CONDITION ASSESSMENT – MATERIAL AND BUILDING PATHOLOGY

This session was created by Tony Crosby and modified by Claudia Cancino.

ABSTRACT

The session on material and building pathology will build on the information covered in previous sessions on material analysis, characterization and construction techniques. It is of no value to consider the actual cause and effect mechanisms in isolation, without considering the nature of the materials and systems within the greater context in which considerations and decisions are made. By understanding something about the proper composition of soils, the appropriate mixture, and the placement of the raw material in a construction, much about the actual performance of the materials and systems is already known; and much of what is not known, is implied. By knowing about the history and background of a site and structure, its associated values, and its history of interventions, much about the decay mechanisms is already known.

This session includes first, a preliminary exercise for the students to identify the existing conditions of a site. This exercise is followed by a lecture in which different types of conditions are explained. Lastly, a very practical exercise will try to simulate the different types of conditions and their relationship to the specific characteristics of earthen materials.

The emphasis will be on the actual decay mechanisms that degrade the materials and the building systems. Excessive moisture in all its forms —rainfall, high and continual relative humidity, standing water, snow—is the single most important factor in the performance of an earthen structure, affecting both the material and building systems. Degradation of the material and the building system can also be affected by excessive winds, physical abrasion by animals and humans, other forms of human intervention, and ground motion. These factors will also be discussed, however the emphasis will be on the significance of the building pre-existing conditions and their effects on the performance of the materials and building system.

If excessive moisture is the most critical factor in decay mechanisms, then it is critical to understand how moisture gains access and is transported through the material. Does moisture move through earthen material by capillary action? Does moisture move through earth in a similar way as through other porous materials? What are the similarities of that vehicle and what are the differences? How does moisture actually affect the mechanical properties of the materials? What are the forces that cause moisture to be retained by the material? How similar and how different are the decay mechanisms of earth compared to other porous building materials? Is the presence of any moisture degrading and should the conservation goal be its complete elimination? These are some of the moisture related questions that will be raised and addressed during the sessions.

Moisture has a direct effect on the performance of earthen material and on earthen building systems, but it also helps provide a hospitable environment for other causes of decay. Soluble salts in themselves are not deleterious to earthen materials and to earthen building systems. In fact, salts can add to the mechanical strength of a material in some cases. As soluble salts that are normally found in an earthen building, however, crystallize and grow through the processes of hydration and dehydration, they exert tremendous pressures in the pores of the material. These pressures can easily break the material apart. Salts can also increase the amount of moisture in materials and can cause the direct decay of other materials that come in contact, such as metal reinforcing. Moisture can also provide a welcoming environment for insects and animals, which otherwise would not be attracted to the earthen structure.

Temperature and temperature changes in themselves have no practical effect on earthen materials. Yet the same temperatures and temperature fluctuations may impact other materials; when the two materials are in contact, the performance of the building material may well be compromised. The effect of temperature and temperature change in the presence of moisture can affect the performance of the earth materials. The most obvious example is the effect that occurs when moisture changes from a liquid to a solid.

This session is divided in three sub-sessions: A preliminary exercise, a classroom lecture, and a decay simulation exercise. The preliminary exercise will introduce the subject, particularly as it relates to the most obvious problems. In this case, "problems" will be primarily defined by the students as they observe previously built and damaged constructions and the site being used for this session. The objective is to look at the buildings and the site from the human scale, from the human perspective, and investigate the actual processes that result in what is observed.

The classroom lecture will present the issues and conditions that affect the performance of the material and earthen building systems—the causes and the effects of the decay process. The emphasis will be on the knowledge of the material and the systems, and will build on the topics already presented in earlier sessions.

As the third part of the session, the decay simulation exercise will pull together the earlier experience of discovery with the understanding of the actual decay mechanism covered by the lecture, with a field exercise that requires the students to "create" various failure patterns on constructions built for that purpose.

The sub-sessions, while drawing on materials presented by earlier sessions, will point ahead to the decay mapping and condition assessments of a future session. In this session, the relation of causes and effects will be direct and clearly presented as current knowledge allows.

OBJECTIVES

As a result of this session, the participant should be able to:

Preliminary exercise:
- Question the ability of earthen materials and building systems to perform under various potentially deleterious conditions.
- Understand the complexities of preserving a site and structures with often complex and numerous issues under the constraints of time, available resources, and staff.
- Value the effectiveness of a multidisciplinary approach, working together and taking advantage of the abilities and knowledge of others.

Classroom Lecture:
- Understand the building/site performance in relationship to the distinctiveness of its material and systems.
- Identify the main factors that result in decay and understand the relative significance of each.
- Understand that the decay mechanisms are complex and interrelated.

Decay simulation exercise:
- Identify the possible and probable causes of specific failure patterns.
- Understand the influence that the material characteristics (soil types, gradation, etc.) have on the building/site overall performance.
- Identify and prioritize the decay type and level depending on the sources of moisture.

- Describe specific failure patterns that will result from various loading and environmental conditions.
- Describe the effects of pre-existing conditions on earthen sites failure patterns.

CONTENT

Preliminary exercise

Four constructions will be used either from those built for other sessions or appropriate samples on specific sites. These constructions/sites will exhibit more obvious examples of different materials and construction techniques, deterioration mechanism and performance.

The specific requirements for the 4 constructions/site sections are:

- A variety of earth construction systems (earth, earth and wood, masonry and earth, load bearing, earth fill in a wood frame, incompatible materials and systems, rendered wall surfaces, non-rendered wall surfaces).
- Examples which can demonstrate surface erosion, poor drainage, potential and current structural failure, rising damp, insects, vegetation, etc. (Try to include macro decay issues as well).
- Constructions should be within close proximity, but not next to one another – approximately 8-10 meters apart.

The exercise will be to "discover" issues and problems in a controlled environment. The students will be divided in four groups but will review the conditions of four constructions/site sections. After, each section will be assigned to each group and will report briefly on what they discovered.

Introduction to the exercise:

The instructor will explain that the task is to identify what perceived problems related to:

1. Use and performance of materials
2. Use and performance of building systems.
3. Environmental decay (wind, humidity, temperature, vegetation).
4. External factors (earthquakes, abandonment).
5. External impact (human mechanical damage, inadequate interventions, insects).

Exercise methodology:

1. Each group will look at a construction/site section for 15 minutes and then rotate.
2. A resource person will be at each section; instructors will also be available to ask, not answer questions.
3. When all the rotations are complete, each group will be given 5-10 minutes to prepare to report on one section, leading a discussion for 5 minutes,
4. Groups present their observations and findings.
5. Resource people, instructors, etc. will comment on the discussions; they will add information where appropriate and continually relate the discussions to subject matter of earlier sessions (example: material performance) and to the next sessions on pathology.

Figure 4.2.1
Students from PAT course investigating pathologies
PAT course, 1999 © J. Paul Getty Trust

Figure 4.2.2
Student from PAT course
presenting his findings in class
PAT course, 1999 © J. Paul Getty Trust

Classroom Lecture:

In support of the objectives of this section, the instructor will discuss:

Introduction:

1. The relationship of this session to earlier sessions emphasizing:
    a. Knowledge of materials, the performance of materials
    b. Knowledge of building systems
    c. Importance of understanding decay in overall management planning
2. The relationship of this session to subsequent sessions emphasizing that:
    a. It is important to understand the effects of decay at different scales
    b. All information is collected for a comprehensive condition assessment to be developed later
    c. The understanding of causes and effects leading to appropriate interventions
3. Emphasis of this session:
    a. Effects of decay processes
    b. Cause-effect relationships

Material Performance:

1. Characteristics of a material that will perform well:
    a. Function as intended
    b. Proper mix – gradation of particle size
    c. Preparation of raw material
    d. Formation of building units (mud bricks; rammed earth; puddled; formed; waddle and daub; etc.
2. Characteristics of systems that perform well:
    a. Compatibility of materials
    b. Protection from rain and ground water
    c. Traditional seismic reinforcements
3. Materials that perform well in some conditions but not in others:
    a. Organic materials added that provide nutrients for insects/microorganisms
    b. High compressive strength of dry materials with inadequate clay fail quickly when subjected to moisture
    c. Class input with others – saline water used in original mix; expansive clays; etc.

Deterioration mechanisms:

1. General failure patterns:
    a. Series of slides of examples
    b. Minimal discussions – numerous examples of all failure types
2. Environmental decay:
    a. Wind
        - Direct
            - Abrasion
            - Displacement of surface materials
            - Differential loading
        - Indirect
            - Increasing evaporation
            - Deposition of deleterious materials
            - Air quality (urban centers); Sulfur and carbon oxides produce carbonic acid and sulfuric acids with water
    b. Humidity
        - General physical properties – porous and permeable
        - Surface and internal moisture – raising damp
        - Conditions that affect moisture movement
            - Temperature (effects of temperature on condensation; show overhead of temperature wall gradient; differential movement of different materials)
            - Vapor pressure
            - Relative humidity
            - Hygroscopic materials
            - Structure and nature of capillaries
        - Salt crystallization
        - Effects on mechanical properties
    c. Temperature and temperature change with moisture:
        - Freeze and freeze-thaw
        - Wet-dry cycles (number of cycles; presence of soluble salts
    d. Vegetation or biological decay:
        - Disruption from roots, etc. that displace and disrupt
        - Lichens produce acids that could be deleterious
        - Moulds
3. External factors for decay:
    a. Earthquake and other natural disasters (rain, floods)
        - Building seismic performances
        - Identification of recognizable symptoms (compare with moisture failure symptoms)
    b. Abandonment:
        - Loss of connections and collapse
        - Vertical loading
            - Normal strength and strength affected by moisture (loss)
            - Normal failure pattern by loss of compressive strength
            - What are the recognizable symptoms (crack patterns; plumbness; increase of width)
4. Human impact:
    a. Human mechanical damage (i.e., graffiti)
    b. Insects and/or animals mechanical damage
        - Termites seek nutrients, physical damage by tunneling

- Animal burrowing and undermining; abrasive action; depositing fetal waste; nesting birds

c. Inadequate/non-compatible interventions
d. Inadequate change of building function

Pathologies:

1. Non-structural damage:
    a. Detachment
    b. Disaggregation
    c. Flaking and blistering
    d. Cracking
2. Structural damage:
    a. Cracking:
        - Horizontal
        - Vertical
        - Flexural
        - Diagonal
        - X-shaped
    b. Settlement of walls
    c. Lack of connections
    d. Displacement:
        - Out-of-plane
        - In-plane
    e. Partial and/or total collapse

Specific Case Studies:

The intent of this portion of the lecture is to show real examples of failure in the context of a structure—what are the "real life" effects of the conditions discussed above? This should be interactive, with class input on specific issues, but directed by the use of the specific examples.

1. Archeological Sites
    a. Archaeological features unprotected from rain and surface erosion
    b. Leaking roofs and gutters
    c. Archeological excavations that turn into rapid drying; formation of salts; concentration of moisture; and/or, physical destruction
2. Structures that have failed from moisture at the foundation or ground level
    a. Show examples of the conditions and interpret the evidence
    b. List the possible causes based on the evidence
3. Plaster damage in general
4. Structures that have failed from earthquake and other differential loading
    a. Show series of slides of earthquake damaged structures
    b. Introduce the effects of "pre-existing" conditions and maintenance on site performances and show specific examples
5. Structures and sites showing a combination of failure systems

Decay simulation exercise

This session will be broken into two types of simulations. Both simulations should be interactive with discussions and exchange of ideas. At the end of each exercise, each group will present their findings to the other groups, instructors and observers.

Small scale simulation exercise:

This exercise will emphasize the movement of moisture through the earth material. Students will:

1. Measure the rate of capillary rise and describe factors that affect the rise, and
2. Record the movement of moisture from sources of moisture on a vertical wall surface, at the base of a wall and from the top.

Sample construction specifications:

1. Capillary Rise: for each of the five groups – three samples each of three different columns of pre-formed and cured earth material of different soil characteristics (specific soil types developed in conjunction with coordinator of sessions 2.2.1 – 2.3.3). columns shall be 5cm X 5cm X 10 cm high. Total of 45 samples.
2. Supplemental Capillary Rise demonstrations – 12 additional earth columns for overall class demonstrations to be treated by session coordinator and instructors the week of the session.
3. Vertical Surface Absorption: for each of five groups – two samples each of three different pre-formed blocks of different soil characteristics (specific soil types developed in conjunction with coordinator of sessions 2.2.1 – 2.3.3). Blocks shall be 10cm thick X 30cm long X 30 cm wide. Total of 30 samples.

Exercise methodology:

1. Capillary Rise Simulation
    a. Small columns of previously molded earth units will be subjected to a constant source of moisture.
    b. Columns will be made of material of different characteristics; each group will have three different material types.
    c. The specific data of the material types will be revealed after the results of the experiment are known; discussion will follow about the effects on capillary rise of different material types.
    d. There will be prepared samples of columns that have been treated and subjected to moisture previously.
    e. These prepared samples will be described and the effects discussed:
        i. Column surface coated with a waterproofing material;
        ii. Column sitting in saline water;
        iii. Column subjected to several wetting cycles;
        iv. Sample saturated and then frozen.

2. Vertical Surface Moisture Absorption Simulation

    a. Large mud brick size samples (vertical surface) will be subjected to:
        i. Surface spray, replicating rain;
        ii. Constant source of moisture replicating conditions often the result of the growth of microorganisms, fungi, and renderings.
    b. Samples will again be made of material with different characteristics; each group will test the various samples:
        i. One sample formed using saline water
        ii. Another sample made primarily of silt and fine sand
        iii. A third of an optimum mixture to produce the most resistant unit

c. Spray will be applied until the surface appears wet; surface will then be scratched to determine depth of water penetration. Spraying will be repeated until the surface appears wet and then continued for another minute.
d. Note differences or erosion of different material types.
e. The specific data of the material types will be revealed after the results of the experiment are known. Discussion will follow about the effects of different material types.
f. There will be prepared samples of units that have been treated and subjected to moisture previously; these samples will be described and the effects discussed.

   Examples: Sponges or similar moisture retaining materials will be applied to the surface and covered with a plastic cover to restrict the evaporation for various periods of time – one full day; one week.

<u>Large scale simulation exercise</u>:

The second type of simulation will be at or near human scale. Walls will be constructed to replicate conditions that might be found in actual cases. After describing these "pre-existing conditions" students will be asked to:

1. Create specific failure patterns.
2. Record the decay phenomena and the effects of pre-existing conditions.

Sample construction specifications:

1. 5 constructions, each 4 meters long with a two meter intersecting wall, 1.5 meters high, and 40 cm wide, of dry-laid mud bricks and plastered with mud plaster.
2. Walls to be laid in a trench approximately 10 cm deep
3. The constructions are to be separated approximately 4-5 meters apart

Exercise methodology:

1. Each group will have a separate construction on which they will work.
2. The groups will describe and record the conditions of their construction: general form and size, material and condition
3. The groups will describe pre-existing conditions that might influence the performance of the construction
4. Each group will be given several structural failure patterns that they will replicate on their constructions; group determines how to "create" crack failure pattern; instructors emphasize creating conditions that are realistic and that might actually occur
5. Actual stresses will be applied and then stopped at the first signs of failure
6. Each group will record their observations: if failure pattern is different than expected, then method is reevaluated
7. After reevaluation, exercise continues – it is important that the instructors answer questions and offer suggestions, primarily by asking other questions and not giving the answers
8. Failures continue until the effects are created; instructors will advise when success is achieved; it is important to stop prior to complete collapse, as these same constructions will be used for the session on intervention; repairs will be made to the constructions, correcting some of the problems created
9. The groups will document the failures

10. Each group will explain the failure pattern: group participants describe what they did and their rationale; they will also describe what real world conditions could exert the forces used; instructors will encourage exploring the full range of possibilities
11. Instructors will preview the interventions of subsequent sessions by explaining that these constructions will be repaired during a future session.
12. The groups will discuss the various conditions and patterns.

Figure 4.2.3
Large scale simulation exercise area
PAT course, 1999 © J. Paul Getty Trust

Figure 4.2.4
PAT student simulating pathology
PAT course, 1999 © J. Paul Getty Trust

Figure 4.2.5
PAT students simulating pathology
PAT course, 1999 © J. Paul Getty Trust

Figure 4.2.6
PAT students presenting in class the decay mechanism on the large-scale sample after simulating pathology
PAT course, 1999 © J. Paul Getty Trust

Session summary:

1. Review the objectives for this session
2. Review the results of the field exercise – ask for student participation
3. Review the relationship of this session with both previous and subsequent sessions.

SELECTED IMAGES

Unprotected archaeological site, Chan Chan Peru, Photographer: Giacomo Chiari

The earthen archaeological site of Chan Chan was severely damaged by "El Niño" rains in 1985. A removable protective shelter was later installed in preparation for the rains of 1998, before the PAT courses. The image shows a flooded section at the Tschudi Palace. The rising damp caused salt crystallization in some of the decorated surfaces, which were later treated and removed.

Leaking roof at earthen house in Cusco, Photographers: Amila Ferron and Sara Lardinois, ©J.Paul Getty Trust

The images show the deterioration of a floor/roof structure in the house of Casa Arones in the historic center of Cusco. Water had percolated through the damaged roof and deposited on the floor. The floor lost its structural stability due to the rooting of the wooden beans and moisture damage of the earthen floor.

Moisture decay at residential unite in Lima, Photographer: Claudia Cancino, ©J.Paul Getty Trust

The image shows loss, detachment and erosion of material at this earthen house in the district of Miraflores in Lima, Peru. Most of the drainage in the historic center of Miraflores is from 1960and in need of repair?, resulting in water being absorbed? into the soil and transferred to the base of the adobe walls.

Wind decay at Cajarmarquilla, Photographer: Claudia Cancino, ©J.Paul Getty Trust

The earthen archaeological site of Cajamarquilla has been unprotected for many years. Strong winds have affected the massive rammed earth walls as seen in the first image. With time, the upper sections of walls have collapsed.

Moroccan sites abandoned, Photographer: Claudia Cancino, ©J.Paul Getty Trust

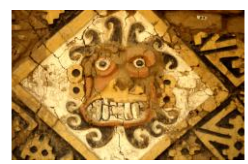
The images show partial and total loss of sections of the rammed earth structure of the Ksour Aghlan Ibacha at the Draa Valley in southern Morocco. Several earthen sites were abandoned after Moroccan independence and they are suffering from severe structural decay.

Plaster decay (blistering, cracking, flaking and detachment) at Cave 85, Mogao Grotoes, Photographer: Lorinda Wong, ©J.Paul Getty Trust

The images show different types of plaster decay at Cave 85 at the Mogao Grottoes in China, mostly due to the presence of moisture and salts. The first image shows blisters and detachment of plaster, and the second image shows cracking, flaking and detachment.

Cracking at Huaca de La Luna, Trujillo Photographer: Giacomo Chiari

The image shows plaster cracking of the earthen decorated high relieves at the archaeological site of Huaca de La Luna in Trujillo, Peru. The cracking could have been produced during excavation.



Cracking at Church of San Javier de Ingenio, Nazca; Photographer: Claudia Cancino, ©J.Paul Getty Trust

The Church of San Javier Ignacio shows severe cracking at its walls, vaults and domes. The site has been abandoned since the 18th century and many earthquakes have affected the site as well. Some of the cracking could be from seismic loads while others are just due to abandonment.

Cracking at Church of San Juan in Ica, Peru Photographer: Claudia Cancino, ©J.Paul Getty Trust

The church was severely damaged by the 2007 Pisco earthquake, magnitude 7.9. The sacristy of the site shows x-shaped cracking typical of earthquake damage.

BIBLIOGRAPHY

📖 = Essential reading material

Aguila Garcia, Alfonso del, Cordinador. Curso de Patologia - Conservacion y Restauracion de Edificios (4 tomos). Madrid: Servicio de publicaciones del Colegio Oficial de Arquitectos de Madrid, 1993.

Ahmet, Kemal. 1994. A note on the discrepancy between various moisture meters. In *ASTM Hand-Held Moisture Meter Workshop,* ed. Sita R. Warren, 49. Madison. WI: Forest Products Society.

Ahmet, K., G. Dai, S. Jazayeri, R. Tomlin, P. Kaczmar, and S. Riddiough. 1999. Experimental procedures for determining the equilibrium moisture content of twenty timber species. *Forest Products Journal* 49 (1): 88–93.

Alessandrini, Giovanna, S. Boscarino, R. Bugini, D. Emmi,L. Giuffre, and E. Tempesti. 1990. The walls of Capo Soprano at Gela (southern Sicily): Materials and their decay. In *La conservazione dei monumenti nel bacino del Mediterraneo:Influenza dell'ambiente costiero e dello spray marino sulla pietracalcarea e sul marmo: Atti del 10 simposio internazionale, Bari7–10 giugno 1989,* ed. Fulvio Zezza, 235–41. Brescia, Italy:Grafo.

Alva Balderrama, Alejandro, and Giacomo Chiari. 1984. Protection and conservation of excavated structures of mudbrick. In *Conservation on Archaeological Excavations: With Particular Reference to the Mediterranean Area,* ed. Nicholas Stanley-Price, 109–20. Rome: ICCROM.

Amer, Saud A., Timothy O. Keefer, Mark A. Weltz, David C. Goodrich, and Leslie B. Bach. 1994. Soil moisture sensors for continuous monitoring. *Water Resources Bulletin* 30 (1): 69–83.

Arnold, Andreas. 1976. Soluble salts and stone weathering. In *The Conservation of Stone I: Proceedings of the International Symposium, Bologna, June 19–21, 1975,* ed. Raffaella Rossi- Manaresi and Centro "Cesare Gnudi" per la conservazione delle sculture all'aperto, 133–36. Rapporti della Soprintendenza alle gallerie di Bologna, vol. 23. Bologna: Centro per la conservazione delle sculture all'aperto. .

1981a. Nature and reactions of saline minerals in walls.In *The Conservation of Stone II: Preprints of the Contributions to the International Symposium, Bologna, 27–30 October 1981,* ed. Raffaella Rossi-Manaresi and Centro "Cesare Gnudi" per la conservazione delle sculture all'aperto, 13–23. Rapporti della Soprintendenza per i beni artistici e storici per le province di Bologna, Ferrara, Forli e Ravenna, vol. 31. Bologna: Centro per la conservazione delle sculture all'aperto.

1981b. Salt minerals in masonry; Salzmineralien in Mauerwerken. *Schweizerische mineralogische und petrographische Mitteilungen* 61 (1): 147–66.

1982. Rising damp and saline minerals. In *Fourth International Congress on the Deterioration and Preservation of Stone Objects, July 7–9, 1982: Proceedings,* ed. K. L. Gauri and J. A. Gwinn, 11–28. Louisville, KY: University of Louisville.

1984. Determination of mineral salts from monuments. *Studies in Conservation* 29 (3): 129–38.

Arnold, A., and A. Kueng. 1985. Crystallization and habits of salt efflorescences on walls. Part I, Methods of investigation and habits. In *Ve Congres international sur l'alteration et la conservation de la pierre: Actes, Lausanne, 25–27.9*

1985; Vth International Congress on Deterioration and Conservation of Stone: Proceedings, Lausanne, 25–27.9.1985, ed. G. Felix, 255–67. Lausanne: Presses polytechniques romandes.

Arnold, A., and K. Zehnder. 1985. Crystallization and habits of salt efflorescences on walls. Part II, Methods of investigation and habits. In *Ve Congres international sur l'alteration et la conservation de la pierre: Actes, Lausanne, 25–27.9.1985; Vth International Congress on Deterioration and Conservation of Stone: Proceedings, Lausanne, 25–27.9.1985,* ed. G. Felix, 269–77. Lausanne: Presses polytechniques romandes.

1988. Decay of stony materials by salts in humid atmosphere. In *VIth International Congress on Deterioration and Conservation of Stone: Toruń, 12–14 September 1988,* ed. J. Ciabach, 138–48. Toruń, Poland: Nicolaus Copernicus University, Press Department.

1990. Salt weathering on monuments. In *La conservazione dei monumenti nel bacino del Mediterraneo: Influenzadell'ambiente costiero e dello spray marino sulla pietra calcarea e sul marmo: Atti del 10 simposio internazionale, Bari, 7–10 giugno 1989,* ed. Fulvio Zezza, 31–58. Brescia, Italy: Grafo.

📖 Ashurst, John and Nicola. *Brick, Terracotta and Earth*, Pratical Building Conservation, Volume 2. English Heritage Technical Handbook. Halsted Press, John Wiley & Sons, Inc. New York. 1988.

🕮 Belsher, D. R. 1979. *Feasibility Study on the Use of a Microwave System for the Nondestructive Evaluation of Historic Adobe Structures.* In National Bureau of Standards NBSIR 79–1610. Washington, DC: U.S. Department of Commerce.

Baggio, Paolo, C. Bonacina, Antonio G. Stevan, and V. Fassina. 1993. Analysis of moisture migration in the walls of the S. Maria dei Miracoli Church in Venice. In *Conservation of Stone and Other Materials: Proceedings of the International RILEM/UNESCO Congress "Conservation of Stone and Other Materials—Research-Industry-Media," Held at UNESCO Headquarters, Paris, with the Cooperation of ICCROM* [et al.], *Paris, June 29–July 1, 1993,* 1st ed., ed. M.-J. Thiel, 170–77. RILEM [International Union of Laboratories and Experts in Construction Materials, Systems and Structures] Proceedings, no. 21. London: E. and F. N. Spon.

🕮 Basma, Adnan A., Azm S. Al-Homoud, Abdallah I. Husein Malkawi, and Mohamed A. Al-Bashabsheh. 1996. Swelling shrinkage behavior of natural expansive clays. *Applied Clay Science* 11 (2–4): 211–27.

Bendakir, Mahmoud, and Francois Vitoux. 1993. Methodologie de recherche pour la preservation du site archeologique de Mari (Syrie). In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 317–23. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Bertagnin, Mauro. [1986?] Il degrado dell'habitat vernacolare in terra cruda: Esperienze di ricerca in Algeria e in Italia. In *Manutenzione e conservazione del costruito fra tradizione ed innovazione: Atti del convegno di studi, Bressanone 24–27 giugno 1986,* ed. Guido Biscontin, 265–73. Scienza e beni culturali. Padua: Libreria Progetto Editore.

Bilborough, J. 1970. Moisture content determination: Indirect microwave methods. *Timberlab Papers: Report of a Seminar on Moisture Content Determination of Wood* 24:9–19.

Binda, L., C. Colla, and M. C. Forde. 1994. Identification of moisture capillarity in masonry using digital impulse radar. *Construction and Building Materials* 8 (2): 101–7.

Binda, Luigia, Giulia Baronio, Francesco Cantoni, and Paolo Rocca. 1995. Full-scale models for the study of repair techniques on brick masonry surfaces. In *Ceramics in Architecture: Proceedings of the International Symposium on Ceramics in Architecture of the 8th CIMTEC-World Ceramics Congress and Forum on New Materials, Florence, Italy, June 28–July 1, 1994,* ed. P. Vincenzini, 453–64. Monographs in Materials and Society, no. 1. Faenza, Italy: Techna.

Binda, L., G. Baronio, and A. E. Charola. 1985. Deterioration of porous materials due to salt crystallization under different thermohygrometric conditions. I. Brick. In *Ve Congres international sur l'alteration et la conservation de la pierre: Actes, Lausanne, 25–27.9.1985; Vth International Congress on Deterioration and Conservation of Stone: Proceedings, Lausanne, 25–27.9.1985,* ed. G. Felix, 279–88. Lausanne: Presses polytechniques romandes.

Binda L., E. Garavaglia, and C. Molina. 1999. Physical and mathematical modelling of masonry deterioration due to saltcrystallization. In *Durability of Building Materials and Components 8: Service Life and Asset Management: Proceedings of the Eighth International Conference on Durability of Building Materials and Components: Vancouver, Canada, May 30–June 3, 1999: V. 1. Service Life and Durability of Materials and Components,* ed. Michael A. Lacasse, D. J. Vanier, and National Research Council Canada, 527–37. Ottawa: NRC Research Press.

Blaser, Harold D., and Oscar J. Scherer. 1969. Expansion of soils containing sodium sulfate caused by drop in ambient temperatures. In *Highway Research Board Special Report,* 150–60. Washington, DC: Highway Research Board.

Bogle, A., J. T. McMullan, and R. Morgan. 1983. Development of a technique for the measurement of moisture levels in building materials. *Building Services Engineering Research and Technology* 4 (3): 77–83. Building Research Establishment.

1975. The measurement of moisture in building materials. *Building Materials* 31:32–34.

1986. Rising damp in walls: Diagnosis and treatment. *BRE Digest* 245:1–8.

🕮 Brown, Paul W., James R. Clifton, and Carl R. Robbins. 1978. *Factors Affecting the Durability of Adobe Structures.* Washington, DC: U.S. Department of Commerce, National Bureau of Standards.

Brown, Roy B., Beatriz Sandoval, and Haydee Orea M. 1990. The protection and conservation of the adobe structures at Paquime, Casas Grandes, Chihuahua, Mexico. In *6th International Conference on the Conservation of Earthen Architecture: 14–19, 1990,* ed. Kirsten Grimstad, 204–8. Marina del Rey, CA: Getty Conservation Institute.

Buil, M. 1983. Thermodynamic and experimental study of the crystallization pressure of water-soluble salts. In *Werkstoffwissenschaften und Bausanierung. Berichtsband des internationalen Kolloquiums. Esslingen, 6–8 Sept. 1983,* ed. F. H. Wittmann, 373–77. Lausanne: Lack und Chemie.

Caneva, Giulia, M. P. Nugari, and O. Salvadori. 1991. *Biology in the Conservation of Works of Art*. Rome: ICCROM.

Carpenter, T. A., E. S. Davies, C. Hall, L. D. Hall, W. D. Hoff, and M. A. Wilson. 1993. Capillary water migration in rock: Process and material properties examined by NMR imaging. *Materials and Structures* 26 (159): 286–92.

Carter, K., and K. Ahmet. 2001. On the uses and misuses of moisture meters: Results from a survey. *Building and Engineer* 76 (3): 13–17.

Charola, A. E., and R. J. Koestler. 1982. The action of salt-water solutions in the deterioration of the silico-aluminate matrix of bricks. In *Il mattone di Venezia: Contributi presentati al concorso di idee su patologia, diagnosi e terapia del mattone di Venezia: Ateneo veneto, Venezia, 29 ottobre 1982,* ed. Istituto per lo studio della dinamica delle grandi masse [Italy], 67–76. Venice: Comune di Venezia.

Charola, A. Elena, and Johannes Weber. 1992. The hydrationdehydration mechanism of sodium sulphate. In *Proceedings of the 7th International Congress on Deterioration and Conservation of Stone: Held in Lisbon, Portugal, 15–18 June 1992,* ed. J. Delgado Rodrigues, Fernando Henriques, and F. Telmo Jeremias, 581–90. Lisbon: Laboratorio Nacional de Engenharia Civil.

Cheetham, D. W., and C. A. Howard. 1999. Wall dampness diagnosis: Let's get it right. *Building Engineer: Journal of the Association of Building Engineers* 74 (1): 12–20.

Chiari, G., F. Colombo, L. Fiora, R. Compagnoni, A. Rava, G. Perino, and E. Barni. 1993. Santa Maria di Vezzolano: Restoration of the facade. In *Conservation of Stone and Other Materials: Proceedings of the International RILEM/UNESCO Congress "Conservation of Stone and Other Materials—Research- Industry-Media," Held at UNESCO Headquarters, Paris, with the Cooperation of ICCROM . . .* [et al.], *Paris, June 29–July 1, 1993,* 1st ed., ed. M.-J. Thiel, 468–78. RILEM [International Union of Laboratories and Experts in Construction Materials, Systems and Structures] Proceedings, no. 21. London: E. and F. N. Spon.

📖 Clifton, James R. 1977. *Preservation of Historic Adobe Structures: A Status Report*. NBS Technical Note 934. Washington, DC: Dept. of Commerce, National Bureau of Standards.

Colegio Oficial de Arquitectos de Madrid (COAM). Curso de Rehabilitacion. (10 tomos). Madrid: Servicio de Publicaciones del Colegio Oficial de Arquitectos de Madrid, 1984.

Coleman, G. R. 1997. Use of electrical moisture meters. *Building Engineer: Journal of the Association of Building Engineers* 72 (5): 18–19.

Cornell, J. B., and A. T. Coote. 1972. Application of an infrared absorption technique to the measurement of moisture content of building materials. *Journal of Applied Chemistry and Biotechnology* 22 (4): 455–63.

📖 Cornestone Community Partnership. 1998. *Adobe Architecture Conservation Handbook*, 1st ed. Santa Fe, NM: Cornerstones Community Partnerships.

Correns, C. W. 1949. Growth and dissolution of crystals under linear pressure. *Discussions of the Faraday Society, London* 5:267–71.

CRATerre. 1983. Aide a la conception architecturale. In *Marrakech 83: Habitat en terre,* 73–84. Villefontaine, France: CRATerre.

📖 CRATerre and Patrice Doat, eds. 1983. *Construire en terre*. Paris: Editions Alternatives.

Crosby, Anthony. 1980. Conservation of painted lime plaster on mud brick walls at Tumacacori National Monument, U.S.A. In *Ucuncu Uluslararasi Kerpic Koruma Sempozyumu: 29 Eylul–4 Ekim, 1980, Ankara; Third International Symposium on Mudbrick (Adobe) Preservation: 29 September–4 October, 1980, Ankara,* ed. Okan Ustunkok and Emre Madran, 59–78. Ankara: ICOM-Turkey / ICOMOS-Turkey.

📖 1983. Common sources of deterioration. In *Adobe, Practical and Technical Aspects of Adobe Conservation,* ed. James W. Garrison and Elizabeth F. Ruffner, 13–18. Prescott, AZ: Heritage Foundation of Arizona.

📖 1988. The causes and effects of decay on adobe structures. In *5th International Meeting of Experts on the Conservation of Earthen Architecture: Rome, Italy, 22–23 October 1987; 5e reunion internationale d'experts sur la conservation de l'architecture de terre: Rome, 22–23, X, 1987,* ed. Cynthia Rockwell, Titane Galer, Regine Riviere, and Pierre-Eric Verney, 33–41. Rome: ICCROM; Villefontaine, France: CRATerre.

1995. "Pre-existing Conditions which Adversely Effect the Performance of Adobe Buildings", *Workshop on the Seismic Retrofit of Historic Adobe Buildings*. Earthen Building Technologies and the Getty Conservation Institute. March 10, 1995.

Crosby, Anthony, et al. " San Diego Presidio Condition Assessment Report." Prepared by KEA Environmental, Inc. for the City of San Diego, California. Oct. 1999. (Disponible en el Instituto Nacional de Cultura, Trujillo)

Dayre, Michel, and Emmanuel Kenmogne. 1993. Etude des transferts d'humidite dans les blocs de terre crue compactee: Influence de la structure des terres. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 348–52. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

De Freitas, V. P., V. Abrantes, and P. Crausse. 1996. Moisture migration in building walls: Analysis of the interface phenomena. *Building and Environment* 31 (2): 99–108.

de Vekey, R. C. 1997. RILEM TC 127-MS: Tests for masonry materials and structures: Recommendations. *Materials and Structures* 30:323–28.

Díaz-Berrio, Salvador y Olga Orive B. "Terminología General en Materia de Conservación del Patrimonio Cultural Prehispánico." *Cuadernos de Arquitectura Mesoamericana*, Número 3, diciembre de 1984.

Dill, M. J. 2000. *A Review of Testing for Moisture in Building Elements*. London: Construction Industry Research and Information Association.

Doehne, Eric. 1994. In situ dynamics of sodium sulfate hydration and dehydration in stone pores: Observations at high magnification using the environmental scanning electron microscope. In *The Conservation of Monuments in the Mediterranean Basin: Stone and Monuments: Methodologies for the Analyses of Weathering and Conservation: Proceedings of the 3rd International Symposium Venice, 22–25 June 1994; La conservazione dei monumenti nel bacino del Mediterraneo: Materiali lapidei e monumenti, metodologie per l'analisi del degrado e la conservazione: Atti del 3o simposio internazionale, Venezia, 22–25 giugno 1994,* ed. Vasco Fassina, Heinrich Ott, and Fulvio Zezza, 143–50. Venice: Soprintendenza ai beni artistici e storici di Venezia.

Dowman, Elizabeth A. *Conservation in Field Archeology*. Methuen & Co Ltd. Great Britian, 1970.

Dubus, Michel. 1990. Le point sur les possibilites de l'electroosmose pour la conservation de l'architecture de terre. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 401–3. Los Angeles: Getty Conservation Institute.

Ducloux, Jacques, Yadji Guero, Paul Fallavier, and Serge Valet. 1994. Mineralogy of salt efflorescences in paddy field soils of Kollo, southern Niger. *Geoderma* 64 (1–2): 57–71.

Eller, H., and A. Denoth. 1996. A capacitive soil moisture sensor. *Journal of Hydrology* 185 (1–4): 137–46.

Feilden, Bernard M. *Conservation of Historic Buildings*. Butterworth Scientific. London 1982.

Forde, M. C., N. McCavitt, L. Binda, and C. Colla. 1993. Identification of moisture capillarity in masonry using digital impulse radar. *Proceedings of the 5th International Conference on Structural Faults and Repair 93, University of Edinburgh, 29 June–1 July 1993,* vol. 2, 397–403. Edinburgh: Engineering Technics Press.

Fouad, Ghomari. 1993. Construire en terre en zone littorale marine. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 547–51. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

French, Pamela. 1987. The problems of in situ conservation of mudbrick and mud plaster. In *In Situ Archaeological Conservation: Proceedings of Meetings, April 6–13, 1986, Mexico,* ed. Henry W. M. Hodges and Miguel Angel Corzo, 78–83. Mexico City: Instituto Nacional de Antropología e Historia de Mexico; Marina del Rey, CA: Getty Conservation Institute.

Fripiat, J. J., M. Letellier, and P. Levitz. 1984. Interaction of water with clay surfaces. *Philosophical Transactions of the Royal Society of London—Series A: Mathematical and Physical Sciences* 311 (1517): 287–99.

Gallego Roca, Francisco Javier, Ignacio Valverde Espinosa, Jose Manuel Lopez Osorio, Ana Maria de los Santos Fernandez, Maria Jose Martin Barranco, Esther Ontiveros Ortega, and Reyes Fajardo Martinez. 1993. The city walls of Granada (Spain): Use, conservation and restoration. In *Terra 93: 7ª Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 272–77. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Garrecht, H., H. K. Hilsdorf, and J. Kropp. 1991. Hygroscopic salts: Influence on the moisture behaviour of structural elements. In *Durability of Building Materials and Components: Proceedings of the Fifth International Conference Held in Brighton, UK, 7–9 November 1990,* ed. J. M. Baker, P. J. Nixon, A. J. Majumdar, and H. Davies, 313–24. London: E. and F. N. Spon.

Guntzel, Jochen George. 1993. Saltpetre and clay buildings. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 92–96. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Gummerson, R. J., C. Hall, W. D. Hoff, R. Hawkes, G. N. Holland, and W. S. Moore. 1979. Unsaturated water flow within porous materials observed by NMR imaging. *Nature* 281 (5726): 56–57.

Hartzler, Robert L., and Anne B. Oliver. 2000. Learning from the site: Evolution of the Fort Union Strategic Preservation Plan. In *Terra 2000: 8th International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon, UK, May 2000: Preprints,* ed. English Heritage, ICOMOS-UK, and University of Plymouth Centre for Earthen Architecture, 39–45. London: James and James.

Helmi, Fatma M. 1990. Deterioration and conservation of some mud brick in Egypt. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 277–82. Los Angeles: Getty Conservation Institute.

Honeysett, B. 1995. Common structural defects and failures in cob buildings and their diagnosis and repair. In *Out of Earth II: National Conference on Earth Buildings,* ed. Rex Harries and Linda Watson, 165–77. Plymouth, UK: Plymouth School of Architecture, Centre for Earthen Architecture.

📖 Houben, Hugo, and Hubert Guillaud. 1989. *Traite de construction en terre*. L'encyclopedie de la construction en terre, vol. 1. Marseille: Parentheses.

📖 1994. *Earth Construction: A Comprehensive Guide*. London: Intermediate Technology Publications.

Howell, Jeff. 1996. Moisture measurement in masonry: Guidance for surveyors. In *COBRA '95: Proceedings of the First RICS Construction and Building Research Conference Held at Heriot-Watt University on 8–9th September, 1995,* ed. Royal Institution of Chartered Surveyors, 145–51. London: Royal Institution of Chartered Surveyors.

Hudec, P., C. MacInnis, and M. Moukwa. 1986. Capacitance effect method of measuring moisture and salt content of concrete. *Cement and Concrete Research* 16 (4): 481–90.

📖 Hughes, Richard. 1983. Material and structural behavior of soil constructed walls. *Monumentum* 26 (3): 175–88.

Hughes, R. E. 1986. Survey techniques and strengthening of existing soil buildings. In *International Colloquium on "Earth Construction Technologies Appropriate to Developing Countries," Brussels, December, 10–12, 1984,* ed. Andre Liebaert, 191–224. Brussels: Belgian Administration for Development Cooperation.

Israel Antiquities Authority and The Getty Conservation Institute. "Assessment Report: The Triple Arched Gate, Tel Dan Israel." (Disponible en la biblioteca del Getty, Primavera 2000)

Jazayeri, S., and K. Ahmet. 1998. Moisture gradient studies in timber by measurement of dielectric parameters. In *Papers and Abstracts from the Third International Symposium on Humidity and Moisture,* 179–86. Teddington, UK: National Physical Laboratory.

2000. Detection of transverse moisture gradients in timber by measurements of capacitance using a multiple-electrode arrangement. *Forest Products Journal* 50 (11–12): 27–32.

Jerome, Pamela Stackley. 1993. Analysis of Bronze Age mudbricks from Palaikastro, Crete. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal,* *24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 381–86. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

📖 Joffroy, Thierry, and Sebastien Moriset. 1996a. *Palais royaux d'Abomey: Projet Prema-Benin II: 1. Circonstances et processus de degradation*. Rome: ICCROM; Villefontaine, France: CRATerre-EAG; Paris: UNESCO.

1996b. *Palais Royaux d'Abomey: Projet Prema-Benin II: 2. Guide d'entretien*. Rome: ICCROM; Villefontaine, France:CRATerre-EAG; Paris: UNESCO.

Justnes, H., K. Bryhn-Ingebrigtsen, and G. O. Rosvold. 1994. Neutron radiography: An excellent method of measuring water penetration and moisture distribution in cementitious materials. *Advances in Cement Research* 6 (22): 67–72.

Keefe, Laurence, Linda Watson, and Richard Griffiths. 2000. Possible causes of structural failure in traditional cob buildings. In *Terra 2000: 8th International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon, UK, May 2000: Preprints,* ed. English Heritage, ICOMOS-UK, and University of Plymouth Centre for Earthen Architecture, 254–60. London: James and James.

Koestler, Robert J., ed. 1991. *Biodeterioration of Cultural Property*. London: Elsevier Applied Science; New York: Elsevier Science Publishing Co. Koestler, R. J., and J. Vedral. 1991. Biodeterioration of cultural property: A bibliography. In *Biodeterioration of Cultural Property,* ed. Robert J. Koestler, 229–340. London: Elsevier Applied Science; New York: Elsevier Science Publishing Co.

Koumas, Ahmed, and Chahrazade Koumas. 1993. Methodologie et technique de conservation. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 231–36. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Krus, M., and K. Kiessl. 1989. NMR-Messung kapillarer Flussigkeitsbewegungen in porosen Gesteinen und Ableitung neuer Kapillartransport-Kenngrosen. *Jahresberichte aus dem Forschungsprogramm Steinzerfall, Steinkonservierung: Ein Forderprojekt des Bundesministers fur Forschung und Technologie* 1:39–45. Melville, Ian A. 1992. *Structural Surveys of Dwelling Houses: Including Structural Surveys of Flats and New Dwellings*. London: Estates Gazette.

Laurent, Jean-Paul. 1990. Influence de l'humidite sur les proprietes thermiques du materiau terre: Problematique, metrologie, resultats experimentaux. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 363–70. Los Angeles: Getty Conservation Institute.

📖 Liegey, Anne. 1990. Les problemes de conservation de l'architecture de briques crues au Proche-Orient; Conservation problems of mud brick architecture in the Near East. *Conservation restauration des biens culturels* (3): 62–63.

📖 Macintosh, Roderick J. 1974. Archaeology and mud wall decay in a West African village. *World Archaeology* 6 (2): 154–71.

Martin, M., J. Cuevas, and S. Leguey. 2000. Diffusion of soluble salts under a temperature gradient after the hydration of compacted bentonite. *Applied Clay Science* 17 (1–2): 55–70.

📖 Massari, Giovanni and Ippolito. *Damp Buildings, Old and New*. Translated by Cynthia Rockwell. ICCROM Technical Notes. Rome 1993.

McHenry, Paul Graham. Adobe: como construir facilmente. Mexico: Trillas, 1996. ISBN 968-24-5131-0

McGreevy, J. P. 1982. "Frost and salt" weathering: Further experimental results. *Earth Surface Processes and Landforms* 7(5): 475–88.

Michon, Jean-Louis. 1987. Earth architecture of south Morocco: Problems of conservation. In *8th General Assembly and International Symposium "Old Cultures in New Worlds": Washington, District of Columbia, United States of America, October 10–15, 1987: Symposium Papers,* ed. International Council on Monuments and Sites United States Committee, and International Council on Monuments and Sites General Assembly, 961–68. Washington, DC: United States Committee, International Council on Monuments and Sites.

Mill, Peter A. D. 1981. Thermographic interpretation of building enclosure deficiencies in Canadian public buildings. In *Thermal Infrared Sensing Applied to Energy Conservation in Building Envelopes (Thermosense 3), 1980,* ed.

Robert P. Madding, 121–36. Proceedings of the Society of Photo-Optical Instrumentation Engineers, no. 254. Bellingham, WA: Society of Photo-Optical Instrumentation Engineers.

Miller, W. P., and J. Scifres. 1988. Effect of sodium nitrate and gypsum on infiltration and erosion of a highly weathered soil. *Soil Science* 145 (4): 304–9.

Milota, M. R. 1994. Specific gravity as a predictor of species correction factors for a capacitance-type moisture meter. *Forest Products Journal* 44 (3): 63–68.

Monjo Carrió, Juan. *Patologia de Cerramientos y Acabados Arquitectonicos*. Madrid: Editorial Munilla-Leria, 1994. ISBN. 84-89150-12-5

Morales Gamarra, Ricardo. 1985. Conservation of structures and adobe decorative elements in Chan Chan. In *Adobe: International Symposium and Training Workshop on the Conservation of Adobe: Final Report and Major Papers: Lima, Cuzco (Peru), 10–22 September 1983,* ed. ICCROM, Regional Project on Cultural Heritage and Development UNDP/ UNESCO, and National Institute of Culture [Peru], 83–89. Lima: Regional Project on Cultural Heritage and Development UNDP/UNESCO; Rome: ICCROM.

Morgan, M. T., R. K. Wood, and R. G. Holmes. 1993. Dielectric moisture measurement of soil cores. *Transactions: American Society of Agricultural Engineers* 36 (1): 17–22.

Ndoro, Webber. 1990. An investigation into the pattern of deterioration of daga (earth) structures at Zimbabwe type monuments. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 377–82. Los Angeles: Getty Conservation Institute.

Newman, A. C. D. 1984. The significance of clays in agriculture and soils. *Philosophical Transactions of the Royal Society of London—Series A: Mathematical and Physical Sciences* 311 (1517): 375–89.

Newman, A. J. 1974. Independent core method: A new technique for the determination of moisture content. *Build Science* 9 (4): 309–13.

Odul, Pascal. 1990. Pathologie humide de constructions en terre: Methodologie de diagnostic. In *6th InternationalConference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 404–13. Los Angeles: Getty Conservation Institute.

🕮 Oliver, Anne B., and Robert L. Hartzler. 2000. Understanding the deterioration of adobe walls: Fort Union National Monument, New Mexico, U.S.A. In *Terra 2000: 8th International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon, UK, May 2000: Preprints,* ed. English Heritage, ICOMOS-UK, and University of Plymouth Centre for Earthen Architecture, 78–85. London: James and James.

Olivier, M., and A. Mesbah. 1993. Behaviour of ancient and new structures made out of raw earth. In *Structural Repair and Maintenance of Historical Buildings III,* ed. C. A. Frewer and R. J. B. Brebbia, 439–47. Southampton, UK: Computational Mechanics.

Osipov, V. I., N. B. Nguen, and N. A. Rumjantseva. 1987. Cyclic swelling of clays. *Applied Clay Science* 2 (4): 363–74.

Palma Dias, Gabriel Jose. 1993. A conservacao das estruturas antigas em terra crua. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 304–9. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Pardini, G., G. V. Guidi, R. Pini, D. Regues, and F. Gallart. 1996. Structure and porosity of smectitic mudrocks as affected by experimental wetting-drying cycles and freezing-thawing cycles. *Catena* 27 (3–4): 149–65.

Pearson, Gordon T. 1992. *Conservation of Clay and Chalk Buildings*. London: Donhead.

Pecoraro, Ana Lucia. 1993. The conservation of the Church of Nossa Senhora do Rosario, Embu, Sao Paulo Brazil. In *Terra 93: 7a Conferencia Internacional sobre o Estudo e Conservacao da Arquitectura de Terra: Silves, Portugal, 24 a 29 de Outubro, 1993; 7th International Conference on the Study and Conservation of Earthen Architecture: Silves, Portugal, 24–29 October, 1993; 7eme conference internationale pour l'etude et la conservation de l'architecture de terre: Silves, Portugal, 24 au 29 octobre, 1993,* ed. Margarida Alcada, 278–84. Lisbon: Direccao Geral dos Edificios e Monumentos Nacionais.

Phillipson, M. 1996. *Effects of Moisture in Porous Masonry: Overview of Literature*. Garston, Watford, UK: Building Research Establishment.

Pique, F., L. Dei, and E. Ferroni. 1992. Physicochemical aspects of the deliquescence of calcium nitrate and its implications for wall painting conservation. *Studies in Conservation* 37 (4): 217–27.

Prost, R., T. Koutit, A. Benchara, and E. Huard. 1998. State and location of water adsorbed on clay minerals: Consequences of the hydration and swelling-shrinkage phenomena. *Clays and Clay Minerals* 46 (2): 117–31.

Puhringer, Josef, and Johannes Weber. 1990. Salt action and material testing. In *9th Triennial Meeting: Dresden, German Democratic Republic, 26–31 August 1990: Preprints,* ed. Kirsten Grimstad, 361–65. Los Angeles: ICOM Committee for Conservation.

📖 Rainer, Leslie. Deterioration and pathology of earthen architecture. In *Terra Literature Review, 2008,* ed. Erica Avrami, Hubert Guillaud and Mary Hardy, 45-61. Los Angeles: The Getty Conservation Institute

📖 Ridout, Brian.V. Moisture monitoring in earthen structures. In *Terra Literature Review, 2008,* ed. Erica Avrami, Hubert Guillaud and Mary Hardy, 62-68. Los Angeles: The Getty Conservation Institute

Rodriguez Navarro, C., and Eric Doehne. 1999. Salt weathering: Influence of evaporation rate, supersaturation and crystallization pattern. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group* 24 (3): 191–209.

Rosenqvist, I. T. 1984. The importance of pore water chemistry on mechanical and engineering properties of clay soils. *Philosophical Transactions of the Royal Society of London—Series A: Mathematical and Physical Sciences* 311 (1517): 369–73.

Scarato, P. 1986. Pathologie et rehabilitation du patrimoine en pise. In *Modernite de la construction en terre, 1984,* ed. Philippe Michel, 251–62. Paris: Plan Construction et Habitat.

Schaffer, R. J. 1967. Causes of the deterioration of building materials. I. Chemical and physical causes. *Chemistry and Industry* 38:1584–86.

Scharff, W. 1990. Umweltschaden: Bedrohung fur archaologische Bodenfunde. *Archaeologie in Deutschland* 2:4–5.

Smith, Baird M. 1986. *Moisture Problems in Historic Masonry Walls: Diagnosis and Treatment*. Washington, DC: U.S. National Park Service, Preservation Assistance Division. Sparvoli, E., G. G. Ristori, and L. D'Acqui. 1989. Clay soils' porosity in relation to water content. Influence of clay type and cements on their structural stability; Porosite des sols argileux en fonction de l'hydratation. Influence du type d'argile et des ciments sur leur stabilite structurale. *Comptes Rendus: Academie des Sciences, Serie II* 308 (3): 327–33.

Šramek, Jiři, and Ludvik Losos. 1990. Outline of mud brick structures conservation at Abusir, Egypt. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 449–54. Los Angeles: Getty Conservation Institute.

TenWolde, A., and G. E. Courville. 1985. Instrumentation for monitoring moisture in building envelopes. *ASHRAE Transactions: Symposium Papers Presented at the 1985 Annual Meeting in Honolulu, Hawaii, of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.* 91 (2B): 1101–15.

Thomson, Garry. 1986. *The Museum Environment*. 2nd ed. Butterworths Series in Conservation and Museology. London: Butterworths, in association with the International Institute for Conservation of Historic and Artistic Works.

Torraca, Giorgio. 1970. An international project for the study of mud-brick preservation. In *Preprints of the Contributions to the New York Conference on Conservation of Stone and Wooden Objects: 7–13 June 1970,* ed. International Institute for Conservation of Historic and Artistic Works, 47–57. London: International Institute for Conservation of Historic and Artistic Works.

1976. Effetti dell'inquinamento atmosferico sui materiali da costruzione dei monumenti. In *Conservazione dei monumenti: Atti della Sezione II del XXIX Congresso nazionale dell'Associazione termotecnica italiana: Firenze, 25–27 settembre 1974,* ed. Associazione termotecnica italiana, 7–13. Milan:A. Barbieri.

📖 1976. "Brick, Adobe, Stone and Architectural Ceramics: Deterioration Processes and Conservation Practices, *The Preservation and Conservation Principles and Practices*, proceedings of the North American International Regional Conference. Williamsburg, Virginia, 1972. The Preservation Press. 1976.

1981. *Porous Building Materials: Materials Science for Architectural Conservation*. Rome: ICCROM.

📖 1988. *Porous Materials Building: Materials Science for Architectural Conservation*. 3rd ed. Rome: ICCROM.

Trotman, P. M. 1991. Diagnostic methods for measuring moisture in walls. In *Seminario Didattico Internazionale: "Umidita ascendente nelle murature: Fenomenologia e sperementazione" (Bari, 17–18 settembre 1991),* sottoprogetto 3, "Qualita ed innovazione tecnologica" del Progetto Finalizzato Edilizia del Consiglio Nazionale delle Ricerche. Rome: Consiglio Nazionale delle Ricerche.

U.S. Army Corps of Engineers, Waterways Experiment Station, Environmental Impact Research Program. 1989. *The Archeological Sites Protection and Preservation Notebook*. Vicksburg, MS: United States Army Corps of Engineers, Waterways Experiment Station.

U.S. National Park Service, Preservation Assistance Division, Technical Preservation Services. 1978. *Preservation of Historic Adobe Buildings*. Preservation Brief 5. Full text available at http://www.cr.nps.gov/hps/tps/briefs/brief05.htm.

Van Balen, Koenraad. 1990. Methodologie de la conservation et de la restauration des monuments en terre. In *6th International Conference on the Conservation of Earthen Architecture: Adobe 90 Preprints: Las Cruces, New Mexico, U.S.A., October 14–19, 1990,* ed. Kirsten Grimstad, 182–87. Los Angeles: Getty Conservation Institute.

Van Olphen, H. 1977. *An Introduction to Clay Colloid Chemistry: For Clay Technologists, Geologists, and Soil Scientists*, 2d ed. New York: Wiley.

📖 Viñuales, G. M. 1981. *Restauración de arquitectura de tierra. Capítulo 6*. Buenos Aires: Instituto Argentino de investigaciones de historia de la arquitectura del urbanismo.

Vos, B. H. 1965. Measurements of moisture content in building structures in-situ. In *RILEM/CIB Symposium on Moisture Problems in Buildings; Problemes de l'humidite dans les batiments, Helsinki, August 16–19, 1965*, paper 6–1, 1–15. Bagneux, France: Reunion Internationale des Laboratoires et Experts Materiaux, Systemes de Construction et Ouvrages.

1970. Measuring moisture content and distribution in constructions. *Build International* 3 (3): 51–54.

Vos, B. H., and H. J. Erkelens. 1958. Ermittlung des Feuchtegehaltes in Baukonstruktionen. *Allgemeine Warmetechnik* 8 (10): 211–17.

📖 Warren, John. 1999. *Conservation of Earth Structures*. Oxford: Butterworth-Heinemann.

Watson, A. 1965. Measurement of moisture content in some structures and materials by microwave absorption. In *RILEM/CIB Symposium on Moisture Problems in Buildings; Problemes de l'humidite dans les batiments, Helsinki, August 16–19, 1965*, paper 6–8, 1–8. Bagneux, France: Reunion Internationale des Laboratoires et Experts Materiaux, Systemes de Construction et Ouvrages.

1970. Measurement and control of moisture content by microwave absorption. *Build International* 3 (3): 47–50.

Webster, Frederick A. "Damage to Historic Adobe buildings from the Northridge Earthquake", *Workshop on the Seismic Retrofit of Historic Adobe Buildings*. Earthen Building Technologies and the Getty Conservation Institute. March 10, 1995.

Wilson, Philip J. 1999. Accuracy of a capacitance-type and three resistance-type pin meters for measuring wood moisture content. *Forest Products Journal* 49 (9): 29–32.

Winkler, Erhard, and Philip C. Singer. 1972. Crystallization pressure of salts in stone and concrete. *Geological Society of America Bulletin* 83 (11): 3509–14.

Wormald, R., and A. L. Britch. 1969. Methods of measuring moisture content applicable to building materials. *Building Science* 3 (3): 135–45.

Yatsu, Eiju. 1988. *The Nature of Weathering: An Introduction*. Tokyo: Sozosha.

Zehnder, Konrad. 1996. Gypsum efflorescence in the zone of rising damp: Monitoring of slow decay processes caused by crystallizing salts on wall paintings; Efflorescence de gypse dans la zone d'humidite du sol: Suivi des processus d'alteration faibles par cristallisation de sels sur des peintures murales. In *Proceedings of the 8th International Congress on Deterioration and Conservation of Stone: Berlin, 30. Sept.–4. Oct. 1996,* ed. Josef Riederer, 1669–78. Berlin: Moller Druck und Verlag.

Zehnder, K., and A. Arnold. 1988. New experiments on salt crystallization. In *VIth International Congress on Deterioration and Conservation of Stone: Toruń, 12–14 September 1988,* ed. J. Ciabach, 320–29. Toruń, Poland: Nicolaus Copernicus University, Press Department.

Zhang, Cuiwen, and Zunqin Wang. 1987. Microscopical research on the crystallization of salts in saline soils [Chinese language]. *Turang Xuebao* 24 (3): 281–85.

Ziegert, Christof. 2000. Analysis of material, construction and damage in historical cob buildings in central Germany. In *Terra 2000: 8th International Conference on the Study and Conservation of Earthen Architecture, Torquay, Devon, UK, May 2000: Preprints,* ed. English Heritage, ICOMOS-UK, and University of Plymouth Centre for Earthen Architecture, 182–86. London: James and James.