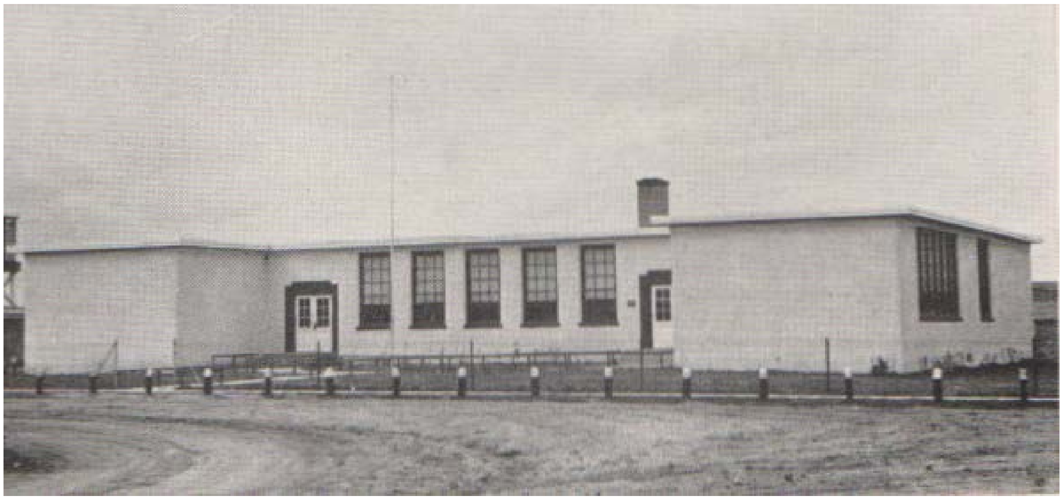

Figure 81. Indian School constructed of rammed earth by Elbert Hubbell in Wanblee, South Dakota in 1938. *Photograph from* The Rammed-Earth House *by Anthony Merrill, illustration insert.*

Another experiment was the North Casper Clubhouse, the front façade of which is shown in Figure 82. Constructed from 1938 to 1939, it was built by the North Casper Improvement Association, a neighborhood organization formed to determine and define improvements to the local area. Goodrich and Krusmark, a prominent Casper, Wyoming architectural firm, designed the building. The National Youth Administration, an agency of the Works Progress Administration, provided the labor for the project. In describing the construction technique, architectural historian Robert Rosenberg wrote, "It was built

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[207] Ibid, 23.

using rammed earth construction, an old European building practice utilized by German-Russians on the high plains of North Dakota in the 1880s." [208] It is one of only a few examples of rammed earth construction currently identified in Wyoming and is on the National Register of Historic Places.

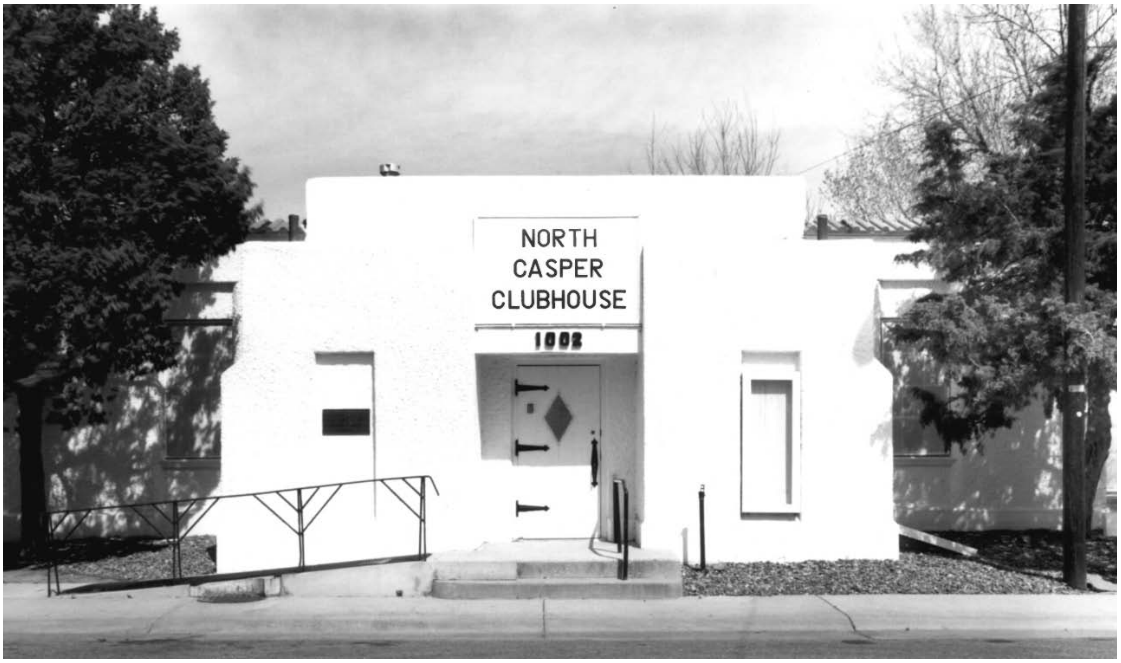

Figure 82. Front façade of the North Casper Clubhouse, Casper, Wyoming, 1939. *Photograph by Richard Collier, April 5, 1993.*

Francis Macdonald, a chemical engineer and rammed-earth builder, performed experiments with adding concrete to rammed earth in an effort to mitigate concerns regarding the integrity of its use in damp environments. He published his results in 1939 in a report titled "Terracrete: Building with Rammed Earth-Cement." To determine the proper amount of concrete to add to the soil, he cited the results of Patty's work in South Dakota and the Portland Cement Association's research on soil-cement mixtures for roads. He determined that the addition of four to eight percent cement to low clay soils

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[208] Rosenberg, "North Casper Clubhouse National Register Nomination," 12.

(those with less than thirty percent clay in the composition) increased the stability and integrity of rammed earth walls.[209] He also warned numerous times of the importance of thorough mixing of the cement with the soil prior to ramming.[210] Merrill reaffirmed Macdonald's recommendation in his publication nearly ten years later.[211]

One final Federal Works Agency project that incorporated rammed earth homes was the Cameron Valley housing development near Alexandria, Virginia. In a similar fashion to Gardendale, Thomas Hibben designed and built some multi-family rammed earth houses for the development using techniques aimed at mass production. He designed a metal formwork system and used compressed air mechanical tampers. The results were unsatisfactory. The metal formwork required a substantial through wall bolt mechanism that left large holes in the walls. This, along with uneven tamping resulting from the use of the mechanical tampers by an inexperienced labor force, led to post-construction erosion of the walls. In addition, experimental coatings used to protect the walls proved inadequate. They sloughed easily and were never repaired.[212]

Frank Lloyd Wright planned a design for seventy-nine homes built of rammed earth for a group of Detroit factory workers. Figure 83 provides concept drawings for the project. The development was to be built on 120 acres at Madison Heights, Michigan on land secured under the organizations name, Cooperative Homesteads. The projected cost of the homes was estimated at $1,700 each. Ultimately only one home was partially

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[209] Francis Macdonald, *Terracrete: Building with Rammed Earth-Cement* (Research Paper, Chestertown, Maryland: Francis Macdonald, 1939), 19.

[210] Ibid, 4, 11, 21, 23, 32-33, and 46.

[211] Merrill, *The Rammed-Earth House*, 37.

[212] Ibid, 29-30.

completed by 1942 when the U.S. entered World War II in earnest. Wright later wrote about the project and hinted at the reason for its demise:

> The drawings and plan of the Cooperative Homesteads are of a low cost scheme for group housing. This berm-type project was begun with the assumption that the work upon the buildings would be done by the Detroit auto workers who intended to live there. It was mainly a drainage and landscape problem. But the times were such that the group could never get together with much effect on progress. The nature of the scheme is apropos to so much of the building problem in our country that it is on record here for what it may be worth.[213]

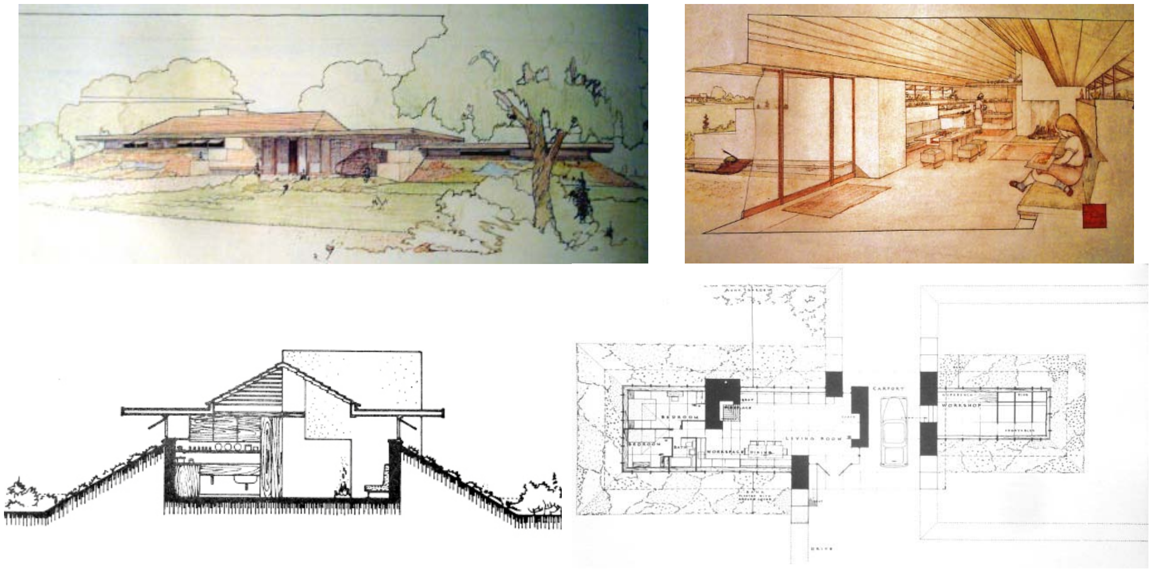

Figure 83. Concept elevation, interior, cross-section and plan drawings for the Cooperative Homestead development planned by Frank Lloyd Wright.[214]

In May 1943, two more bulletins on the use of rammed earth were published. “Bulletin No. 3: Rammed Earth Building Construction” by Howard E. Glenn of the Department of Civil Engineering, Clemson Agricultural College (later Clemson University) and “Publication No. 54: How to Build Your Own Home of Earth” by John

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[213] Cooperative Homesteads, *History of the Cooperative Homesteads - Frank Lloyd Wright Design (unbuilt),* March 28, 2012 (http://www.cooperativehomesteads.com/frank-lloyd-wright-on-cooperative-homesteads-project/), accessed April 22, 2012.

[214] Ibid.

Edward Kirkham of the Department of Civil Engineering, Oklahoma Agricultural and Mechanical College (later Oklahoma State University). Glenn's bulletin was a study of the nature of rammed earth construction and its viability as a low-cost alternative. It documented the building of a test house on the college campus. Kirkham's work was a detailed description of rammed earth block construction from block molds to construction techniques including header designs and framing considerations.

Kirkham prefaced his work by describing the intent of the bulletin. "The object of this bulletin is to stimulate personal initiative in people for building their own homes by showing them how to do the work at a small cost and one they can afford. The author believes the actual building of such a house can be accomplished by the average person if a persistent application of energy and common sense is used."[215]

He introduced the subject by describing his own five-room pisé home built seven years prior to the publication of the bulletin.[216] This single disclosure added much to his credibility. Built around 1935, Kirkham included the cost to construct the building, $887.80.[217] He included photographs of his completed home in the bulletin. Exterior views of which are shown in Figure 84.

Glenn concluded his bulletin by stating, "From the results of these experiments and others it seems to be conclusively proven that rammed earth construction is feasible,

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[215] John Edward Kirkham, *Publication No. 54: How to Build Your Own Home of Earth* (Stillwater, Oklahoma: Oklahoma Agricultural and Mechanical College, Engineering Experiment Station, 1943), 3.

[216] Ibid, 5.

[217] Ibid, 3.

practical, and economical."[218] The significance of these bulletins is less about the information contained within them and more about the acknowledgment that rammed earth was a valid construction technique.

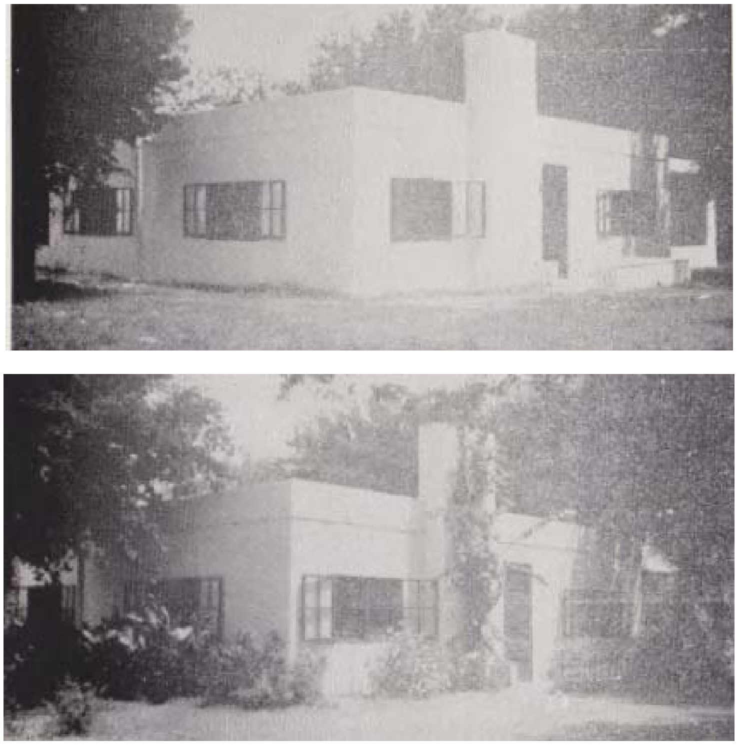

Figure 84. Exterior views of John Kirkham's five-room home near Stillwater, Oklahoma, ca. 1935. *Photographs from "Publication No. 54: How to Build Your Own Home of Earth," page 1.*

Rammed Earth Construction by the U.S. Government During World War II

Eleven rammed earth revetments were constructed during World War II at Edwards Air Force Base, near Kern, California. Two revetment types were designed – one for bomber aircraft and a second for pursuit aircraft. Intended to provide shelter and cover for aircraft in case of an attack from the Pacific, the revetments are among only a few remaining World War II era buildings and structures at Edwards AFB. Six of the

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[218] Howard E. Glenn, *Bulletin No. 3: Rammed Earth Building Construction* (Clemson, South Carolina: The Clemson Agricultural College of South Carolina, Engineering Experiment Station, 1943), 17.

revetments are extant; however, only two were eligible for listing in the National Register of Historic Places, AR-8 and AR-9. AR-8, seen in Figure 85, retains the highest degree of integrity of the bomber revetments, and AR-9, is the only extant pursuit aircraft revetment.[219]

Figure 85. Perspective view of AR-8, a bomber revetment at Edwards Air Force Base near Kern, California built in 1943. *Photograph from Library of Congress, Prints & Photographs Division, HAER CA-308-B-5.*

Post-World War II Rammed Earth Construction Projects – Experiments in Frustration

Anthony Merrill's tome *The Rammed-Earth House* was published in 1947 just after the close of World War II. The first chapter of the book is devoted to the evolution of rammed earth in the U.S. And, as Williams-Ellis had tried to encourage the use of rammed earth for low-cost housing in England post-World Wars I and II, Merrill did

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[219] Historic American Engineering Record, "Edwards Air Force Base, South Base, Rammed Earth Aircraft Dispersal Revetments, Western Shore of Rogers Dry Lake, Boron, Kern County, CA," (Historic American Buildings Survey, Engineering Record, Landscapes Survey, after 1968), http://www.loc.gov/pictures/item/CA3125/ (accessed April 2012, 22).

likewise in the U.S. post the second world war. He extolls the virtues of rammed earth and explains that "in America [rammed earth] is for the man who wants to save money, primarily, and if willing to work to do so, he gains in return not a mass-produced house but a distinctive residence of his own which will reflect his taste and character in its appearance."[220]

As a testament to the diversity of rammed earth and even its use for high-end home construction, Merrill discussed the Millard Sheets home built in 1946 in Claremont, California. A photograph of the front façade and a copy of the floor plan are shown in Figure 86. Designed by H. A. Lamberton and Roy Carlson, Merrill described it as the "fanciest earth house in America."[221]

Merrill also described the tribulations experienced by Sheets in the construction of his home. He cited how the lack of knowledge of rammed earth by Los Angeles County building inspection officials added unnecessary expense to Sheets project. The uneducated bureaucrats forced him to spray Gunite (a concrete spray) on the walls hiding their intrinsic beauty. Merrill pointed out that "[w]hen [Sheets] finished the cost of the combined operation was so high that for the same price he might just as well have made his walls of reinforced concrete."[222]

David and Lydia Miller were initially introduced to the concept of rammed earth construction after reading an article by Dr. Ralph L. Patty in the August 1938 issue of *American Home Magazine*. This is when they first began to research rammed earth and adobe wholeheartedly. They credited much of their initial exploration to Patty's bulletin,

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[220] Merrill, *The Rammed-Earth House*, 33.

[221] Ibid, 28.

[222] Ibid, 28.

"Rammed Earth Walls for Farm Buildings" and a bulletin by J.D. Long titled "Adobe Construction."[223]

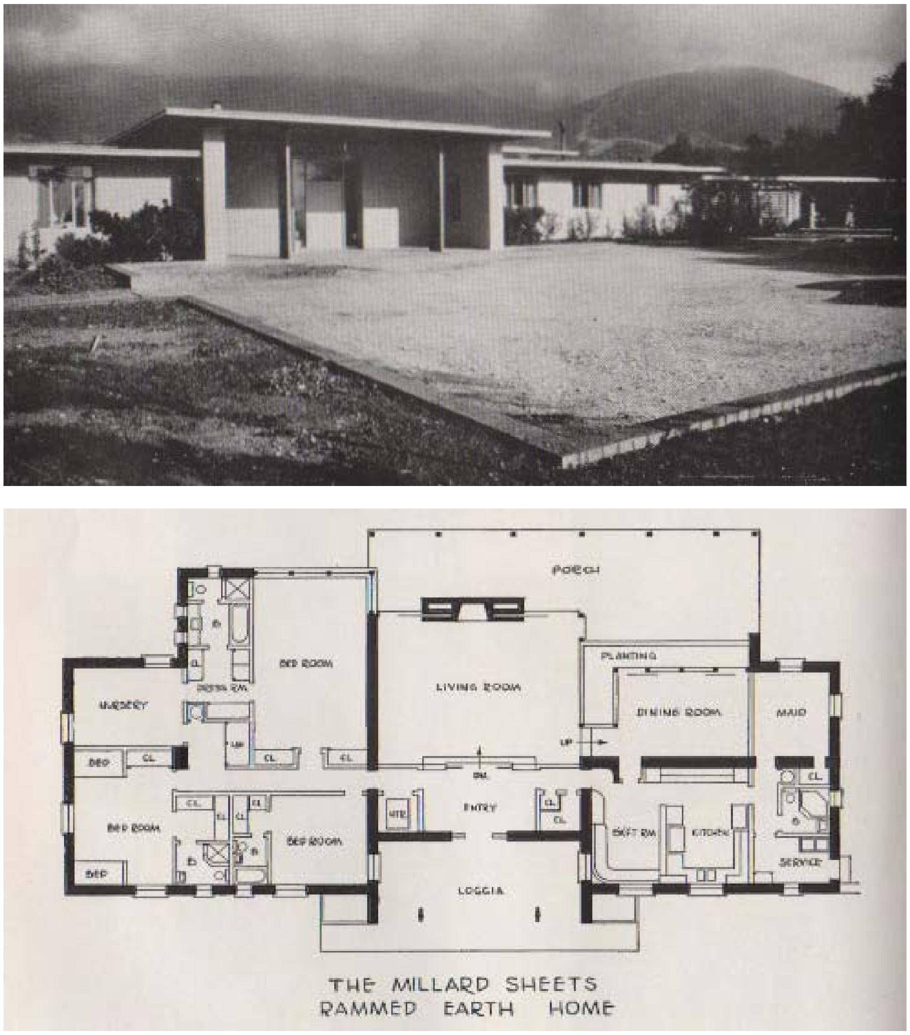

Figure 86. The Millard Sheets Home front façade and floor plan, Claremont, California, 1946. High-end homes designed of rammed earth were discussed by Merrill. *Photograph and drawing from* The Rammed-Earth House *by Anthony Merrill, illustration insert.*

Not long after their introduction into rammed earth, the Millers moved from Greeley, Colorado to Germany where David served as a lawyer in Nuremberg after

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[223] Lydia A. and David J. Miller, *Rammed Earth: A Selected Bibliography with a World Overview* (Greeley, Colorado: Rammed Earth Institute International, 1982), 7.

World War II. While in Germany, they continued their education in rammed earth architecture including visiting a number of locations and chronicling what they saw.[224] In 1945, after returning to Greeley, they decided to build homes of rammed earth on Lydia's family farm. They named the development Alles Acres after Lydia's father. The Millers built five homes at Alles Acres.

J. Palmer Boggs was the architect-engineer who planned the homes for the Millers. Boggs designed with the same guiding principal as Mies van der Rohe, "Form follows function." He prided himself in the simple, honest, and lifestyle-conforming schemes he developed for the Miller homes. All of the Miller homes were built without basements and "without a single stair step anywhere."[225] Each design was about 1,300 square feet, with fourteen to sixteen inch thick walls, and incorporated radiantly heated concrete floors. The homes were "oriented to the south-southeast for optimum solar benefits…with windows to the garden and the sun, and facing away from the street."[226] They were built on estate-size lots to allow for individual gardens to aid in owner self-sufficiency.

The Millers developed their own rammed earth formwork system, shown in Figure 87, based on a design developed by Boggs. Boggs felt that the designs of their homes required a form system that allowed the walls to be built as complete full-height sections. "Boggs designed a new form that could be put up in lifts like a commercial

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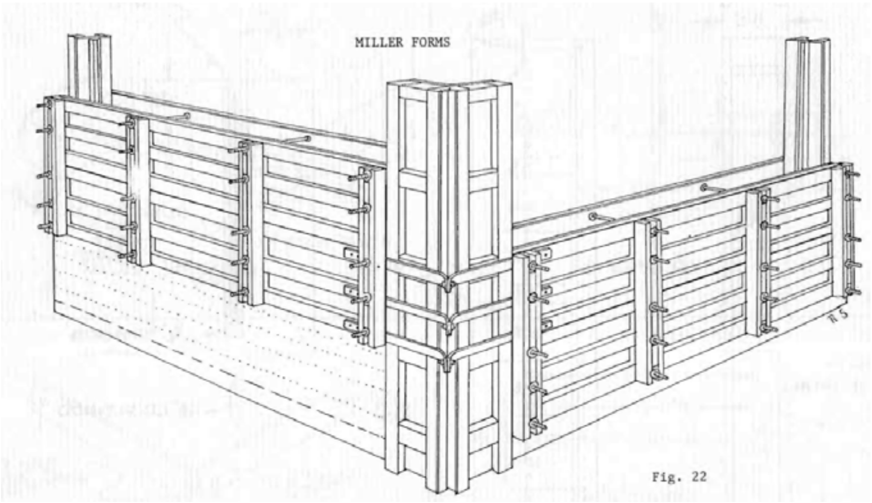
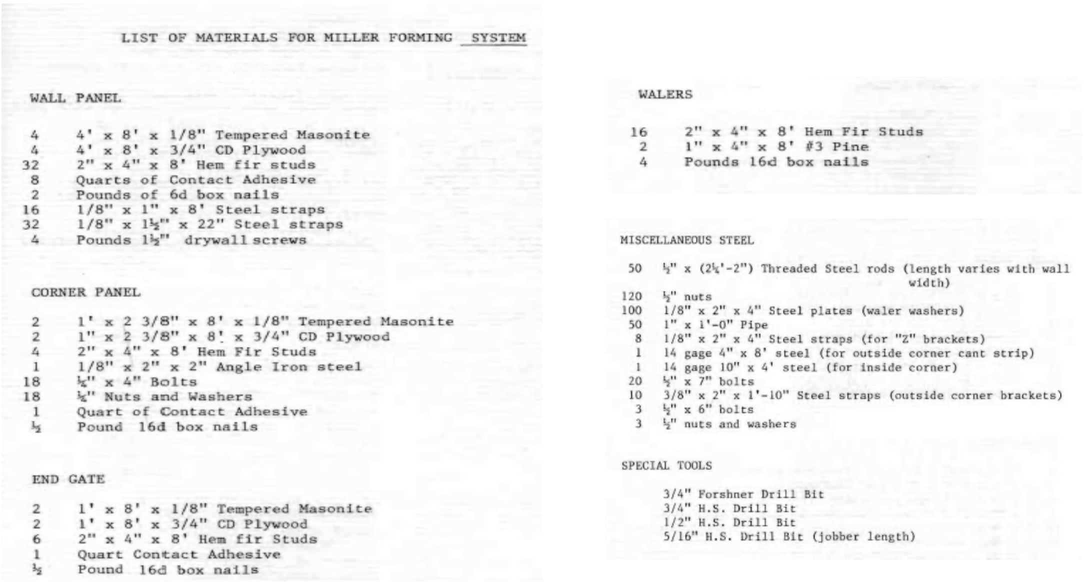
[224] Lydia A. and David J. Miller, *Manual for Building a Rammed Earth Wall*, 50-52.

[225] Ibid, 9.

[226] Ibid.

concrete form, to complete an entire wall section at one time."[227] Boggs's design merged traditional rammed earth processes with modern concrete construction techniques.





LIST OF MATERIALS FOR MILLER FORMING SYSTEM

WALL PANEL

4	4' x 8' x 1/8" Tempered Masonite
4	4' x 8' x 3/4" CD Plywood
32	2" x 4" x 8' Hem fir studs
8	Quarts of Contact Adhesive
2	Pounds of 6d box nails
16	1/8" x 1" x 8' Steel straps
32	1/8" x 1½" x 22" Steel straps
4	Pounds 1½" drywall screws

CORNER PANEL

2	1' x 2 3/8" x 8' x 1/8" Tempered Masonite
2	1" x 2 3/8" x 8' x 3/4" CD Plywood
4	2" x 4" x 8' Hem Fir Studs
1	1/8" x 2" x 2" Angle Iron steel
18	½" x 4" Bolts
18	½" Nuts and Washers
1	Quart of Contact Adhesive
½	Pound 16d box nails

END GATE

2	1' x 8' x 1/8" Tempered Masonite
2	1' x 8' x 3/4" CD Plywood
6	2" x 4" x 8' Hem fir Studs
1	Quart Contact Adhesive
½	Pound 16d box nails

WALERS

16	2" x 4" x 8' Hem Fir Studs
2	1" x 4" x 8' #3 Pine
4	Pounds 16d box nails

MISCELLANEOUS STEEL

50	½" x (2½'-2") Threaded Steel rods (length varies with wall width)
120	½" nuts
100	1/8" x 2" x 4" Steel plates (waler washers)
50	1" x 1'-0" Pipe
8	1/8" x 2" x 4" Steel straps (for "Z" brackets)
1	14 gage 4" x 8' steel (for outside corner cant strip)
1	14 gage 10" x 4' steel (for inside corner)
20	½" x 7" bolts
10	3/8" x 2" x 1'-10" Steel straps (outside corner brackets)
3	½" x 6" bolts
3	½" nuts and washers

SPECIAL TOOLS

3/4" Forshner Drill Bit
3/4" H.S. Drill Bit
1/2" H.S. Drill Bit
5/16" H.S. Drill Bit (jobber length)

Figure 87. The Miller formwork design with materials list. *Drawing and list from manuscript of* Manual for Building a Rammed Earth Wall *by Lydia A. and David J. Miller, pages 36 to 38. University of North Colorado archives.*

The Millers documented their designs and, after becoming world renown because of their exposure in *Mother Earth News* magazine, organized the Rammed Earth Institute

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[227] Ibid, 21.

International in 1981.[228, 229] The intent of the organization was to promote rammed earth development in the United States.

One of the Miller homes was featured in an article about the rammed earth process in the journal *Architectural Forum* in December 1946. Figure 88 shows the front façade and plan for the house. The design incorporated floor-to-ceiling fenestration with louvered ventilation panels on the southeast and southwest sides. Solid rammed earth walling was built on the northeast and northwest sides. By taking advantage of the interior wall designs of story-high cases, a large amount of built-in storage was designed into the house, as well.[230]

Blissfully ignorant of the concerns cited by Thomas Jefferson and others regarding the viability of rammed earth in harsh northeastern winters, Lester and Margaret Clarke of South Lee, Massachusetts began building their rammed earth home in 1948. They used information obtained from "government publications and other literature…including a report on studies carried out by South Dakota State College in the 1930's."[231] The build process took them three years but they completed all of the work themselves.

The Association for Preservation Technology documented their home in 1983, thirty-two years after construction. As seen by the photograph in Figure 89, the house was in excellent condition even after so many northeastern winters proving that rammed

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[228] Easton, *The Rammed Earth House*, 20.

[229] Lydia A. and David J. Miller, *Rammed Earth: A Selected Bibliography with a World Overview*, 7.

[230] "Products and Practice: Rammed Earth," *Architectural Forum* 85, no. 6 (December 1946), 149.

[231] Morgan Phillips, "A Rammed Earth House in Massachusetts," *Bulletin of the Association for Preservation Technology* 15, no. 2 (1983): 33.

earth construction was viable where “ ’nor’easters and freeze-thaw cycles wreak havoc even with Portland cement concrete.”[232]

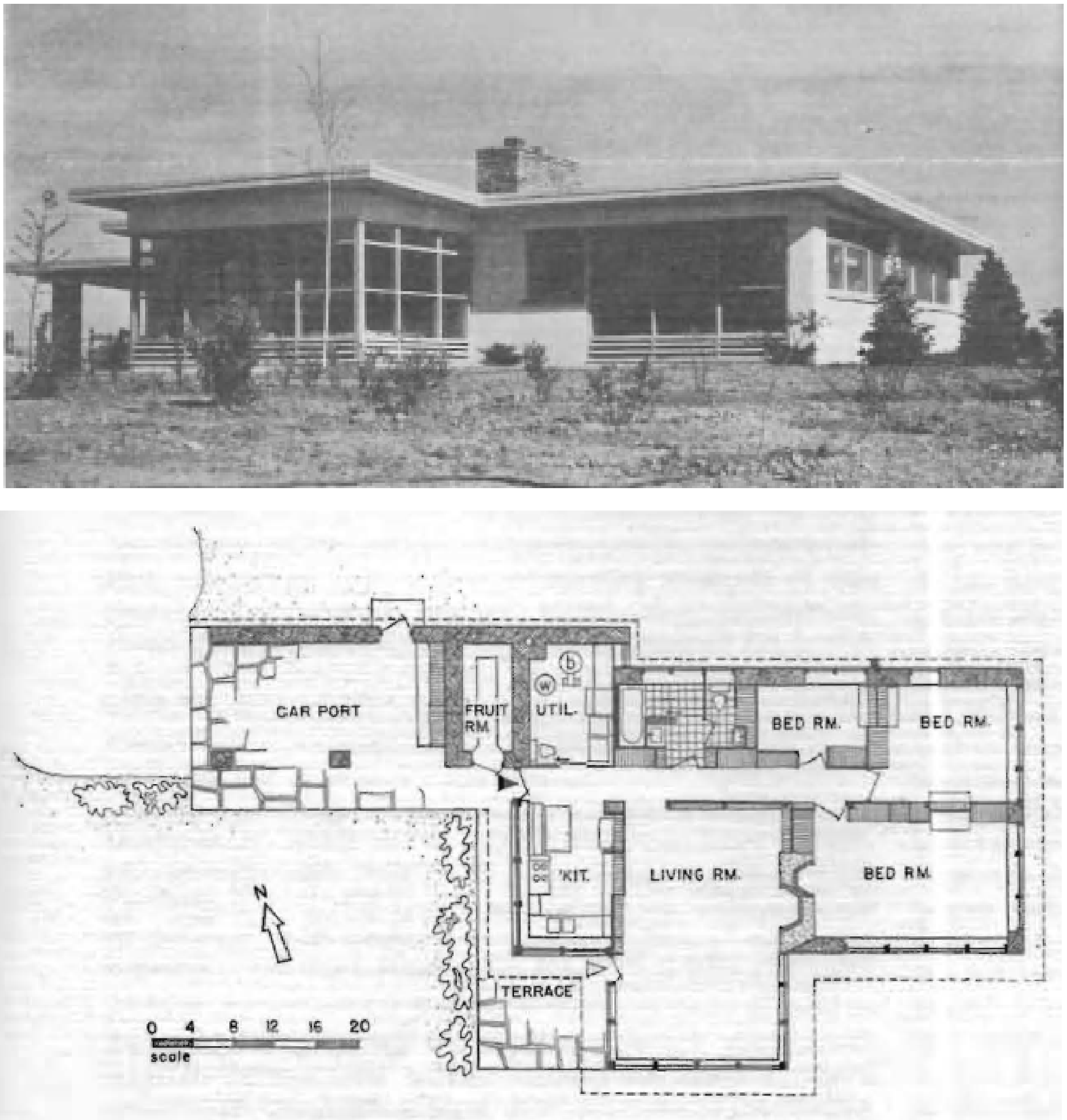

Figure 88. A Miller House from the Alles Acres development, Greeley, Colorado, 1946. *Photograph and drawing from* Architectural Forum *article “Products & Practice: Rammed Earth,” pages148 and 149.*

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[232] Ibid.

Figure 89. Lester and Margaret Clarke's Home in the Bershire Hills of western Massachusetts, 1951. Documented in 1983, it had survived thirty-one harsh northeastern winters without failing. *Photograph from* Bulletin of the Association for Preservation Technology *article "A Rammed Earth House in Massachusetts," page 35. Photograph 1983.*

Barriers to Rammed Earth Success

Rammed earth as a mainstream building technique within the U.S. seems far from possible. Even in areas where its use is both practical and obvious, it is seldom considered or openly ignored. There are several reasons for this:

- The initial attitude of Thomas Jefferson and the perceived abundance of natural resources our ancestors found on this continent.
- Political influences of manufactures of building materials, the railroad and other special interests including those that preclude it from being incorporated into building codes.
- The association of earth architecture as housing for the poor immigrant farmer, the unsuccessful, or the non-progressive.

In the early 1800s, Thomas Jefferson never took the use of rammed earth seriously for two reasons that seem to plague it to this day. Natural resources in the form of forests and land were available in abundance in the U.S. In addition, the moist climates to which he was very familiar seemed antithesis to using dirt to build homes and other structures. Even those that advocated for its use relegated it to agricultural and farming areas, and slave quarters. Few saw it as a housing solution for towns and cities even though Cointereaux promoted it as a fireproof building technique. It is interesting to speculate what might have been if Washington, D.C. had been built of rammed earth when the British invaded in 1812 and destroyed the city.

As shown in this paper, rammed earth was used in this country at different times throughout the 1800s and into the early twentieth century by immigrant farmers and natural born Americans. It even seemed to achieve a place in the architectural ethos when it was documented by the USDA in the 1920s and when it became the subject of numerous studies conducted in the 1930s. However, as Anthony Miller pointed out in his 1947 book, *The Rammed-Earth House*, rammed earth construction had few supporters in the building trade. Merrill drew attention to the political influences that seemed to hinder its use as a workable building technique:

> Rockwell King DuMoulin, writing in a consumer magazine, summarized the opposition's reasoning very shrewdly. He pointed out that there is no profit to anyone in rammed-earth except the man who is going to live in the house and for that reason no industry has seen fit to publicize the method.
>
> What Mr. DuMoulin, an architect and a student of rammed-earth, didn't touch upon except indirectly is the fear and ignorance of the masonry and lumber producers who will instinctively fight any building method that is "free." All that the brick and lumber people see when they hear the phrase "rammed-earth" is a big flashing neon sign which reads,

> FREE WALLS, AMERICA, COME AND GET IT! and that thought is enough to ruin a brick manufacturer's nervous system.[233]

In his Master's project on rammed earth use in Colorado, Michael Shernick speculated on the impact the brick lobby may have had on the use of alternative building materials during the early days of settlement:

> Interestingly, in the late 1870s, Denver passed ordinances that specifically forbade the use of adobe bricks. Bricks for construction were required to be 8-1/4 x 4-1/4 x 2-1/4 inches in size and had to be kiln fired. Shortly thereafter, the Robinson Brick Company formed in 1880. By the 1920s the Denver/Golden area, with large clay deposits, had over 20 brick manufacturers. While not confirmed by research, it is possible to surmise that these ordinances against using adobe were passed due to successful lobbying of Denver government by brick industry interests, ultimately resulting in the Robinson Brick and Golden Brick companies being some of the largest brick manufacturers in the nation.[234]

The industrial revolution and expansion the U.S. experienced in the 1800s would not have been possible without the development of the transcontinental railroad. Much of the impetus behind the railroad was the transport of lumber for construction. Those that benefited from this massive growth would not have wanted a local dirt home solution to the housing crisis.

After World War II, the U.S. government seemed to turn its back on rammed earth when the country experienced another major housing shortage. Lydia and David Miller described the frustration they faced when trying to obtain FHA or VA loans for rammed earth construction:

> In 1945 when we attempted to get approval from F.H.A. and or V.A. for a rammed earth project we were unable to accomplish anything. We finally got financing from a local savings and loan association. All the Miller homes have been financed and refinanced at various stages of

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[233] Merrill, *The Rammed-Earth House*, 19.

[234] Michael Shernick, *Front Range Earth Architecture: Why and Why Not?* masters project, (Denver: University of Colorado, 2009), 3.

> construction, and sale. Lenders on the five homes have included savings and loans associations, commercial banks, and insurance companies.[235]

This lack of support was most likely attributed to political pressure from those that saw little profit in earth architecture.

Lack of knowledgeable of its structural integrity and a limited skilled labor pool from which to draw add other barriers to the use of rammed earth for construction. Lack of knowledge lead to costly mistakes. That is, building codes that do not support earth construction can drastically affect construction costs. In describing Millard Sheets' experience with untrained inspectors in the construction of his Claremont, California home, David Easton, pointed out the high cost of ignorance:

> When [Sheets] was first building the house, a skeptical official at the local building department insisted that the walls be encased with a structural concrete jacket, adding significantly to the cost of the project. Years later, a contractor undertaking some remodeling work had the chance to see how unnecessary this supplemental coating had been. While attempting to cut a doorway through the rammed earth wall, he found the rammed earth interior every bit as hard and durable as the concrete 'skin.'"[236]

This lack of understanding directly affects the costs of testing earth construction for building safety and integrity, as well. The result is tests that are complicated and expensive.[237] For example, while special consideration must be given to earthquake hazards, if building codes incorporated rammed earth construction, the cost of verifying earthquake safety would be very lower. Other considerations that could be mitigated through inclusion are design standards that protect foundations and potentially vulnerable

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[235] Lydia A. and David J. Miller, *Manual for Building a Rammed Earth Wall,* 45.

[236] Easton, *The Rammed Earth House*, 19.

[237] Oliver, "Earth as a Building Material Today," 32.

walls against flooding hazards in wet regions or erosion prevention and protection from attacks by termites or other insects in dry climates.

A less analytical and more emotional barrier is the counter-culture stigma that is associated with earth construction. It was traditionally used by “fringe” society for such entities as slave housing, plantation outbuildings, homesteading, housing for the poor, immigrant housing, and as a symbol in the 1970s of back-to-nature living. Generally considered a low-cost housing alternative, there have been few exceptions to its use as a middleclass, middle America, home style.

Finally, earth construction is considered moving backward, not forward. As Paul Oliver explained in “Earth as a Building Material Today:”

> ..for much of the world the renaissance of earth as a building material is a meaningless concept, in that mud construction, in one of its forms, is still the customary method of building. But the influence of Western architecture, and the status given in the developing countries to the use of modern materials has led to widespread dismissal of the old methods. Concrete, steel frame construction and plate glass have all acquired prestige, even if they are expensive, unnecessarily used and climatically inappropriate.[238]

Overcoming the Barriers

Knowledge is key to overcoming the barriers to rammed earth. Lessons learned from the past help to ameliorate concerns regarding long-term viability. An analysis of extant buildings such as the Humphrey House, the Church of the Holy Cross, and the homes of Gardendale and Alles Acres help to alleviate concerns regarding reliability and integrity. As concerns over the impact of our carbon footprint and the consideration of embodied energy come into play, rammed earth construction takes on a certain appeal.

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[238] Ibid.

Leveraging modern practices for soils analysis methodologies, concrete forms ingenuity, and better tools aid in lowering the cost of testing buildings. Lastly, overcoming the counter-culture stigma may fall away by virtue of the use of rammed earth in high-end homes.

The next chapter addresses why preservation of rammed earth buildings is important and needed. It also describes the ways in which rammed earth can degrade or deteriorate. Finally, it includes a section on how to sensitivity repair damaged rammed earth and discusses some considerations for adaptive reuse.

CHAPTER V

THE IMPORTANCE OF RAMMED EARTH FROM AN HISTORIC PRESERVATION PERSPECTIVE

The importance of historic preservation is voiced by O.G. Ingles in his article, “Impressions of a Civil Engineer in China,” for *The Australian Journal for Chinese Affairs*. “It was pleasing to note the attention now given to the preservation of important legacies from the past. The labour [sic] of so many millions over so many thousand years has not been forgotten and passed over, but forms a real part of the daily life, and a constant challenge to today's citizen to add his own contribution to a better future.”[239] John Warren agrees with Ingles and expands on his idea in the introduction to his book *Conservation of Earth Structures*. Warren states, “[O]ne fundamental purpose…is the retention of the fabric which meets the deep psychological needs of those who inherit it and pass it on. An allied purpose…is the retention of a culture.”[240]

Preservation of rammed earth technology is needed to keep the record. Few rammed earth buildings are on the National Register of Historic Places. While its history in the U.S. may seem to some less relevant than log cabins, Craftsman homes, or Victorian-era estates, it does hold a place in our past. Its very existence in this country shows the distribution of technology and ideas across continents in the same manner as log cabins showed a connection to Europe.[241]

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[239] O.G. Ingles, “Impressions of a Civil Engineer in China,” 144.

[240] John Warren, *Conservation of Earth Structures* (Oxford: Butterworth-Heinemann, 1999), xiii.

[241] Richard Pieper, “Earthen Architecture in the Northern United States: European Traditions in Earthen Construction,” *Cultural Resource Management* 22, no. 06 (1999): 30.

Its use in agricultural settings is an added dimension to its place in our history. Not considered particularly valuable (in fact, it was considered particularly cheap), it has held a certain distinction and even some curiosity. Its allure is in its practicality. Keeping the historic record means keeping the knowledge alive. Most interestingly, in eras when energy becomes scare, rammed earth comes into its own. To study the historic record of rammed earth structures in the U.S. is to study the art of long-term sustainable design.

This chapter discusses the maintenance and repair of rammed earth structures from the perspective of the historic preservationist. The chapter begins with a discussion of the historic preservation goals of the particular project under consideration. Next, the chapter focuses on what causes deterioration of rammed earth buildings. One of the most important aspects of rammed earth repair is an understanding of the materials used in the original construction. To this end, a description is provided of the ways in which to determine the composition of the earth used in the building. This includes field tests, laboratory tests, and regional context. The chapter concludes with general recommendations for sensitive repairs and maintenance guidelines as preventative measures against natural deterioration and destructive forces.

Rammed earth is somewhat unique in the class of earth architecture in that it can be monolithic as well as segmented in form. This chapter concentrates on rammed earth maintenance and repair. The maintenance and repair of other forms of earth architecture, for example, cob, adobe, or wattle and daub, are not specifically discussed unless the particular repair method overlaps with one of these other earth architecture forms.

Preservation of rammed earth has been given limited attention in the preservation bulletins provided by the Technical Preservation Services office of the Heritage Preservation Services Division of the National Park Service, U.S. Department of the Interior. Only one bulletin mentions rammed earth. Anne Grimmer refers to it in "Preservation Brief 22: The Preservation and Repair of Historic Stucco" when she is discussing common terminology related to render and coatings.[242] There is one bulletin, "Preservation Brief 5: Preservation of Historic Adobe Structures," dedicated to adobe. Some of the preservation maintenance and repair techniques described in this bulletin are amendable to rammed earth structures.[243] This bulletin is used a reference in this thesis for repair considerations of rammed earth.

Hugo Houben and Hubert Guillaud point out in *Earth Construction: A Comprehensive Guide* that conservation of structures made of raw earth requires delicacy. Appropriate restoration treatments for raw earth sometimes require techniques that are incompatible with those suited to other material types. To exemplify, they explain that problems can occur if an impenetrable render is used as this type of render can cause chronic damp. They caution that know-how of proper restoration methods for

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[242] Anne Grimmer, "Preservation Brief 22: The Preservation and Repair of Historic Stucco," *Technical Preservation Services, Preservation Briefs* (Washington, D.C.: Technical Preservation Services, Heritage Preservation Services Division, National Park Service, U.S. Department of the Interior, 1990), 2.

[243] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings," *Technical Preservation Services, Preservation Briefs,* August 1978, http://www.nps.gov/history/hps/tps/briefs/brief05.htm (accessed May 12, 2012).

earth structures is an imperative when performing restoration and maintence on this structure type.[244]

Considerations Before Beginning Any Restoration Project

The particular goals of the project, along with the buildings condition, determine the methods used for preservation or restoration. As Houben and Guillaud explain, three key questions must be addressed when planning the restoration methodology:[245]

- How much intervention is adequate?
- Is modification of the environment surrounding the project needed?
- How much expertise is required for the project?

If the goal of the conservation of the site is to maintain its current state regardless of its condition, that is, without transformation of its appearance in any way, then the preservation effort will concentrate on protection techniques such as the provision of shelter or stabilization. The roof structure over the Great House at Casa Grande Ruins National Monument is an example of this technique.

If it is determined that the cause of deterioration or decay of the building to be preserved is the result of problems in the surrounding environment, then the environment needs modifications. For example, if standing water near the base of the structure is causing damage, then grading of the soil surrounding the building is required.

If it is determined that the goal of the project is either partial or full restoration of the building to its original appearance, then any demolition and reconstruction techniques

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[244] Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide* (London: Intermediate Technology Publications, 1994), 301.

[245] Ibid.

must be completed with great care and technical competence to insure that the methods implemented do not cause further decay or disfiguring of the building. The restoration of Fallingwater in Pennsylvania is an example of this consideration.

Once the goals of the project are defined, then the restoration methodology can be determined and planned. For rammed earth structures, the plan cannot be established without an understanding of the causes of the deterioration.

Causes of Rammed Earth Wall Deterioration

This section discusses the causes of rammed earth wall decay exclusive of catastrophic events such as earthquakes or flooding. There are four basic causes for the deterioration of rammed earth structures: [246]

- Water penetration
- Plant growth
- Destruction by humans or animals
- Damage caused by wind

The remainder of this section discusses the causes and effects of each of these destructive forces in more detail.

Water becomes a destructive force to rammed earth when protective measures such as renders, coatings or damp courses are compromised. As moisture penetrates the earth wall, the volume of the wall varies resulting in different modes of wear. These modes of wear are exacerbated by the cyclical nature of the problem. That is, the more the wear, the more moisture that is able to breach the wall causing even more damage.

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[246] Warren, *Conservation of Earth Structures*, 75-87.

Protective coatings are normally applied to rammed earth structures built in areas with expected high moisture content. Compromise of the coatings occurs for one of two reasons: particle decay of the surface coating or incompatibility between the coating's measures of strength and elasticity with the underlying earthen structure. Examples of particle decay include the erosion of mud render, the dissolving of limewash, the cracking of lime or mortar render, the peeling away of tar or paint, and the complete detachment of brick or tile elements.[247] Incompatibles as a result of different strengths of materials, elastic properties, or thermal responses between the protective coating and the rammed earth base structure result in the detachment of the protective shell from the core. The protective coating depends on the earth structure for its structural support. Without this, the coating weakens and will eventually facture admitting the water it was meant to protect against.

The compromise of damp courses is most often the result of deterioration of the roof structure or building foundation. These are usually the result of poor or lacking maintenance either of the building itself or of the building's surroundings.

Once water has breached the wall, its destructive effects become visible. Water damage usually occurs top-down or bottom-up. The erosion of earth material as water sheets down the wall forms fissures and runnels. Undercut of the wall occurs from water absorption at the wall base.

As water runs down a rammed earth wall, the crystal bonding structures between the clay and aggregate are broken down. Once compromise of the crystalline structure on the surface of the rammed earth wall occurs, the resulting friable material is sloughed by

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[247] Ibid, 75.

drying winds and follow-on rains. Runnels and fissures, such as those seen in Figure 90, result in areas of the wall where the water run-off is concentrated.[248]

Figure 90. Example of runnels and fissures. Note the failed roof structure. *Photograph from* Terra Britannica *edited by John Hurd and Ben Gourley, page 14.*

Water absorption through the base of a rammed earth wall, called rising damp, can result in either saturation of the surface soil or efflorescence. The effect of saturation is the decay of the soil structure as seen in Figure 91. Efflorescence results when salt deposits form as the absorbed water dries leaving behind ions that coalesce into salt structures. The salts break apart the soils causing decay of the soil structure. In either case, the decayed material is subsequently eroded by wind leaving a cavity at the wall base. Shown in Figure 92, this effect is called coving.[249] Continued erosion undercuts

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[248] Ibid, 78.

[249] de Teel Patterson Tiller and David W. Look, “Preservation Brief 5: Preservation of Historic Adobe Buildings.”

the wall. If the undercut is severe enough, the wall collapses, unable to hold its weight.[250]

Figure 91. The effect of rising damp. Either there was never a damp course or the damp course failed. *Photograph from* Conservation of Earth Structures *by John Warren, page 147.*

Interestingly, the freeze-thaw cycle of winter generally has little effect on rammed earth structures. This is because in most areas where freezing and thawing cycles are common, the winter humidity is low. The formation of ice crystals within the wall occurs when the wall is close to reaching saturation, that is, when there is significant moisture in the air. This is rare in low-humidity environments.[251]

Figure 92. Coving at the base of an adobe wall. *Photograph from* "Preservation Brief 5: Preservation of Historic Adobe Buildings." *Photograph from NPS files.*

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[250] Warren, *Conservation of Earth Structures*, 79.

[251] Ibid, 82.

Harm from plant growth occurs differently depending on whether the plant has a root system or not. Plants cause harm to rammed earth walls in one of two ways, either by burrowing into the wall or through causing decay on the wall surface. Plants with root systems cause damage as the roots penetrate the soils and expand compromising the integrity of the wall structure. Furthermore, roots inject moisture into the wall, which can cause water-related damage.[252] Once the plant dies away, a tunnel remains. Within the tunnel is leftover organic material that attracts insects and other pests, which result in more damage.[253]

Plants such as lichens, mosses, fungi, and algae cause a different type of damage by breaking down the interlocking bonding structure of the earth components on the surface of the wall. In addition, the acids formed by the breakdown of the plant matter cause the chemical structures of the clay particles in the soil to change. The effect of this type of plant damage is the erosion of the surface as the compromised soil becomes powder-like and is sloughed by wind or rain.[254]

Human damage can be unintentional or intentional. Improper design or construction techniques such as not incorporating design elements that minimize water damage or not using appropriate damp proofing techniques can have unintentional consequences. The only means to mitigate this is through awareness, knowledge and understanding of how rammed earth structures function. Other unintentional human damage is caused by everyday use. For example, wall contact that results in rubbing

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[252] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

[253] Warren, *Conservation of Earth Structures,* 82.

[254] Ibid.

away of the surface. Leaning a bicycle against a wall can cause surface scaring as can the planting of trees and vegetation too close to the wall.

Purposeful human harm is usually the result of intentional defacement. Exemplified by the scavenging of artifacts at Casa Grande and the resulting devastation to the structure, Figure 93 shows the systematic destruction of the fabric of the Great House between 1853 and 1902 when federal protect was first granted to the site.[255]

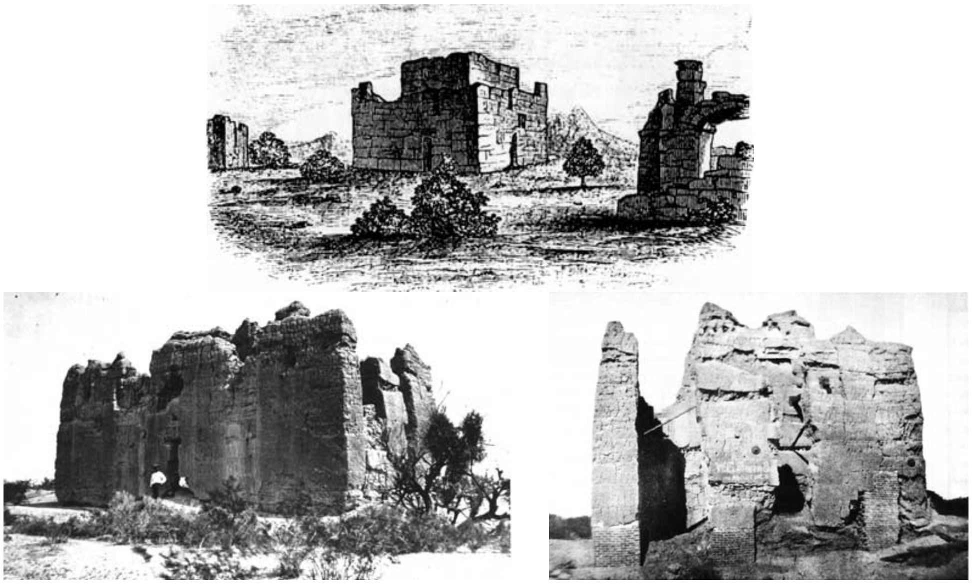

Figure 93. Destruction of Casa Grande caused by looting. *Counterclockwise from the top: 1853 drawing by Brantz Mayer of the Great House with other structures surrounding created soon after the rediscovery of the ruins; 1878 photograph of the Great House with some destruction visible; 1902 photograph shows the results of massive looting. Images from* Casa Grande Ruins National Monument, Arizona: A Centennial History of the First Prehistoric Reserve 1892 – 1992 *by A. Berle Clemensen, pages 12, 20, and 25.*

Warren relates a story that shows how human innovation led to intentional damage to and loss of rammed earth structures in France during the reign of Napoleon. It was discovered that saltpeter, used in gunpowder, is made when animal waste leeches

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[255] A. Berle Clemensen, *Casa Grande Ruins National Monument, Arizona: A Centennial History of the First Prehistoric Reserve 1892 – 1992,* 15.

through rammed earth walls. Many structures were compromised when people scraped down the walls of rammed earth barns and animal pens to obtain this valuable commodity, a practice that was sanctioned by the Napoleonic regime.[256]

Unlike the damage caused by humans, animal damage is instinctual. Animal damage is caused by insect invasion, varmint attacks and, as with humans, simple wear and tear. Most animal damage is controllable through proper maintenance and repair. However, there are destructive insect invaders such as carpenter ants and termites, which not only compromise the earth, but also attack embedded timbers. The results can include the loss of bearing capacity of the rammed earth structure, triggering the collapse of the roof or walls.[257]

The destruction caused by wind is less related to erosion than to water evaporation. Wind effects on rammed earth walls include: the compromise of coatings resulting from large fluctuations in wall moisture content caused by cycles of wet followed by drying winds; erosion of wall surfaces caused by the sandblasting effect of wind-borne particles; and, the sloughing of friable wall surfaces by blowing rain. Large fluctuations in water content, up to fifteen percent by weight, cause wide variations in the expansion and contraction of the earth walls resulting in cracking of protective coatings. Blowing dust and driving rain can aggravate surface areas where powdering has occurred causing surface erosion, runnels and fissures.

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[256] Warren, *Conservation of Earth Structures,* 85.

[257] Ibid.

Understanding Rammed Earth Wall Composition and Build Structure to Aid in Determining the Proper Repair Method

The original composition of the materials used to build the rammed earth structure must be understood for its proper repair. Often, simple field tests can determine the makeup of the materials. The performance of more extensive laboratory testing is also possible. The particular intent of the repair or renovation determines the extent of the testing that is required.

Table 10, derived from information in Chapter 5 of *Conservation of Earth Structures*, provides a list of simple field tests.[258]

Table 10. Simple Field Tests to Determine Material Composition of Earthen Structures

Test	Test Description
Feel to determine moisture content	Crumbles to a powder (very dry) to amorphous liquid mass (very wet)
Feel to determine composition of sand, clay and silt	Relative grittiness for sand when rubbed between the fingers Slipperiness of moistened sample for clay Slightly gritty sensation on teeth when tasted for silt
Visual inspection – clay color	Clay color aids in determining the mineral content of the soil. Clay colors range from blue-gray to gray-green to yellow to white. Color can also range from browns to reds based on the amount of iron in the soil.
Visual inspection - surroundings assessment	Type of vegetation in the vicinity of the structure can help determine the pH value of the soil.
Smell	Of limited value, this test helps to determine if organic components are present or if the soil originated in anaerobic conditions.

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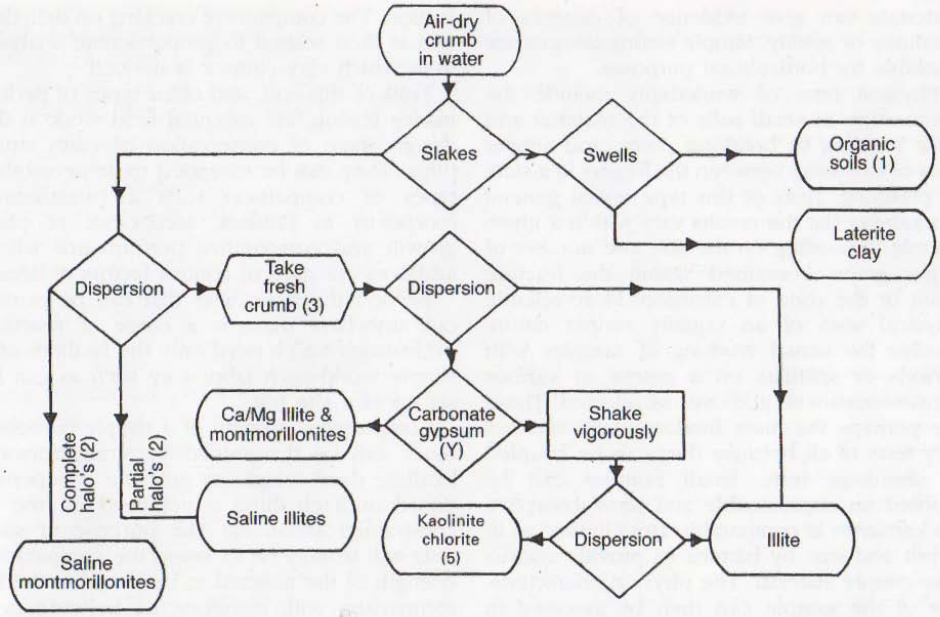
[258] Ibid, 99 – 100.

Along with the tests described above, an aqueous test, also known as the Emerson Test, can be performed in the field to determine clay type. Performed on small, air-dry samples of material (usually one-half inch cubes), the test is designed to breakdown the composition of the soil in stages. Figure 94 is a flow graph of the test process. What follows is a description of the Emerson Test.



(1) If the crumbs are not air-dry at first immersion, the scheme is still valid, but this category will contain the non-saline illites and montmorillonites as well as organic soils.

(2) Dispersion is most readily detected by the formation of fine misty halo's around each crumb, easily visible against a dark background. The more pronounced the halo, the more dispersive the soil.

(3) Take fresh crumbs and moisten, remould lightly, and immerse,

(4) The presence of carbonate, if not already recognized, can be readily verified by effervescence in the soil when a drop of acid is placed on it.

(5) Settling to a clear supernatant liquid in less than 10 minutes is to be regarded as non-dispersion.

Figure 94. The Emerson field test procedure determines the chemical composition of soil in the field. *Flowchart from* Conservation of Earth Structures *by John Warren, page 101.*

A material sample, placed in a see-through container, is covered with distilled water and softly shaken. If the sample swells without collapsing, it is most likely a lateritic. Lateritic soils contain iron and aluminum. They are often red in color because of the iron oxide in the soil. If the sample swells and then disperses, it is smectite, a clay mineral. That is, the material is composed of illite and montmorillonite components.

The composition of the illite and montmorillonite constituents in a smectite sample can be estimated by looking at the immersed sample against a dark background. A halo of particles around the sample indicates the presence of montmorillonites; the larger the halo, the more montmorillonites that are present. The presence of organic material, iron salts, hydroxides, chlorites, and carbonates is determined based on pH testing of the sample.

The presence of kaolinites and chlorites is determined by vigorously shaking a sample in distilled water until it has completely dispersed, then leaving it to rest for ten to fifteen minutes. After this time, examination of the sample determines if the material is still in suspension. Smectites remain in suspension for longer than ten to fifteen minutes, kaolinites and chlorites do not.[259]

Other field tests determine the presence of carbonates, organic material, and alkalinity or acidity of the soil. If a sample immersed in a hydrochloric acid solution effervesces, carbonates are present. The presence of organic material is determined by placing a sample in a limewater solution for forty-eight hours. After this time, the sample is shaken and the solution is allowed to resettle. A dark tint to the solution indicates the presence of organic matter. Methyl red, phenolphthalein solution, or litmus testing determine the degree of alkalinity or acidity in the soil, as well.[260]

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[259] Ibid, 100 - 101.

[260] Ibid, 101.

Additional field tests of equal importance determine the workability of the soil. These tests are very similar to the field tests describe in Table 2. Tests that should be particularly performed include cutting, ball dropping, consistency and cohesion (ribbon) tests. Furthermore, testing of any new building material compositions prior to use insures compatibility with the existing material in the building. Test blocks, as described in Chapter II and Table 3, aid in evaluating compatibility through evaluation of cracking, erosion rate, water penetration, and compressive strength.

Much more extensive testing is performed in a laboratory environment. These tests are generally very expensive and are only required if the structure is massive or if it has the potential of being damaged or destroyed by seismic activity, the results of which are seen in Figure 95. The obvious concern is for the loss of human life. Table 11 is a list of the eighteen tests that comprise this in-depth analysis. It is derived from information in Chapter 5 of *Conservation of Earth Structures*.[261]

Figure 95. The result of seismic shock and settlement on an earthen structure. *Photograph from* Conservation of Earth Structures *by John Warren, page 187.*

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[261] Ibid, 108 – 110.

Table 11. Laboratory Tests to Determine Structural Integrity of Earth Structures

Test	Test Description
Density	Aids in determining compactiblity
Permeability	Ability to move liquid without compromise of crystalline structure; ability to discharge water effectively and efficiently
Porosity	Volume and size of internal spaces within the crystal structure indicate thaw-freeze performance and water retention characteristics.
Stability when saturated	To determine the strength and stability of the soil composition under wet conditions.
Dry and wet strengths	Soil strength.
Atterberg limits	Determines the behavior of the soil in four states: solid, semi-solid, plastic, and liquid. Shrinkage limit, plastic limit and liquid limit of the material are ascertained.
Plasticity and workability	Tests similar to those that can be conducted in the field to determine the workability of the soil composition.
Particle size	Test used to determine the gradation of the soil. • Colloids: ≤ 2μm • Silts: > 2μm to 6μm - fine; > 6μm to 20μm - medium; > 20μm to 60μm - coarse • Sands: > 60μm to 200μm – fine; > 200μm to 600μm - medium; > 600μm to 2mm – coarse • Gravels: > 2mm to 60 mm The particle size tests are conducted by dry sieving, wet sieving, or settlement analysis to determine percentage content of each size.
Clay fraction shrinkage	Changes in water content is the governing factor in soil movement. This testing determines the amount of clay fraction resulting from the response of the soil to changes in water content.

Table 11. Continued

Test	Test Description
Nature and percentage of clay types	This test is used to determine the cohesiveness and swelling / shrinkage characteristics of the clay in the soil sample. • Attapulgites and kaolins expand generally by about five percent to a maximum of ten percent • Illites generally have an expansion factor between eight and eleven percent • Montmorillonites generally have an expansion between twelve and eighteen percent, but can rise to twenty-four percent
Nature and percentage of soluble salts	Salinity testing measures the amount of impurities in the soil.
Nature of organic matter present	This testing determines whether decomposition has produced or will produce materials of an acidic or chelating nature that affect the distribution of metallic ions within the soil.
Dating by inorganic methods	This test measures the age of the soil material and the date of its burial. The measurements are determined by rates of decay or the accumulation of the effects of radiation. These measurements are approximate, but may be of value to the historian.
pH value and carbonation	High acidity or high alkalinity in soils are indications of instability or impending change in the soil composition.
Chemical analysis	This analysis provides a fingerprint of the soil and can determine the origins of the materials within its composition.
Geological classifications	The geological classifications of materials in the soil are of the greatest assistance in determining the nature and behavior of the soil mixture. This testing and the Emerson Test are the most important soil composition tests to the historic preservationist.

Table 11. Continued

Test	Test Description
Biological analysis	This testing revels the presence of active or potentially active organisms which may affect the structure of the soil material. It can also revel the presence of inactive or decaying organic matter which may produce other unwelcome affects.
Scanning electron microscopy, diffraction and spectroscopy	These tests allow physicists to interpret or predict phenomena related to the soil composition with high precision. Considered of limited value to historic preservationists, if this testing is performed, it should be included in the historic record for application to other material studies where it might bring additional insight.

Sensitive Methods for Repair of Rammed Earth Buildings

Once a determination is made as to the causes of deterioration to a rammed earth building and the material composition of the soil structure of the rammed earth walls is understood, a plan to conserve, rehabilitate or repair the building can be made based on the intent of the project. However, before any other action is taken, the major causes of deterioration or decay must be resolved. That is, water penetration, plant growth, destruction by humans or animals, or damage caused by wind must be eliminated.

If the damage is caused by rising damp, several remedies can be considered. Table 12 lists three possible solutions.

Table 12. Remedies to Eliminate Rising Damp[262]

Remedy	Description
Removal of plantings around the structure	Eliminates root growth into the structure that may be conducting moisture into the walls.
Re-grading of the ground immediately adjacent to the building to slope away from the building's foundation	Eliminates poor drainage issues and pooling water around the foundation.
Installation of footing drains around the building's foundation	Eliminates poor drainage issues and pooling water around the foundation.

Footing drains consist of two to two and one-half feet wide by three feet deep trenches dug around the building at the base of the walls or at the foundation. The bottom and sides of the trench are lined with a polyethylene vapor barrier to prevent collected water from saturating the surrounding soil and the rammed earth wall. Clay

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[262] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

tile, or plastic pipe, which drain to a sump or to an open gutter, are laid in the bottom of the trench. The trench is filled with gravel to within six inches of grade. The remaining excavation is filled to grade with porous soil.[263]

The process for removing plant growth is determined by the plant type and size. Seedlings are removed as soon as they are seen. Large plants are removed carefully so that their root systems will not dislodge any rammed earth material.[264] Lichens and other surface plants are carefully removed using a stiff bristle brush. The institution of preventive measures against their return is the only means to prevent further damage.

The presence of animals and insects is the most easily controlled and eliminated. However, careful consideration should be given in the use of pest control chemicals. The immediate and long-lasting effects of the chemicals on the building must be accessed.[265] Specific to rammed earth walls without protective coatings or renders, the chemicals may be transported into the walls by capillary action and have a damaging effect on the wall fabric. Additionally, reasons of human and environmental safety must be considered.[266]

Damage caused by wind can be difficult to determine as the results are similar to water erosion. However, the furrowing caused by wind is usually most prominent on the upper half of the wall and at the corners. In addition, water damage tends to be vertical while wind damage usually has a distinctive diagonal or horizontal appearance. Moreover, coving from rain backsplash and rising damp is normally seen on the lower

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[263] Ibid.

[264] Ibid.

[265] Robert A. Young, PE, *Historic Preservation Technology* (Hoboken: John Wiley & Sons, 2008), 71.

[266] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

one-third of the wall. A wind screen or wind break in the form of fencing or trees can be implemented to mitigate wind damage.[267] If trees are planted, as with other plantings, they must be placed far enough away from the structure to guarantee that their roots will not destroy the foundation or trap moisture or that their branches rub against the building.[268]

Material incompatibilities must be considered when determining the particular repair method. Techniques and materials that were once deemed acceptable are no longer used in earth building repair. As described previously, moisture content in earth buildings cause continual swelling and shrinkage. Because of this, it is likely that repair work was already performed during the life of the building and the work may have caused further damage.[269]

As explained in "Preservation Brief 5," philosophies regarding earth building preservation have changed, as have restoration and rehabilitation techniques. In the past, Portland cement was often used to patch rammed earth walls. Wood lintels and doors were replaced with steel ones. Earth walls were sprayed with plastic or latex surface coatings.[270] Each of these techniques caused more problems than they remedied. In fact, the hygroscopic nature of earth walls rendered these techniques both ineffective and destructive.

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[267] Warren, *Conservation of Earth Structures*, 157.

[268] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

[269] Ibid.

[270] Ibid.

As shown in Figure 96, the higher strength of Portland cement causes weaker earth structures to crack and crumble because of the differences in the expansion properties between the two materials.[271] In addition, when an earth building expands, the flexibility inherent in the walls allows a twisting motion. If steel lintels have been incorporated, the wall-to-lintel connection will crack as the lintels are much more rigid. The use of plastic and latex wall coatings as a surface sealant keeps the surface of the earth structure from expanding when the inside of the wall expands. This results in breaks in portions of the wall.[272] If possible, incompatible materials should be removed. This is only if more damage to the structure is not entailed by their removal.

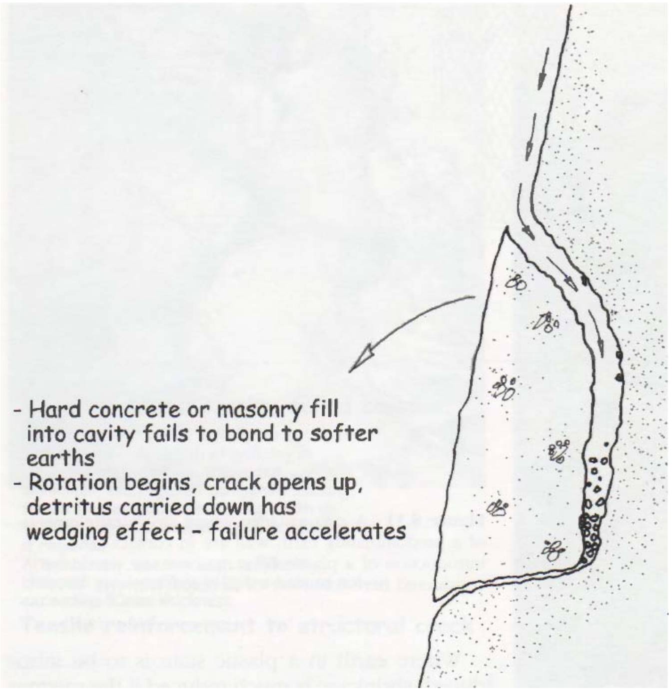

Figure 96. This drawing illustrates the effect of the use of incorrect materials to repair rammed earth. *Drawing from* Conservation of Earth Structures *by John Warren, page 154.*

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[271] Warren, *Conservation of Earth Structures*, 154.

[272] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

Once repairs have been completed to eliminate the deterioration of the building, structural damage repair and restoration can begin. Per "Preservation Brief 5," as much as possible, traditional or original materials should be used to replace, repair or reproduce those that have been damaged.[273]

Direct in-kind replacement is often not achievable with rammed earth construction, particularly monolithic rammed earth walls. However, Warren suggests in *Conservation of Earth Structures* that different materials with the same properties of thermal expansion can be used as identification markers and to aid in reversibility decisions later. He explains that "[s]uccess has been claimed for mixtures of fly-ash, brick dust and lime which can produce a setting material free of the problems of shrinkage and with characteristics of thermal movement, strength, resilience, loading and self-weight comparable with an earth structure."[274]

As shown in Figures 97 and 98, Warren provides several techniques for the repair of deep cracks or failed corners. In the first method, he suggests the use of a mesh fabric made of terylene (polyester fiber), aluminum, or other material. After cleaning out the damaged wall, the exposed surface is lightly dampened to aid in bonding. The mesh is laid inside the wall and replacement earth in a stiff but plastic state is troweled over the mesh to a thickness of no more than fifty millimeters (about two inches). The layered in earth is allowed to partially dry before the next layer is applied. This eliminates shrinkage which causes cracking. Cracking is controlled because shrinkage only occurs

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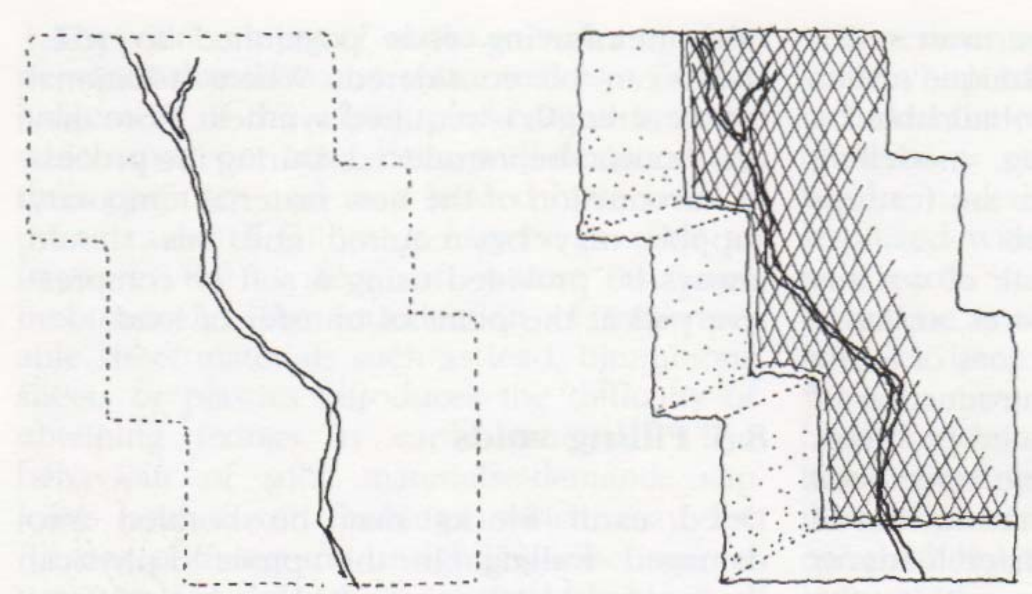
[273] Ibid.

[274] Warren, *Conservation of Earth Structures*, 151.

within the thickness of the applied layer.[275] If the repair site allows, rammed earth forms can be used to aid in the repair as a means to hold the still moist earth in place and to enable tamping of the earth to insure consolidation of the new material.



Deep structural cracks, failed corners

To restore continuity to wall, cut out to maximum of half-depth of wall, lay in mesh (terylene, fabric, expanded aluminium, etc.) against dampened backing, trowel in semi-plastic matching earth up to 50mm layer and repeat with reinforcement if required.
Alternatively, use mix with terylene chopped random fibre in layers tamped not exceeding 50mm thickness.

Figure 97. The tensile reinforcement method to repair deep structural cracks or failed corners using mesh infill. *Drawing from* Conservation of Earth Structures *by John Warren, page 152.*

In the second method, Warren uses infill materials such as stone or tile. The infill is randomly placed inside the prepared repair site. Damp earth is tamped into place in

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[275] Ibid, 153.

layers. The tamped earth is pared or smoothed to match the wall surface while still soft.[276] As with the mesh fiber method, rammed earth forms can be used.

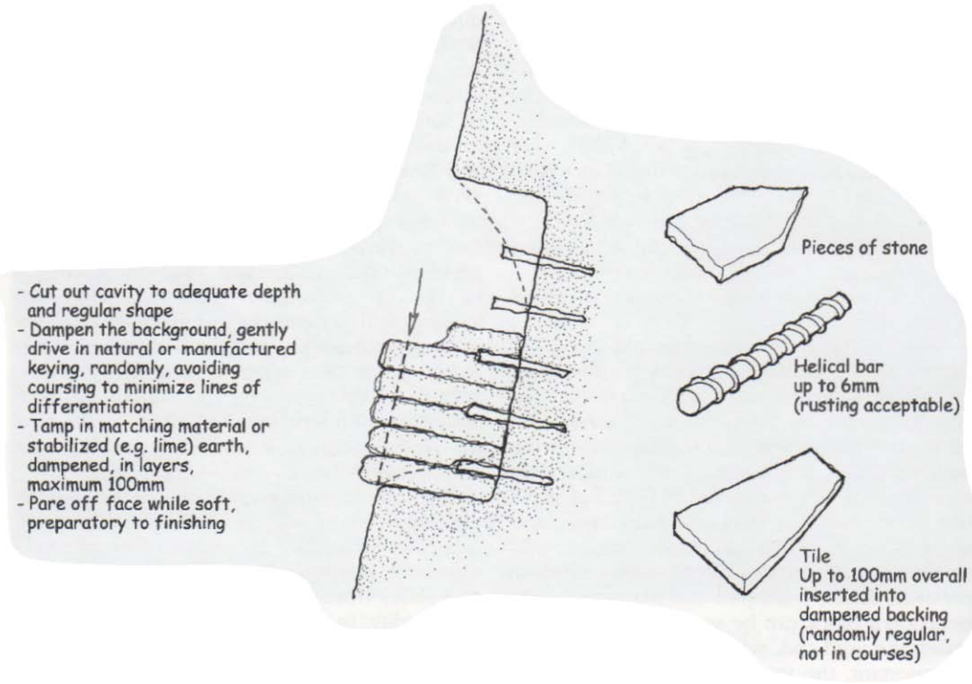

Figure 98. Another method using stone or tile infill to repair deep structural cracks or failed corners. *Drawing from* Conservation of Earth Structures *by John Warren, page 152.*

Wood should always be used in the repair and replacement of wooden members including vigas, savinos, lintels, wall braces, and flooring. Any wood that is rotted or infested with termites must be removed and replaced. The repair of carved corbels using specially formulated low-strength epoxies or patching compounds may be employed to save original artisanship. Tests should be made prior to these types of repairs to determine if the desired results are achievable since they usually are not reversible.[277]

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[276] Ibid, 152 – 153.

[277] de Teel Patterson Tiller and David W. Look, "Preservation Brief 5: Preservation of Historic Adobe Buildings."

When patching and replacing surface coatings, every effort should be made to use the same material as originally applied to the wall surface. Mud plaster coating is the easiest to repair. The deteriorated mud plaster is scraped off and replaced with like materials. Application techniques to match the repair work as closely as possible to the original surface enable the repair to be nearly invisible.[278]

The use of lime plaster or Portland cement stuccos as the original coating material complicates the repair process. The deteriorated surface coating must be removed to the extent possible without injuring the fabric underneath to determine the cause of the damage. Lime plaster or Portland cement stucco should never be applied directly over a deteriorated surface coating. Serious deterioration on the surface indicates the likelihood of far greater deterioration underneath.[279]

A lath and plaster technique that incorporates a moisture barrier may be considered if recoating of the building with lime plaster or Portland cement is very extensive. It is important to patch the surface coating with in-kind replacement material. Lime plaster and Portland cement stucco are less desirable as surface coatings; however, many earth buildings have always had them. Complete removal is not advised, as the process of removal may cause more harm.[280]

When considering roof repair, roofs should be restored and maintained with their original form and materials as much as possible. Any new roof construction cannot be heavier than the roof it is replacing. A heavier roof will exacerbate uncorrected moisture

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[278] Ibid.

[279] Ibid.

[280] Ibid.

or deterioration problems in the walls. For example, deformation can occur if the earth is in a plastic state because the added weight of a new roof may cause the walls to bulge. Compression failure can occur if the walls are severely deteriorated as the added roof weight may cause the walls to crack or crumble.[281]

Whenever feasible, a reasonable effort should be made to retain original interior and exterior details including windows, doors, floors, and other original elements. The introduction of high efficiency windows and doors, the installation of floors that are easy to maintain, or the incorporation of other modern conveniences may preclude efforts at retaining original features.[282] However, the more original the elements within the structure, the more valuable it is to understanding the history of its time.

Maintenance Considerations for Rammed Earth Buildings

As with all restored earth buildings, cyclical maintenance is the key to successful building survival. A plan for continued maintenance should be established as soon as the rehabilitation or restoration project is completed. Regular inspections of the walls for signs of cracking, sagging, or bulging should be instituted. Any damage resulting from water infiltration should be repaired as soon as it is detected. The roof should be periodically inspected, as should any surface coatings. Problems with either should be repaired or replaced as the need indicates. Inspections for plant, animal, and insect damage should be included along with the other inspections. Any damage from plants or pests should be stopped before becoming significant.[283]

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[281] Ibid.

[282] Ibid.

[283] Ibid.

The building's mechanical systems should be monitored, as well. Leaking water pipes and condensation can be very damaging to a rammed earth building. Observation of the building for subtle changes and the performance of regular maintenance will go a long way in guaranteeing the stability of the historic building.[284]

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[284] Ibid.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This thesis provided an overview of the *pisé de terre* or rammed earth building technique in which extremely sturdy and long lasting walls are formed by compacting moist earth layer by layer between temporary wooden forms. The thesis began by providing an overview of rammed earth building along with information on rammed earth tools and techniques, and the evolution of these, as a means to aid historic preservationists and those interested in material culture in determining the age of structures and methods of building. Next, it provided a global perspective on the history of rammed earth from the time it was first documented to its introduction to the United States. The core of the thesis concentrated on its application from the Depression Era into the 1950s in the U.S. This time was of particular significance in that the government had promoted its development. Included in this thesis was a brief discussion of its applicability today including barriers to its use and potential resolutions of these. The thesis concluded with a discussion of the importance of preserving the history of the rammed earth building process and, as such, methods for its preservation, repair, and maintenance.

Summary

Though first documented by Pliny the Elder in *Natural History* in about 77 AD, it was a building method that had already been in existence for thousands of years. Its use has been global, isolated, and independent as is exemplified by extant buildings in China from 709 AD, Spain from 1348 AD, and Brazil from 1592 and 1732 AD. Each of these buildings is a testament to its adaptability, versatility, and longevity.

In the more recent history, rammed earth became a studied building form after French architect François Cointereaux grew the vernacular architecture of rammed earth into an international presence when he promoted its use in the late eighteenth and early nineteenth century. His advancement of the technique of nouveau pisé in which rammed earth walls were built of modular compressed earth bricks instead of monolithic single-unit structures intrigued noted architects of the time including David Gilly and Wilhelm Jacob Wimpf of Germany, Adam Menelaws and Nicolai L'vov of Russia, and Henry Holland of England. Indeed, rammed earth was so popular in northern Europe that Denmark built over 4,000 buildings based on Cointereaux's methods. Cointereaux's influence reached to such far-away regions of the world as Australia and New Zealand. Even today, Australia is on the forefront of rammed earth design.

Cointereaux learned early in his career as an architect that his passion was in the improvement of rural living conditions and he saw rammed earth as the answer to the plight of the poor. His passion prompted him to create numerous fascicles and to build a school dedicated to rammed earth architecture. He even showcased rammed earth to Thomas Jefferson giving him a tour of homes built of rammed earth in Lyons that were well over one-hundred years old.

While Jefferson was intrigued by the technology, he never embraced rammed earth, as he believed it was not practical for the harsh winter conditions of the northeastern United States. Nor did he believe it was necessary as the U.S. had plenty of natural resources in the form of old-growth timber. However, he held in his library *École* *d'Architecture Rurale*, a four-volume compilation of Coinetereaux's fascicles, along with S. W. Johnson's *Rural Economy*.

There is no direct evidence that Jefferson introduced rammed earth to Bushrod Washington or John Hartwell Cocke, however, both of these contemporaries of Jefferson built rammed earth structures as secondary support buildings for their plantations at Mt. Vernon, Bremo Recess, and Pea Hill. They saw rammed earth as a means to improve the living conditions of plantation slaves, as the buildings were cool in summer and warm in winter.

Rammed earth use in the U.S. might have been destined for obscurity after the Jeffersonian Era if not for Dr. William Wallace Anderson. Dr. Anderson used rammed earth to build a portion of the main house, as well as, for a number of outbuildings on his plantation in South Carolina. So passionate and committed was he to rammed earth, he was able to convince the congregation of his local church to build their new church edifice of rammed earth as a money-saving proposition. The Church of the Holy Cross, built in 1851 near Sumter, South Carolina, became the catalyst for rammed earth resurgence in the U.S.

In the early 1920s, nearly seventy-five years after it was originally constructed, members of the Church approach the U.S. Department of Agriculture for help in the repair of a crack that had developed in one of the church walls. Thomas A. H. Miller, an agricultural engineer with the USDA, was sent to investigate and help provide a repair plan. With absolutely no familiarity with the rammed earth building process, Miller soon found himself learning and documenting this "new" form of building.

To learn of rammed earth and provide recommendations for repair, Miller relied on information from sources including the work of Clough Williams-Ellis, an esteemed architect from England who strongly believed rammed earth was the answer to housing and materials shortages that were being experienced in England after World War I.

Dr. Harry Baker Humphrey, the chief plant pathologist at the USDA, was so intrigued with rammed earth and Miller's work that he had a home built of rammed earth in Washington, D.C. The house was showcased in *Popular Mechanics Magazine* where it peaked the interest of many in the general public. Humphrey soon tired of the constant questions he was receiving on the technique. Therefore, he assigned Miller, along with Morris Cotgrave Betts, to author a pamphlet on rammed earth. "Farmers' Bulletin No. 1500: Rammed Earth Walls for Buildings," first published in 1926, was the result. This pamphlet became the de facto endorsement by the U.S. government of rammed earth as a viable building technique.

Rammed earth became particularly popular during the 1930s Depression Era. Labor was plentiful and the main material needed for construction was cheap. Several agencies under President Roosevelt's New Deal program including the U.S. Resettlement Administration, the Progress Works Administration, and the National Youth Administration, incorporated rammed earth building into their development plans. It also became the source of studies at agricultural colleges including Oklahoma Agricultural and Mechanical College (later Oklahoma State University) and South Dakota Agricultural Experiment Station, South Dakota State University.

From 1932 to 1937, rammed earth homes were constructed at Gardendale, Alabama under the direction of Thomas Hibben, an architectural engineer with the

Resettlement Administration. Elbert Hubbell, a vocational instructor at the Turtle Mountain Indian School in Belcourt, North Dakota learned of rammed earth by studying experiments conducted by Dr. Ralph Patty of the South Dakota Agricultural Experiment Station. Between 1935 and 1939, Hubbell oversaw the construction of rammed earth buildings including barns, schoolhouses, and other dwellings on the Pine Ridge Indian Reservation. The National Youth Administration used rammed earth to build their Casper, Wyoming Clubhouse, completed in 1939.

In 1943, John Kirkham of Oklahoma Agricultural and Mechanical College published, *Publication No. 54: How to Build Your Own Home of Earth*, a how-to manual on building a single-family home using rammed earth. He used his own home, built in Stillwater, Oklahoma in 1935 as the case study for the pamphlet.

Rammed earth was also employed by the U.S. military during World War II. Rammed earth revetments were constructed at Edwards Air Force Base in California to protect U.S. bombers and pursuit aircraft from potential attacks out of the Pacific.

Lydia and David Miller, who had learned of rammed earth prior to the start of World War II, studied it extensively while they were in Germany after the war supporting the Nuremberg trials. The Millers built rammed earth homes at Alles Acres in Greeley, Colorado after their return to the U.S. in the late 1940s.

Rammed earth was sidelined in the mid-1950s when mass construction of single-family homes became the norm. Industries such as lumber, brick, and transportation boomed post-World War II when the U.S. transitioned from a wartime to a peacetime economy. Labor became expensive and materials cheap. This precluded the use of rammed earth.

However, rammed earth resurfaced in the late 1970s and early 1980s with the back-to-nature movement. The Miller's gained national prominence when *Mother Earth News* featured a story about their homes in their January/February 1980 issue. The article emphasized the thermal properties of rammed earth, a prospect that was particularly appealing as the U.S. was still feeling the effects of the 1979 oil crisis.

Rammed earth continues to be employed, though certainly it is not common. It has been used in custom design-build architecture as a means of creating environmentally friendly buildings that require minimal heating and cooling. Architects including Mary C. Hardin and John Folan of the University of Arizona, and Rick Joy and Associates utilize rammed earth to create both energy efficient and unique living spaces that embody the connection between earth, man, and nature.

Conclusions

During the 1920s and 1930s, the U.S. government documented the rammed earth construction method and funded experiments in its implementation. This appeared to be an endorsement of it as a timely and cost effective building practice during an economically distressed and resource limited time in U.S. history. In reality, rammed earth was viewed more as a construction technique to be studied than to be implemented.

Ultimately, rammed earth was relegated to the back burner of the American architectural culture. Promoted under the banner of cheap, low-cost housing, it was almost too economical. After all, any building technique that involves dirt as the chief construction material was destined to be perceived as housing for those with the most limited of means, and, certainly not meant for anyone pursuing the American dream. This stigma was encouraged for a number of reasons, most notably because of its origins.

Rooted in the rural taxonomy, many proponents of this architecture type saw it as valuable only to the agricultural community.

Rammed earth is significant to historic preservation for three distinct reasons. First, it is a vernacular architecture type. While not regional, it is still an architectural style built by the common man that maintains the traditions and utilizes the resources of the people. Second, it is inherently environmentally suited. Rammed earth walls have a nominal twelve-hour temperature cycle – keeping them cool in the daytime and warm at night. This minimizes the need for artificial air conditioning and heating with their associated costs. And third, as with the study of any architectural type, knowledge is gained from its challenges more than from its successes.

Future Studies

The existence of the rammed earth building method in the U.S. is a testament to its place in the building of this country. From its vernacular origins in Europe to its common use on the high plains of North Dakota and Wyoming, it presumes to articulate the legacies of resourcefulness and innovation that define the American ideal. Rammed earth has been at times controversial. It is definitely unique. It has certain and specific environmental advantages. Lessons learned from its implementation provide ample justification for continued study and protection of this matchless sustainable building technique.

This thesis was a study of rammed earth as a single earthen architecture type. By providing an historic perspective, the insights required to understand what has limited its use in the past help to articulate the importance of this build style for the modern age.

Sustainable building techniques have become an imperative and rammed earth has a place in this ethos.

This thesis did not include an in-depth study of the particular factors that have limited the acceptance of rammed earth into the U.S. material culture. Nor did it attempt to provide a roadmap for overcoming prejudices against it as a building technique. The latest resurgence of rammed earth was notionally described, but no details of the newest building practices, especially those associated with earthquake protection were included. A detailed analysis of the barriers to rammed earth use and specific means to overcome those barriers would add greatly to the body of knowledge on rammed earth use in the U.S.

Additionally, farm and agricultural outbuildings built using rammed earth, such as the one shown in Figure 99, were mentioned only in the context of describing overall design. As seen by this thesis, rammed earth has been traditionally considered a rural construction type. There are numerous rammed earth outbuildings that have never been documented, especially in areas such as North Dakota which was originally settled by German immigrants familiar with rammed earth building. A more complete look at rammed earth use in rural farming areas would add significantly to the body of information on this topic. In particular, a study which catalogs rammed earth

Figure 99. The remains of a rammed-earth farmhouse near Fairfield, North Dakota. *Photograph from "German-Russian Houses in Western North Dakota" by Alvar W. Carlson, page 52.*

structures in rural settings could provide significant insight into the development of rammed earth technology within the U.S.

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