adobe

INTERNATIONAL SYMPOSIUM AND TRAINING WORKSHOP ON THE CONSERVATION OF ADOBE

Final Report and Major Papers

Lima - Cusco (Peru)

egional Project on Cultural Heritage
d Development UNDP/UNESCO

ternational Centre for the Study
the Preservation and the
estoration of Cultural Property

ICCROM

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10-22/September 1983

Organized by:

UNDP/UNESCO REGIONAL PROJECT ON CULTURAL HERITAGE AND DEVELOPMENT

INTERNATIONAL CENTRE FOR THE STUDY OF THE PRESERVATION AND THE RESTORATION OF CULTURAL PROPERTY (ICCROM), ROME

In collaboration with:

National Institute of Culture (Peru)

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International Council on Monuments and Sites (ICOMOS)

Italo-Latin American Institute (IILA)

Concern at international level for the conservation of adobe has a brief history. It is only a little more than a decade ago that action in this area was initiated and for this we are greatly indebted to Professor Piero Gazzola.

Professor Gazzola, who was President of ICOMOS and a member of the Council of ICCROM as well as a teacher on ICCROM's Architectural Conservation courses, arrived at the conclusion, after travelling extensively and observing the situation at first hand around the world, that cooperation at the international level was the best way to combat effectively the deterioration of adobe structures. He put the initial accent —and rightly so— on research and field projects. The first of these began in 1968, with ICCROM's participation in the research being carried out then in Iraq with the cooperation of the Institut Royal du Patrimoine Artistique in Brussels, the Institute of Mineralogy and Archaeology of the University of Turin, and at the Iraqi-Italian Institute in Baghdad. This research resulted in the formulation of a series of questionnaires aimed at pinpointing the basic problems and defining the general characteristics in the various regions, as well as stimulating a deeper concern for the study of the protection of adobe structures.

In the wake of these researches two International Symposia on this subject were organized and held in Yazd (1971 and 1976) by the Iranian National Committee of ICOMOS.

Since the second symposium aimed to produce a document that would serve to establish a methodology for the study of adobe structures and archaeological ruins, another questionnaire was drawn up by ICCROM and presented as a major issue at the Regional Meeting on Conservation held at Santa Fe, New Mexico, in 1977. As a result of this meeting, this questionnaire became a fairly detailed model for the full investigation of the use of adobe as a building material. The ultimate aim was to stimulate experimentation and to standardize methods, and it was felt that this task of standardization ought to be entrusted to international organizations and committees.

The third symposium, organized in Ankara in 1980, provided an opportunity to revise the more important tests carried out after the second Yazd meeting. Althcugh some positive results had been obtained, the majority of the real problems remained unsolved, especially with regard to the long-term reliability of the testing methods. While scientists favoured further testing and research, conservators objected to expensive long-range experiment in view of the rapid deterioration rate of the material.

Evidently, it is not possible to arrive at definitive solution on the basis of a few international meetings. Such meetings can serve only to indicate a possible orientation for research activities and to suggest possible areas of study and field work. In fact, following the second Yazd meeting two pilot projects were initiated: one at Tumacacori, U.S.A., and the other in Peru at Chan Chan.

In 1983, sufficient time had elapsed since the symposia held in Yazd and Ankara to justify the organization of another international meeting. It was felt, however, that at this meeting special emphasis should be placed upon training. This led us therefore to select for this meeting experts who were also trainers and participants who could be readily integrated into the workshop. It is with these criteria in mind that ICCROM, in collaboration with the Regional Project on Cultural Heritage —the cultural dimension of development and communication— of UNDP/UNESCO, and the ICOMOS International Committee on Adobe, with the support of the World Cultural Heritage Convention of UNESCO, and under the auspices of the National Institute of Culture of Peru, organized the International Symposium and Training Workshop on the Conservation of Adobe in Lima and Cusco.

Thus this neeting, which was a follow-up at national level of the previous international symposia on adobe conservation, had the ambitious aim of expanding current knowledge of the appropriate methods and techniques for adobe conservation among those technicians responsible for the conservation of the cultural heritage.

It should be stressed once more that any development in this field requires both financial investment and long-term sponsoring. These can and should be provided by national agencies, with international organizations acting merely as promoters. Continuity can be secured through national efforts and agencies alone.

The way in which this Symposium was organized, and the Peruvian contribution to it, are a perfect example of this. This lightens our pessimism somewhat and we believe that it could herald a turning-point in the field.

We trust that this publication, which includes the major papers presented at the symposium, will be of aid to those restorers and conservators engaged in the preservation of adobe monuments, sites, and historic centres throughout the world.

Prof. Dr. Cevat Erder

Director of ICCROM

Adobe monuments and the technology for building with earth are part of the heritage of many nations. Earth, which has been used as a building material for over 10,000 years, has given rise to a great variety and wealth of architectural forms throughout the world.

This monumental heritage is seriously endangered today, both by urbanization and industrialization processes, as well as by natural and human causes of decay.

But the cultural heritage of a people comprises more than its monuments and historic centres. The task of conservators and restorers therefore, should be not only to safeguard of monuments and other adobe edifices but to rescue as well the traditional methods and endogenous technologies still in use in those countries where earth is used as a building material — and which are in danger of disappearing.

The Symposium-Training Workshop on the Conservation of Adobe held in Cusco in 1983 brought together experts from Latin America and the Caribbean, the United States, Africa, Asia and the Middle East thanks to the collaboration of the National Institute of Culture of Peru, of ICCROM, of UNDP, the World Heritage Convention of UNESCO, ICOMOS and various public and private foundations, such as the Ford Foundation and IILA

This colloquium centred on the different preservation techniques applicable to adobe monuments, taking into account natural causes of deterioration due to the passage of time, as well as the damage caused by earthquakes and other natural disasters. After studying the characteristics of adobe as a building material and analyzing its physical, chemical and mechanical properties, the structural conservation of adobe buildings was discussed. Various techniques for the assessment of structural faults, the consolidation of foundations and strengthening of walls were explained, as well as the preventive measures which should be taken in view of earthquakes.

The treatment of painted and decorated surfaces over adobe structures was analyzed in depth, given the number of adobe monuments that possess valuable mural paintings.

The adaptation of adobe buildings to new use was also discussed. Different typologies of earthen buildings were studied, and existing attitudes toward adobe conservation were analyzed.

Finally, the protection and conservation of historic cities and urban complexes built with adobe was discussed.

These topics were analyzed by architects, art historians, chemists, structural engineers and urban planners who had been brought together by the Symposium.

The special characteristics of adobe, and notably its fragility were taken into account, as well as the specific techniques required for its conservation, which differ from those applicable to the conservation of other materials, such as stone or wood.

This Symposium-Training Workshop is comparable to the Wood Conservation Course organized in Norway, or that of Conservation of Stone, which takes place in Venice. Many of the Third World countries also face problems concerning the preservation of wood (especially in tropical regions) as well as stone. It is hoped that, in the future, these courses will be projected to developing countries.

It should be stressed that the two previous meetings on the conservation of adobe (the Seminars at Yadz and Ankara) took place in Third World countries. This Symposium was, thus, the third to be organized in a developing country.

The conservation of adobe should be placed within the global context of development. For this reason, parallel lectures were organized during the Symposium and open to the public, dealing with the use of adobe in contemporary housing.

One of the main problems in the world today is the housing shortage. We know that, between now and the year 2000, it will be necessary to build 500 million homes to house the inhabitants of developing countries. This deficit continues to grow; in most Third World countries, at least 25% of the population (and sometimes 50%) lives in slums, shantytowns or improvised shelters.

The solution in many parts of the world will be to turn to adobe. For a building material to be used for the habitat of the poor, it must be used by the poor themselves. It must be cheap, easy to use and immediately available.

Adobe has all these characteristics. One hears a lot about "appropriate technology" today: it is time that city planners and builders stop *praising* traditional construction materials and start *using* them. It is necessary, therefore, to change existing attitudes toward adobe housing.

Some Third World leaders, such as Nyerere and Indira Ghandi, have spoken about these problems. Says Nyerere: "People insist on waiting to obtain a tin roof over 'European earth' — that is, cement. If we are to progress... we must overcome these mental blocks... The majority of the people do not have means to buy a cement house. Therefore, if we do not help them build a house made of improved traditional materials... we will have done nothing to help them live in a decent home".

Indira Ghandi, during a personal interview with Earthscan in 1980 stated: "all the new houses are built to consume energy. They are hot in summer and cold in winter. But not our old houses... We should take another look at the old technology. There is much logic in what people have been doing throughout the years, in accordance with their climate, their environment, their lifestyle. We cannot conserve all of it, because our way of life has changed, but I do believe we can conserve a great deal, adapting it and making it more efficient".

We should like to recall here Hassan Fathy, the Egyptian architect who revalued adobe architecture in Egypt and built a whole town in adobe near Luxor, in spite of mockery and opposition. In 1980, Fathy obtained the Aga Khan prize for Islamic architecture and today his work is seen as a significant contribution to contemporary architecture. Fathy's experiments should be food for thought in our architecture schools.

One hears much today about "horizontal cooperation" as well. It is true that there is no easy way to break the existing technological dependence vis a vis the industrialized nations, yet we believe that the developing world can and should benefit from technologies to be found in countries which face similar problems. A greater exchange of information is necessary, and many projects could be faced jointly. In the field of adobe, this "south-south" cooperation is extremely pertinent: this became evident in the Lima Symposium-Training Workshop. Events such as this one help further technological exchange and lead to share conservation experiments which can be applied in other parts of the world where problems are similar.

The aim of this publication is to disseminate knowledge concerning adobe, and to create an awareness of the need to preserve and revalue both the old monuments and sites in raw earth and the appropriate techniques for building with this material.

On the eve of the next meeting on this subject, which will take place in Senegal in 1986, we hope it will be of help to those who work in this area of conservation.

Sylvio Mutal

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International Symposium and Training Workshop on the Conservation of Adobe

Lima - Cusco, 10-22 September 1983

Background

The International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM), in close collaboration with the International Council of Monuments and Sites (ICOMOS) and UNESCO has organized, in past years, a number of international Symposia related to the conservation of adobe.

Following the seminars held in Iran and Turkey, an International Symposium took place in Lima and Cusco, Peru, from 10 to 22 September 1983. This event was of an innovative nature, inasmuch as it consisted at the same time of a training Workshop.

The Symposium-Workshop was part of a series of courses organized since 1975 by the UNDP/UNESCO Regional Project on Cultural Heritage and Development in the city of Cusco on the Conservation and Restoration of Archaeological and Architectural Monuments, as well as of Historical Centres and Sites.

The Symposium-Workshop brought together over 80 lecturers and participants from Latin America and the Caribbean, Africa, the Middle East, Asia, Europe and the United States. This event received the support of the UNESCO Convention for the Protection of the World Cultural and Natural Heritage and the United Nations Development Programme, and that of governmental and non-governmental specialized agencies interested in the field of cultural heritage. The Symposium was organized jointly by ICCROM and the UNDP/UNESCO Regional Project on Cultural Heritage and

Development under the auspices of the National Institute of Culture of Peru.

The main objectives of this meeting were:

—To provide a meaningful follow-up to previous symposia on the conservation of adobe, in keeping with the established functions of ICCROM.

—To strengthen ICCROM's active collaboration in decentralized and joint programmes with the Regional Project on Cultural Heritage and Development in Latin America and the Caribbean, thus attending to the need of constant support in the training of local personnel dedicated to the conservation of adobe.

—To encourage a greater exchange of information on the techniques of adobe conservation, as known in different parts of the world where this material is still part of a traditional, endogenous technology, used both in present-day construction and in the conservation of monuments and historical sites. This exchange, it was deemed, would help to strengthen horizontal cooperation between developing nations (TCDC).

The dissemination of appropriate methods and techniques for the preservation of earthen building materials and mud structures was the main priority of the Symposium, which provided a forum where international specialists from related disciplines presented and exchanged ideas and information.

Development of the Symposium

The meeting was inaugurated by the former Minister of Education of Peru, Mr. Patricio Ricketts who addressed the participants and stressed the importance of this event. Other speakers at the inaugural session included Dr. Cevat Erder, President of ICCROM; Mr. Sylvio Mutal, Chief Technical Advisor and Regional Coordinator of the UNDP/UNESCO Regional Project on Cultural Heritage; Mr. Eric Perrin, Resident Representative, a.i., United Nations Development Programme (UNDP) and a representative of the National Institute of Culture of Peru.

The Symposium-Workshop discussed extensively, in conference-courses and working papers, the following topics:

—"Concepts and attitudes in conservation: an introduction to the historic use of earthen building materials".
"Use and techniques of earthen building materials in a world context".
"Inventory and survey of adobe buildings".
"The characterization of adobe as an earthen building material; physical and chemical properties; mechanical properties, methods for the characterization and preservation of adobe as a building material".
"Structural conservation of earthen architecture, consolidation of foundations, monitoring structural movements, repair of earthen walls, reinforcement of adobe masonry, assessment of earthquake damage, prevention and repair".

"Painted and decorated surfaces on adobe structures: characterization, damage and treatment".
"Adapting adobe buildings and monuments to new use".
"The protection and conservation of earthen historic towns and/or urban settlements".

The topics discussed centred on the history of adobe and its use from antiquity to the present, as well as with the problems of its conservation. It was stated that earth, which constitutes 74% of the world's crust has been used as a building material since over 10,000 years ago. A. Stevens, from Belgium, lectured on the extremely varied edifices which have been built with this material throughout history. Archaeological and historical remains in the Near East, Egypt, Iran, Central Asia and North and South America were analyzed. Franca Helg (Italy-IILA) and C. Erder (ICCROM) also intervened in these discussions.

The use and techniques of building with earth were also analyzed in the Latin American context. Different regional techniques, such as compacted earth, compressed earth (*tapia, tapial*) and *quincha* or *bahareque* (wattle and daub) were examined.

It was emphasized that before any intervention in a building, these techniques should be studied and the main causes of deterioration should be assessed. Restorers should be knowledgeable of the different restoration procedures, which must be applied in a correct sequence. Lecturers Samanez (Peru) and Reyes (Mexico) provided specific examples of restoration carried out in Cusco, Peru and Tlaxcala, Mexico. Mr. Reyes showed a booklet published in Mexico as part of a government training programme for self-help in building.

A. Crosby (USA) spoke of the importance of surveying an adobe building or structure to determine the causes of decay. Signs of deterioration such as basal erosion, surface erosion, cracks, bulges, creep or upper wall displacement should be examined. Problems of deterioration he explained, might be caused by running water, strong wind, high water-table, excessive humidity or external loading. The different tools available to detect these problems were examined. Simple ones, including plumb-bobs, levels and probes, as well as more sophisticated ones, including laser and microwave technology, were discussed. The importance of understanding and having respect for the material were stressed.

When dealing with the characteristics of earth as a building material, G. Chiari (ICCROM) and Sergio Rojo (Chile) discussed its main properties. Soil analysis and different lab and *in situ* tests were explained. Recommendations for stabilization and improvement were discussed, as well as the different existing techniques for making the adobe blocks. This last aspect was treated in depth by A. Alva (ICCROM), who presented a paper on the fabrication and preservation of mudbricks.

J. Vargas (Peru) analyzed seismic behaviour in adobe structures. He stressed the need to develop prevention programmes, rather than having to perform restoration interventions.

T. Rutenbeck (USA), lecturing on structural monitoring, explained how to predict the danger of structural collapse. He discussed the precise levelling equipment (such as electronic gages) used to measure deflection, differential settlement, geological movements and progressive wall tilts.

S. Rojo (Chile) gave examples of different structural systems used in adobe construction, and showed structural restoration work carried out in historic monuments in Chile.

The conservation of high-relief friezes and painted surfaces in Chan Chan and other sites of the Moche culture in northern Peru was the topic addressed by R. Morales (Peru), while R. Estabridis (Peru) gave a history and description of the mural paintings over adobe walls found in the cloister of San Francisco in Lima.

P. Schwartzbaum (ICCROM) and S. Lewin (USA) explained the use of an ethyl-silicate based solution as part of the treatment for conservation of a mural painting of the Chalcolithic Age found in Jordania in 1979, and discussed the long-term effects of this consolidant on adobe.

R. Samanez (Peru) and F. Helg (Italy-IILA) dealt with the adequate adaptation of old buildings to new use. They insisted that the same materials as those used originally should be utilized in restoration, while not disregarding structural reinforcement. Both experts saw the need to renovate old buildings in historical centres, adapting them to new use, in keeping with the needs of the community.

J. Vérité (France-UNESCO) analyzed "vernacular architecture" as opposed to "culture architecture". He underlined the problems faced in conservation and warned against "nostalgia".

N. Bouaré, from Mali, and Ashley de Vos, from Sri Lanka gave examples of vernacular architecture in both countries. Bouaré explained different African techniques for building with earth while De Vos related his experiments in the consolidation of painted surfaces over earthen cave walls in Buddhist shrines in Sri Lanka.

The present publication includes an abridged version of the main papers presented during the Symposium.[1]

Aside from the regular sessions of the Symposium, a series of lectures on the use of adobe in contem-

1. Because of lack of space, the following papers are not included in this publication: Ricardo Estabridis, "Mural Paintings in the Main Cloister of San Francisco el Grande, Lima"; Sergio Rojo, "Physical Characteristics of Adobe"; Ricardo Morales, "Moche Murals: Technique and Conservation"; Roberto Samanez Argumedo, "Use and Techniques of Earthen Building Materials in the Latin American Context"; Ignacio Gárate, "Address to the Symposium on Adobe". We have, on the other hand, included two papers in their entirety; those presented by Giacomo Chiari and Alejandro Alva, both from ICCROM, for we believe their content to be useful for those restorers dedicated to the conservation of adobe.

porary housing were open to the public during the evenings. Both rural and urban experiences in different parts of the world were discussed, as well as the attitudes of the population towards adobe housing.

The Symposium-Workshop reiterated the technical conclusions of the meetings held during the previous decade on the preservation and treatment of adobe. Special emphasis was placed on protective measures to be taken during and after archaeological excavations: the new treatments developed for conservation and maintenance; the appropriate techniques to be used in sites made of partially baked mud and the adequate methods of conservation and protection of historical centres and monuments.

Two photographic exhibits were displayed in galleries adjoining the main meeting hall. "Adobe in America: its History, Conservation and Contemporary Use" (mounted by Mario and Maria Acha from the UNDP/UNESCO Regional Project on Cultural Heritage with the support of the Ford Foundation) gave examples of adobe buildings in the New World, while "Mudbrick Architecture" (Centre Georges Pompidou, France) displayed photographs of earth architecture throughout the world.

Trips to Cusco and Chan Chan gave the participants a chance to examine Colonial and Pre-Hispanic adobe buildings and the problems confronted in their structures and surfaces. The conservation methods applied were analyzed and evaluated in each case.

An afternoon at the Structures Laboratory at the School of Civil Engineering of the Catholic University of Peru provided a chance to see the experiments being carried out by a team of experts headed by J. Vargas, to achieve seismic-resistant structures and bricks.

The members of the Symposium were received in the Presidential Palace by the President of Peru, Fernando Belaunde, an architect himself, who lectured on the history of adobe in Peru and throughout the Andes, and later showed the participants the different housing projects in the metropolitan area.

In and around Lima visits were made to several archaeological adobe sites, including the temple-complex of Pachacamac, the Huaca Juliana and the palace and museum at Puruchuco.

Follow up activities 1984/85

Pilot projects

The Symposium emphasized the need to establish a pilot project to study the specific problems of painted surfaces on mud walls in order to improve preservation Techniques. Peru, a country with a rich cultural heritage in this field, was chosen as the site of this project, which will also include the training of competent personnel in this area.

Other pilot projects under consideration include the conservation of mudbrick buildings in seismic areas, as well as in regions affected by environmental pollution and climatic erosion.

Bearing in mind the recommendations of the Symposium, early in 1984 the UNDP/UNESCO Regional Project on Cultural Heritage began to contact specialized institutions and funding sources in order to develop these projects, which will be initiated during the second part of 1984 in Chan Chan.

With great satisfaction, the organizers of the Symposium have taken note of the work undertaken since the meeting by different participants. During the first part of 1984, fifty mudbrick houses, destined for lower-income families, were built in Lampa, Chile by the local municipal government. Sergio Rojo (Chile), one of the lecturers at the Symposium, acted as structural consultant for this project. In Brazil, a working group has been set up to analyze mudbrick conservation techniques at a national level. A group of young Peruvian architects, accompanied by the painter F. de Szyszlo, visited Hassan Fathy in Egypt and exchanged information about the technology of adobe. Cooperation links have also been established between North Africa and Latin America for the exchange of specialists in adobe conservation.

Funds provided by the ICOMOS Committee on Mudbrick Conservation to ICCROM have made possible the publication of the exhibit: "Adobe in America. Its History, Conservation and Contemporary Use", mounted by the UNDP/UNESCO Regional Project on Cultural Heritage during the Symposium. This exhibit, now in the form of a book, has been distributed internationally.

This same photographic exhibit has travelled to Colombia, Brazil and Venezuela during the present year. In 1985, it will be shown in Spain, while the Georges Pompidou exposition on adobe architecture has travelled to Argentina, Brazil and Venezuela.

The Symposium received wide publicity in ICCROM's *Newsletter* N° 9, where a detailed account of the events was given. Conclusions and Recommendations of the Symposium were presented to ICCROM's General Assembly which took place in Rome in May 1984.

Venue and date of next meeting

With satisfaction, the Symposium took due note of the offer made by the representative of the Republic of Senegal that a future meeting on adobe take place in that country during the middle of this decade. This meeting would discuss scientific progress in this field and would establish an inventory and study of the typical endogenous technologies used in the conservation of adobe and other types of earthen buildings, both ancient and contemporary, in order to give them an appropriate use in present-day society.

Closing session

The Conclusions and Recommendations presented by the Symposium (see below) were read and adopted at the last session, held at the headquarters of the Andean Pact (Acuerdo de Cartagena) where the Minister of Housing of Peru, Mr. Javier Velarde Aspíllaga, officially closed the Symposium and presented the participants with certificates of attendance.

Introduction to the Historic Use of Earthen Building Materials. Case Study: Mesopotamia

André Stevens

Summary

From antiquity, much use has been made of raw earth —a material covering three quarters of the earth's surface— from Mesopotamia to Egypt. In Europe, Africa and the Middle East, Roman and then Muslim civilisations built in earth, as did in Asia the civilisation of the Indus Valley, the Buddhist monks and the empires of China. In the Middle Age, this material was still used in Europe, as it was in North America by the Indians, in Mexico by the Toltecs and the Aztecs, in Peru by the Mochicas.

For more than 10,000 years, earth has been used to raise monuments both prestigious and appropriate to the material and spiritual development of communities. Warehouses, ziggurats, pyramids, churches, mosques, monasteries, palaces, stupas: all sought to use to the best advantage the resources of this material and to devise the most varied architectural forms for it, without necessarily feeling constrained by its nature, so often considered poor and weak. Even the most dispassionate observer could not help but be moved by this inscription found at the base of a pyramid in raw earth near Cairo: "Do not disdain me when comparing me to pyramids of stone: I am as high above them as Jupiter is above the other gods, for I was built in bricks made from the silt at the botom of the lake".

This paper, which addresses a public from widely varying backgrounds, seeks to fill a gap too evident in the history of architecture in general. The subject is of such breadth and scope that we must perforce narrow it down. Thus we shall particularly emphasize the ancient sites of Mesopotamia (Sumer, Elam, Akkad, Babylon, Assyria) covering 4,000 years of monumental architecture in earth beginning well before the invention of writing in Sumeria.

1. Brick (Adobe)

Brick has a long prehistory.

Supple earth, rich in clay, was first used in unformed rubble. This primitive technique appeared for the first time in the eighth millenium in the proto-neolithic installations at Jericho. These "primitive bricks" took the form of balls of clay grouped around low ridges or mounds, which formed the basis for light construction. We can see at this same site that the following era was already in possession of real brick.

In the first phase (around 6,800 BC) round houses were constructed out of raw bricks, formed by hand and called hogbacked bricks (*en dos d'âne*). The base was level, the upper side quite well rounded.

In the second phase, around 6,250 BC, houses were rectangular, their walls and floors covered by a thick coating of purified clay, smooth and coloured. Bricks now took the form of a quadrangular prism with irregular edges. Deep thumb impressions on the surface serve to strengthen the adhesion of the mortar. These were called "thumb-impressed bricks".

We note also the use of plain lumps of clay, joined together by a mortar of mud mixed with dry grass, in the ruins of the first neolithic 'village' of Hassuna, in Iraq, in the 5th millenium. We find renewed use of bricks with digital impressions on the Iranian plateau, at Sialk. Brick was used there for foundations and floors, while walls were constructed in mud.

Moulded brick, packed by hand into open moulds, appeared toward the end of the 5th millenium, in the north of Mesopotamia: At Chagar-Bazar, they measured 22 x 20 x 7.5 cm, at Tell Aswad 33 x 33 x 10 cm, at Sialk 30 x 30 x 10 cm. Before 2800 BC, moulded brick, level and in more or less regular geometric forms, was the common construction material, varying only in size or dimensions from one site to another.

At Tépé Gawra, in the middle of the 4th millenium, unbaked bricks were of excellent quality, and were secured by a mortar of soil and ashes. Their dimensions were 36 x 18 x 9 cm, 48 x 28 x 10 cm, or 56 x 28 x 14 cm. This rectangular format used half bricks at the same time as whole square bricks. The alternance of two formats of identical proportions, by facilitating the placement of cornerstones (*carreaux boutisses*) assured a more secure fit, especially in chaining at an angle. This method was universally adopted and long retained. In the temple of Eridu, at the same period, the foundation bricks were of larger dimensions than those of the walls — 43 x 13 x 7 cm as opposed to 28 x 23 x 6 cm.

At Uruk, the more recent constructions — such as the white temple, built around the middle of the 4th millenium — used a small sectional square brick varying from 16 x 6 x 6 cm to 24 x 10 x 10 cm (called *Riemchen* in German). In the following period, the section was rectangular, 28 x 14 x 8 to 9 cm (*Flachziegel*); certain sections were much larger, with sides of 80 cm (*Patzen*).

The normal evolution of raw brick, which had stabilized around a geometric form of regular proportions, was interrupted at the beginning of the 3rd mill. by the appearance of a more primitive form. This newer method is known as the 'plan-convexe' or flat-convex brick. The upper part was distinctly rounded and was marked by finger prints or by ripples formed by the edge of the hand. The first flat-convex bricks were found at Tello in the last century. Since then, at nearly every Mesopotamian site, they have coincided with the ruins of the proto-dynastic era. They have not been found at Mari, where the pre-Sargonic temples were still built with flat bricks. The flat-convex bricks disappeared at the time of Sargon of Agadé, around 2,350. The special fitting of these bricks has been studied with precision at the sites of Diyala. The flat-convex bricks could be baked, but this was done almost exclusively for the construction of pits, basins, canals, pavements and baseboards.

We find in the Sargonic era the return to the use of flat brick, alternating with large square bricks or half bricks. Later, quarter bricks, bricks in the form of archstones, corners and circle segments appeared. We come finally to the glazed brick, arranged in friezes cr in vast panels as at Babylon or Susia, which spread a symphony of colour over the previously drab walls.

Often built in unbaked brick, Mesopotamian architecture needed much protection and consolidation. This double requirement was met in turn by innumerable cones of coloured baked earth planted in clay, by baseboards (orthostats) of stone reinforcing the walls, by gigantic baseboards (plinths) ornated with bas reliefs, finally by brick panels glazed with colour. Large panels of glazed brick appeared in the second millenium, but it was only a few centuries later that they constituted the richest decorations of palaces and temples in Assyria, Babylon and Persia. There were then veritable 'tableaux' in glazed brick, effected on level clay surfaces, and there were also, in another style, uncoloured bas-reliefs in brick. On the brick columns of Uruk, Ur and Tello, at the 4th and the beginning of the 3rd millenium, slender cones of baked earth, their bases tinted in red, white or black, were planted in close set rows, to the point of covering the columns completely in bands of colour. Their purpose was at once to decorate and protect the surface. At Obeid, columns in the form of trunks of palm trees framed the entrance to the temple built in the 3rd millenium; their surface covered with triangular laminations of shell fixed in asphalt.

Documentation is abundant on the innumerable uses that the Mesopotamians made of 'solid asphalt' in all its forms: We can say that their country is the only one in the ancient Near East which has, throughout its history, consistently employed this product in nearly every technical domain. But it was above all as an adhesive, or cement, and as water-proofing that asphalt found its most wide-spread use over the centuries. At Ur, in the beginning of the second millenium, the mausoleum of Bûr-Sîn was built out of bricks and asphalt - its arch had not budged for four milleniums when it was re-discovered in 1930. In the neo-Babylonian epoch, in the middle of the first millenium, asphalt was even used, jointing layers of bricks, covering them in long sheets, and so on, to 'macadamise', as it were, the processional routes of the gods and their faithful from one temple to the next. Asphalt was also used to waterproof floors, pavements, roofs and partitions, whether of stone, brick, gypsum or wood.

2. Construction

Architecture in the Orient made its greatest strides in regions where, paradoxically, the construction materials *par excellence* stone and wood, were almost entirely lacking. The raw material whose nearly exclusive use conditioned the subsequent development of construction, imposing form, proportion and use, was alluvial earth, the clayey silt deposited on the Mesopotamian plains by the Tigris and the Euphrates. Wood and stone nonetheless had some role to play in constructions of brick.

Adobe imposed its characteristic form on the Mesopotamian edifice — great masses with thick walls and a few narrow windows. Adobe is a material which does not allow the builder to cut any corners. Ornamentation has to be sober and form part of the construction. Here the wall is master: seen from the outside, the monument —house-palace, temple or ziggurat— is a perfect expression of its internal structure. Its structure expresses its function. But the use of brick —especially of raw brick, used for large-scale projects— has a number of drawbacks. The building should be resistant to deterioration and pressure from arching roofs. Builders provided meticulously for the risks of erosion and seepage —with drain pipes, gutters, beds of reeds, asphalt joints, wall clamping, and so on— showing a precise sense of precaution. At Uruk, the oldest constructions rest on platforms made of brick placed on beds of reeds and swamp grass, alternating with layers of clay.

Foundations could be constructed by layers of bricks —baked or unbaked— protruding from the upper parts of the wall. These foundations sometimes formed genuine socles or pedestals, as at Uruk, for the "white temple" of the god Anu, which was built on terraces.

The laying of flat-convex bricks was more complex. Bricks were either laid horizontally —the level side of the upper brick placed on the convex side of the lower— or laid in a chevron pattern (*en épi*) as at Tello. The chevron layers were almost always intersected by even beds of bricks. But bricks laying *en épi* is impossible with openings — at the approach of doors and angles appear massive horizontal layers of brick. These more stable constructions, most likely laid previously, also served as supports for the structure in chevron. This mode of bricklaying disappeared even before the appearance of flat-convex brick, around the middle of the 3rd mill.

Whether baked or simply dried in the sun, bricks were habitually jointed with a clay mortar, only occasionally with a mortar of lime or of earth mixed with cinders. But unbaked brick could also be laid before completely dry, without mortar. The layers adhered to each other and formed a solid block. To protect the facing of these walls of bricks, they were habitually covered by a coating of earth mixed with ground straw or of lime. In the interior, these coverings existed already in ancient times and were often carefully polished and coloured, as in Jericho, Hassuna and Sialk.

The delicate problem of covering was early resolved in various ways. The flat terraced roof, on traversal beams covered by matting or branches supporting a bed of trodden earth, was the easiest and the most common solution. The double-beamed roof with tiling was found in Hassuna as early as the 5th mill. The *tholoi* of Arpachiyah, of Tépé Gawra, were probably covered by a mud dome. The bas-reliefs of the palace of Assurbanipal, at Ninive, sometimes represent the image of a city whose houses are capped by a semi-spherical flattened dome, or *calottes,* or by elevated cupolas exactly like those to be seen today in the Syrian villages in the regions of Hama and Alep.

The tombs of the first dynasties at Ur were fitted with cantilevered arches, a procedure requiring no cintre or soffit and creating no tension. The true vault, or cradle arch, with slightly narrowing brick and exerting lateral pressure, was probably born in Mesopotamia. The Greek geographer Strabon well understood that the vault was created in this country "due to the lack of wood". With a soffit in half-circle, or slightly elongated, its construction was based on vertical sections placed —from the first sections— at a slant in order to strengthen the adhesion of the bricks. (This was called a *voute en tranches* or in vertically inclining sections). The palace of Sargon (8th century BC) on the site of Khorsabad, has admirably conserved examples of these vaults. We already know the true cradle arch or *arc clavé,* used to cover passages and doors. It was at Ur, Tello, Khafadjé and Tell Asmar that the oldest examples of vaults appeared during the first half of the 3rd mill. Only small cradle arches have had the force to survive for our study. The excavations of Tchaga Zanbil in Susiania demonstrate, for the 8th century BC, a remarkable mastery of the assembled arch. The use of brick was moreover limited in range and required architects to build in oblong shapes over limited surfaces. The largest surfaces have been found in the ruins of the palace of Sargon, at Kharsabad, where some rooms were as large as 32 m. in length and 8 m. in breadth.

3. Architecture

The art of building came about at the moment when men abandoned natural or artificial shelters to settle in one place. The beginnings of architecture are bound up with other developments — the domestication of animals, the growth of skills in agriculture, weaving, pottery and so forth, and above all the appearance of collective living arrangements, first in villages, then in cities. This shift was favoured by the climatic changes which had put an end to the last Ice Age, from 8,500 to 8,000 BC, especially within western Asia where cereals grew already wild, and where cows, sheep, goats, and pigs roamed wild. Whether we speak of the primitive setting of Jericho, or of the villages of Jarmo or Muallafat in Iraqi Kurdistan, the first structures, the first houses marked the same cultural phase. (The first houses following a regular plan were found at Tell es Sawwan, inside a fortified enclosure, the first known in Mesopotamia).

Toward the end of the Tell Halaf period, appeared the material which was to play an essential role in oriental architecture — brick. It was used somewhat earlier on the Iranian plateau of Sialk, it would seem, than on sites we have found on the plains. It was first used for foundations and pavements, whilst walls continued to be built of mud covered with a thick coating of earth and mashed straw (*torchis*), the whole covered with an ochre red paint.

With the generalized use of brick, a new impetus was given to construction, which became during the El Obeid period a veritable monumental architecture. Now brick imposed on an edifice form and proportions. In the south, still marshy but progressively dried out and colonised, there grew up alongside the reed huts edifices in brick at Erides, Ur and Uruk, in which we can see the prototype of the future architecture of the whole Orient.

At Eridu, 13 temples superimposed indicate the progressive adaptation of a programme. The temple of level 7 —the best preserved— shows us the model of an edifice which spread throughout the Near East. The plan in nearly that of a rectangle, the triple internal grouping is underlined by the internal partition walls. The recess has expanded and occupies the entire back. Two wings flank the central room all along its length, divided into multiple rooms which respond to the complexities of ritual. With the site of Eridu, we are in a position to speak for the first time in the history of architecture of a sacred architecture.

In the far north we find at Tépé Gawra (on level 13) a temple identical in conception. It is at this epoch that we also find an element of decoration which shall remain one of the distinctive traits of Mesopotamian architecture: on the outside, sometime on the inside as at Tépé Gawra, long brick walls are intersected by the regular alternance of simple or compoud projections, sometimes even forming profound recesses which break up the monotony of the surface.

At Uruk we find the most representative monuments of these new tendencies: construction on a large scale, sanctuaries elevated on artificial terraces. At Uruk, eight successive temples were erected on an embankment which measured originally 9 m. in height. The platform was raised at the same time that new structures were built on the ruins of the previous ones. At last, the enormous terrace was enrobed in a mass of unbaked brick formed in slopping walls, ornated by projections. We find the terraced temple at Uquair, and also much further north, at Tell Brak in the Khabur valley. It was from these sanctuaries on a platform that derived a seemingly related structure, the ziggurat, which is a sort of tiered tower. The architectural vestiges of the ziggurat only appear with certainty at the end of the 3rd mill.

The main innovations concerned the 'temple' complex. At Khafadjé the successive stages of sanctuary building reveal the junction of a courtyard with the building proper. The courtyard became little by little one of the essential components of the new temple. The sanctuary was relegated to the back of the open-aired surface which was soon to be surrounded by multiple adjoining rooms. Religious architecture became progressively more complex. The courtyard was now an integral part of the temple in which it was enclosed. The adjoining rooms also formed a part of this block which on the outside tended toward simple geometric forms — oval at Khafadjé, square at Tell Agrab, rectangular elsewhere. The temple became a "house of god", sometimes difficult to distinguish from a private home.

One example of civil architecture at the time of Uruk was the "round house" of Tépé Gawra (4th mill.), a veritable turret or keep placed at the centre of a fortified tower built on a rise overlooking the plain. Even the plan alone evokes the power of this circular construction (19 m. in diameter): the walls, one metre thick, were built in massive unbaked bricks (50-56 x 26-28 x 10 m.). Royal palaces were also based on the plan for meridional houses; the main body on the house built around a central courtyard. By the simple juxtaposition of units, we come to the large ensemble in which each part develops organically in function of its destination. The palaces of Mari and Kish (2,700 BC) provide an outstanding example of this.

The golden age of architecture in the ancient Near East was the end of the 3rd mill. Its most significant accomplishment was certainly the famous edifices known under the Babylonian name of ziggurat. Taking the form of a tiered tower, they were usually temples dedicated to the principal god of the city, but their precise symbolic meaning still escapes us. The construction of these enormous superimposed terraces created enormous problems for Sumerian architects, problems of weights, pressures, setting, consolidation, water seepage, access. . . Brick, the only material at their disposal, only added to their difficulties. The care which they lavished on the laying of foundation beds, jointing them with asphalt, the incorporation of mats of reeds, of beams forming a clamp at the interior of slid masses, the abundance of drains, of gutters — all these indicate their own consciousness of the difficulties faced. The ziggurat of Kurigalzu (app. 1,350 BC) situated not far from Baghdad, presents even today an impressive central core, revealing its original structure (height app. 57 m.).

At the beginning of the second millenium, Mesopotamian architecture was in possession of principles and means, which remained constant in the following centuries. We find in Assyria (Assur, Nimrud, Ninive, Khorsabad), in Elam, and in the Babylon of Nebuchadnezzor ziggurats and Sumerian temples. The warrior kings of Assur, steeped in the colossal, transformed cities and palaces (the palace of Assurnazirpal II at Nimrud, or of Sennachérib at Ninive) into citadels bristling with towers and enclosures. But the laws and methods of construction remained practically unchanged. After flourishing for more than 2,500 years, the Mesopotamian civilisations fell into a nearly total oblivion.

Notes

1. *Cultural eras in Mesopotamia*

Proto-historical periods

Hassuna — First half of the 6th millenium
Samarra — middle of the 6th millenium
Halaf — from 5,500 to 5,000 BC
Eridu — from 5,000 to 4,500 BC
Obeid — from 4,500 to 3,500 BC
Uruk — from 3,500 to 3,100 BC
Djemet-Nasr — from 3,100 to 2,900 BC

Around 3,200 BC, the Sumerians, who had recently settled in Mesopotamia, invented writing. For 2,500 years, cuneiform writing kept its syllabic and logographic character with nearly 7,000 characters. It was only with the Persian era (5th century BC) that this writing became alphabetic, with 41 characters.

Historical periods

Era of the ancient dynasties — from 2,900 to 2,340 BC
The Agada Empire — from 2,340 to 2,150 BC
The Sumerian renaissance — from 2,150 to 2,000 BC
The first Babylonian dynasty — from 2,000 to 1,595 BC
The Kassites — from 1,595 to 1,155 BC
The Assyrian Empire — from 1,100 to 612 BC

In 539 BC, at the taking of Babylon, the Persians were welcomed as the liberators of a people subjected to the kings of Syria and Babylon.

2. *Construction*

L-shaped bricks: placed at the angles of certain structures have been found at such sites as Mari and Larsa, and rounded triangular-shaped bricks have been found in the circular supports installed in the ziggurat of Tchoga Zambil.

Patzen: a type of brick (80 x 40 x 16 cm) used in terraces and ziggurats.

Riemchen: bricks measuring 20 x 9 x 9 cm, used at the time of Uruk II — IV (3,200-2,900 BC).

Flat-Convex bricks: 2,900-2,400 BC.

Reeds: their resistance to decay and rot made them useful in solid masses of bricks: they were used in matting, inserted between layers in order to prevent masses from slipping. They were also used for a better distribution of weight and the righting of supports

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Conservation and Use of Historical Centres and Monuments

Franca Helg

My contribution to this Symposium will be limited to the problems concerning the conservation and use of historical centres and monuments.

That which has been built: cities, isolated towns, the countryside —cultivated or contemplated— stand as witness to the history of man and, in our daily uncertain existence, this centuries-old testimony contributes significantly to our will to live and to do.

Indeed, it is in the continuity of tradition that our own roots lie, as well as our awareness of universal values, and of those specific to our ancestors.

Nonetheless, in moments of great perturbation, these values are not always felt or taken into account.

Such is the case of Italy, after the great destruction caused by the war; such is also the case of Peru after the earthquake.

The vital need to surmount the disaster left no time for reflection. It was necessary to build, and to do so with scarce materials.

The need to renovate was in the air, to build any which way, to obtain the maximum immediate profit. Thus, to the catastrophe caused by war or by the earthquake was added the disaster caused by a hasty reconstruction, unplanned and based on myopic concepts of speculation or economy.

The centres of the cities hit by the war, the areas devastated by bombs, were rebuilt without any attention to existing typologies or to the morphology of the city.

The volume of the context was disregarded; no effort was made to insert new buildings harmoniously in the pre-existent ensemble. In the highlands devastated by earthquakes and natural disasters, reconstruction took place without any regulation or character as well.

While the old cities represented an element of cohesion, the new cities were transformed into an element of alienation.

In Europe and, more specifically, in Italy, the economic boom of the fifties and sixties caused ravages in all our cities and in the more sought-after tourist locations.

Autocriticism concerning these actions and the historicism characteristic of our cultural moment have given rise to a revision movement, which is important and articulated in a complex manner.

Authorized persons —both critics and decision—making officials, have stated the following:

1. it is necessary to preserve all that which is preservable.
2. a monument —be it of outstanding quality— loses part of its significance if it is not inserted in its own context. This context must preserve its character and be a true "history-book".
3. the city, the urban conglomerate, is a common good; as such, it must be used and enjoyed by all the community.

These lucid statements are followed by more schematic "slogans". One of the more diffuse ones states that the less favoured sectors of the population should "re-appropriate" the city — that is, those sectors which the capitalist city tends to displace and expulse towards the periphery.

The battle which ensued over this concept was very fruitful and contributed to:

a. create an awareness in the public regarding issues upon which the common man had ceased to reflect.
b. induce politicians and the legislative powers to stop speculation.

This constituted an important cultural and political operation which, once more, stated the need to save historic centres in an integrated manner, as wholes.

. . . And all the world spoke of Bologna and Ferrara and Venice. But, in truth, very little of what was to be expected was done in Bologna or Ferrara or Venice. The partial failure in the operative phase is due —in my opinion— to three causes.

1. Deficient legislative and administrative instruments, which hindered public intervention.
2. Imprecise intervention plans, which delayed their execution.
3. An erroneous will to rebuilt (or restore or "enhance") "as before and where before" — not taking into consideration the fact that things change daily.

Building techniques, materials, manual labor, new customs, contemporary quality of life, the ever-growing city and the qualifications of its inhabitants - all these things require new solutions and new interventions. At the same time, we know too, that it is necessary to maintain a continuity with our recent and less-recent past, and to revalue the vestiges of the civilizations that went before us.

An Italian philosopher of the XVIth century, Giordano Bruno, believed the culture of the last civilization to be the sum of the culture and experience of our ancestors. To it is added contemporary progress.

Indeed, today the object of our concern and attention is not only the isolated monument renowned for its historical value or significant because of its artistic merit, but the total context. We cannot think of integrating a monument in its context, however, without taking into account the needs of contemporary life, for it is erroneous —from the point of view of cultural progress— to renounce to the expression of contemporary language.

The ancient cities —as Leonardo Sciascia, the Italian writer says: "the cities where the past of man lies in every stone"— are stratified due to successive contributions, and their significance and message lie precisely in these rich and multiple strata. Our own contribution must also become a part of the history and character of the context.

The problem is how to intervene — and we know that it will be different in each case and in each situation. Nonetheless, it will always be necessary to find an appropriate function or use for a building, which can be carried out without damage to the edifice and which will, at the same time, guarantee its vitality. If a historic centre is not intensely vital, it becomes, in a few years, a ruin.

Possibly, special adaptations are to be made, necessary to the new function. Often, the building must be equipped and fitted with contemporary installations.

In my view, every intervention —apart from being reversible, when this is possible— should have a contemporary character and should be done with a light hand and with respect for the character and nature of what pre-exists. The volume, height and shape of spaces should be respected and merit close attention. In a historic complex, inserting a tall building will destroy the whole of the context, while this will not happen if buildings of a scale similar to the existing ones are inserted within the historic texture, even if they are built following contemporary norms.

The experience at Bologna, where "voids" in the medieval context were rebuilt and town-houses were restored servilely following medieval shapes with modern materials and techniques, seems to me very naive. Eaves, for example, were built using concrete beams for support, made to look like the ancient wooden ones. The result is one of imitation, with little value, except for a poor scenographic effect.

The windows are shaped like the old ones, but to improve (according to contemporary criteria) hygenic conditions, ventilation and insolation, they have been made larger. Proportions change, and the whole looks inharmonious and false. There was a will to maintain the character of the whole —which is commendable— but the error was to think that past styles and shapes can be repeated and rebuilt without more ado. This results in stylistic falsity and turns these buildings into something surfeited and devoid of value.

The Municipality of Bologna studied, researched and understood in depth the morphology of the city and the existing interdependence between residential and civil architecture. The result should have been a proposal to complement the old texture of the city with buildings whose volumes would respect the context, and would be harmoniously and carefully inserted in it while at the same time being an expression of contemporary "architectural language" and technology.

When completing missing parts in old buildings that have become slums, one must be attentive and sensitive to ancient colours and materials, yet one must also be conscious of the fact that modern materials can be added next to the old ones and that, by affinity or by contrast, an interesting expression may be achieved.

I might continue giving other examples; however, given the nature of this meeting, I would like to end by relating what I have previously expressed specifically to architecture built with earth.

It has been said that adobe is a "poor" material: I do not believe we can accept this limiting definition if we bear in mind the long span of time throughout which adobe-building techniques have been developed, as well as the wide geographic distribution of this building tradition. There is poor architecture and noble architecture: it is not only the quality of the material, but proportion and character which lend solemnity to architecture.

In Peru, as in Morocco, Afghanistan, or in Saudi Arabia, there are rich and solemn buildings and complexes built in adobe; often, surrounding them there is (or was, unfortunately) a group of minor buildings, perhaps poor ones, that, nonetheless, constitute a context charged with vitality which enhances the value and significance of the larger complex.

In many countries, as a result of an eagerness to "modernize", devoid of any good judgement and only looking for "change" in customs and in technology, as well as a result of an uncontrolled desire to increase real-estate profits, "monuments" have been surrounded by anodyne buildings of shining glass or plastic materials, dissonant among themselves because of their difference in volume and proportion and, even more so, dissonant with the monument.

In the traditional centre of Riyadh, in the highlands of Najdi, in Saudi Arabia, today almost nothing is left of the pink city, rich in fascination, which voyagers from the turn of the century describe. It was a city entirely built in raw earth; its architectural typology and morphology were perfectly harmonious and adapted to the climate and lifestyle. This city endured until the oil boom — today, however, only the Masmak, in the centre of Riyadh has withstood the "renovating" destruction.

Our architectural offices were in charge of the restoration of the Masmak. It was necessary to determine *in situ*, on the basis of very few existing documents, and by analogy with similar buildings, what the original shape had been, what had been added rationally and which parts were fake. We carried out a study (with the collaboration of Professor Giacomo Chiari, from Torino) in order to improve the chemical and physical endurance of raw earth. Then we proceeded to restore the complex, using traditional methods; we were able to turn to the surviving craftsmanship of the Bedouin laborers, experts in adobe, and we had access to the appropriate material for the fabrication of adobes.

Restoration was completed by installing the necessary electrical fittings, as well as by providing it with water and sewage — obviously using contemporary materials.

The restoration —including new installations— was done in view of establishing in this complex a Historical Museum, following the instructions of the Minister of Culture of Saudi Arabia.

Restoration was, in our opinion, satisfactory: we do regret that this "palace-fortress" is now surrounded by a city without character. This diminishes the value of the building and makes it look anachronic —which leads us to reflect upon the artificiality of this type of conservation, limited only to one vestige of the past.

There was an opportunity to restore the entire city — and it was lost. A regulating plan had been established by the architect Doxiadis; it was rather schematic and rationalist — but there was no "programme plan" to restore the whole of the city, to adapt the old earthen houses and to complete those missing parts, already destroyed, using contemporary technology. This completion of missing parts should always be done with respect and atention to pre-existing volumes, taking into account the density of the urban texture, so that the new buildings be in a harmonious relation with the context.

Even within the general framework of the Venice Charter, restoration methods vary, according to what is to be restored: whether remains, ruins or monuments of great historic or artistic value, or whether restoration implies contexts of more modest characteristics. It is obvious that the general principles must be interpreted following the healthy norm of "case by case".

We must respect "tradition", and tradition implies the collective awareness of the continuity between present and past; it means a continuous integration between the ethical and cultural values of all times; it means a collective recognition of the permanent cultural values. Yet, at the same time, we must bring tradition "up to date", according to the criteria, the ideology and the opportunities of today.

In certain conditions of economy and productivity, in certain geographical latitudes with climates having a wide range of thermic variation, in the presence of adequate materials, etc. it may be reasonable to propose again —and once more— the ancient technique of building with earth. Adobe, its building techniques, its formal characteristics, its appropriateness in view of existng conditions and the lifestyle of the country, constitutes an important element in the continuity of tradition and represents a search for the expression of ethnic identity. On the other hand, the styles and architectural typologies must evolve in a manner coherent with our times.

All restoration work must be done taking into account two poles, respect for and interpretation of tradition, and the contemporary quality of life. The solution to this problem means keeping alive the techniques and the craftsmen who know how to build with adobe; to continue studying consolidation techniques which will reduce the cost of maintenance of adobe throughout time and to undertake studies and propose plans to introduce into this ancient technique the essential technological elements of contemporary civilization, such as electrical installations, water and sewage systems, and air conditioning.

I believe it is necessary to take into account these different needs, and to adopt solutions which will not damage the solemn and at the same time elemental character of adobe, while allowing an autonomy of design in contemporary buildings.

Characterization of Adobe as Building Material. Preservation Techniques

Giacomo Chiari

Introduction

The study of adobe as a bulding material for conservation purposes is fairly recent with respect to other branches of conservation. Work has been done in the last decades, but we still need standard test methods for characterizing the relevant physico-chemical properties both for the soil to be used to make new adobes and for the mud bricks of historic buildings. (Clifton, Brown and Robbins (1) made a relevant contribution in this direction and in this review I will extensively refer to their work). Also standard procedures to assess the effectiveness of protective interventions (from surface treatments to structural repairs) are very much needed, not to talk about the conservation techniques themselves.

The analysis of adobe soil or bricks may have several purposes, and according to them, different procedures should be selected. A complete study tending to determine the causes of deterioration of adobe involves obviously much more work than an enquiry to establish if a given soil is adapted to produce good adobes, compatible with those of a historic damaged wall.

A complete chemical, mechanical and mineralogical characterization of soil is a difficult task, since beside humus, the mixture of mineral components of soil is, in general, very rich. The mineralogy of clay minerals is in itself fairly complex. However, simplified procedures of tests and analyses could be useful in determining the most important properties of adobe, especially in connection with its conservation and will be briefly described here.

A review of the causes of deterioration for different climates and building typology is attempted, together with some suggestions for possible conservative interventions. Many of the techniques applied for this goal are still at experimental level and sometimes controversial. A critical evaluation will be attempted, hoping that it will provoke a profitable discussion. One should keep in mind that no final solution has been found yet to the problem of conservation of adobe; and one can seriously doubt that some recipe will ever be found to fix in time the conditions of a mud structure. All we could hope for is to find ways of slowing down to acceptable rate the processes of deterioration which, for adobe materials, are very rapid.

1. Classification of soil in terms of particle size

The particle size distribution of an adobe is a very important piece of information related to the behavioural characteristics of the material and its durability. The *granulometric analysis* is not too complicated and does not require sophisticated laboratory equipment. Therefore it should be one of the first to be performed for adobe characterization. For our purposes the particle size distribution curve is normally broken down into four sections:

gravel	:	particle diameter larger than 2 mm.
sand	:	particle diameter between 0.02 mm. (20 microns) and 2 mm.
silt	:	particle diameter between 2 and 20 microns.
clay	:	particle diameter less than 2 microns.

Gravel and sand are considered to be the filling material. They consist normally of minerals rather resistant to weathering such as quartz, feldspars, mica, calcium carbonate, etc. Each grain has good mechanical properties but no coherence is ensured among different particles. The binding elements are clay and to certain extent silt. Clay particles, especially in flocculated form, adhere well to each other and to the sand, keeping the adobe together. Clay, as we shall see, tends to become more plastic and to swell with increased water content. Conversely the excessive shrinkage upon drying of pure clay causes cracks. For good adobes an optimum compromise between filling and binder is between 60 to 80 percent sand, 20 to 40 percent silt and clay, and little or no gravel present (1).

1.1 *Clay Minerals*

Being the binding agent of adobe, the clay fraction is particularly important. Clays are metamorphic minerals formed by atmospheric weathering of many types of rock. Clay could be chemically classified as aluminosilicates hydrated; some contain as major components sodium, potassium and calcium; in other iron and manganese may substitute aluminum and silicon in the framework.

From the structural point of view a large part of clay is amorphous or shows a low degree of crystallinity. When crystalline, clays present a layered structure: the silica layer is built up by tetrahedra containing Si at the centre and oxygen or hydroxilic groups (OH) at the corners. These layers can be joined together in different combinations, can accept interstitial positive cations (to compensate for the lack of positive charge due to iron-aluminum substitution), and water, giving rise to the various clay families (e.g. kaolin, illite, montmorillonite, chlorite). Water can penetrate between silica and alumina layers forming a net of hydrogen bonds and surrounding the interstitial cations. This causes clay in the presence of water to become more plastic because the layers can slide easily over one another; if more water is added, the platelets, completely surrounded will be dispersed, passing freely in suspension. A small amount of water causes swelling in the direction orthogonal to the layers, with correspondent contraction upon drying. This happens in different extent according to the type of clay. Kaolin, for example, does not expand because water cannot penetrate between layers (2), (3). On the other hand sodium montmorillonite can increase its interplanar distance orthogonal to the layers from 9.6 to 21.4 Å. The other clay families show intermediate behaviours toward water.

It is generally accepted that for conservation purposes the precise identification of the clay type is not necessary, with the only exception perhaps of sodium montmorillonite, which for its tremendous swelling-contraction properties, should be avoided in the manufacture of new adobes, to eliminate cracks.

2. Types of analyses available for adobe, and critical evaluation of the information obtainable

2.1 *Granulometry or size distribution analysis*

The importance of selecting a sample representative enough of the adobe under consideration should be stressed. Good solid adobes should always be taken, avoiding powdery material or severely damaged bloks. Possibly several samples located in different points of the adobe structure should be analyzed and results compared. The mass of the sample should depend on the size of the largest particle present; but for historic adobes, sample mass between 150 and 300 grams were found to be adquate (1).

The detailed procedure for the size distribution analysis is given in (1). Here a brief outline is sketched. The separation concerning sand and gravel relies on sieving, while clay and silt fractions separation relies on particle sedimentation.

First the moisture content is determined by weighting before and after drying the sample in oven at 105ºC (percentage based on dry weight). The crushed material is then immersed in a solution of sodium hexametaphosfate in distilled water and allowed to stand overnight to facilitate the dispersion of clay particles. A filter Nº 8 or 10 can remove the larger particles and twigs, thus simplifying mechanical stirring. The remaining organic part, less dense than water, floats on the surface and can be removed with tweezers, weighted and retained for further analysis.

To minimize clogging of the finer sieves it is advisable to perform a partial separation of the clay-silt portion by magnetic stirring, followed by dispersion in a 8-10 cm high column of water, settlement for a prescribed period of time and syphoning of the clay-silt suspension (repeat 3 or 4 times). A normograph developed by Tanner and Jackson (4) in which the settling time in cm/seconds is plotted against the particle diameter in microns for various temperatures allows to determine the appropriate settling time.

A series of sieves can now be used to separate the coarser material (see (1) for detailed number of sieve-size opening correlation). The material catched by each sieve in the column is rinsed, dried and weighted. The part that goes through Nº 400 sieve (38 micron size) contains a fraction of clay-silt of less than 20 microns that should be fractioned by sedimentation and added to the part already separated. Since clay content is calculated as difference between the total sample weight and the combined weights of silt, sand, gravel and organic material, any loss of material that may occur during the procedure will be calculated as clay. So it is very important to avoid that particles remain entrapped in the sieves, by brushing the inverted sieve with a stiff brush. Also the amount of soluble salts determined, as described in section 2.2. should be subtracted from the total amount of clay.

The separation clay-silt follows the same principle of sedimentation, only with different, and much longer, settling times. Since for a 2 micron clay particle the settling time for a 10 cm high column is 8 hours and 20 minutes at 18ºC (as it can be deduced from the normograph), several days are required to properly separate clay from silt. This is only needed if further identification of clay minerals is planned (in this case the clay fraction after long sedimentation should be dried at 60ºC to avoid possible irreversible dehydration).

The granulometric analysis is useful to establish and, if necessary, to correct the ratio between filling and binding elements in the soil selected for the manufacture of new adobes, to avoid cracks (too much clay) or disgregation (too much sand). Alternative much simpler "tricks" for the same purpose will be presented elsewere during this course.

2.2 *Soluble salts analysis*

Adobe may often contain appreciable amounts of soluble salts, which may affect its durability by crust formation, efflorescences, stress due to crystallization, hygroscopicity. Given the large size of pores in adobe, these effects are generally less dramatic than for stone (5). The determination of the amount and composition of soluble salts is in any way a datum of significant interest. The procedure simply consists in dispersing in distilled water a weighted dry sample and collecting the filtrate (a Buchner aspiration filter may help). This should be repeated 4 times to ensure complete washing. The filtrate, evaporated without boiling, and dried in oven is then weighted.

Elemental chemical analysis can be performed with a series of techniques. Quantitative data so obtained may be related to the mineral phase determination performed by X-ray diffraction and described next.

2.3 *X-Ray diffraction analysis: the powder method*

It allows the phase identification of crystalline meterial (semi-quantitative), but requires sophisticated equipment and trained analysis.

Theoretic principles: the angle at which an x-ray beam of given wavelength is diffracted is related to the interplanar distance d of the crystallographic diffracting plane. These distances depend upon the unit cell dimensions and geometry; the intensity of diffraction is related to the type and arrangement of atoms within the crystal. The use of finely crushed powder as sample, allowing all possible orientations of crystals of a given phase with respect to the incident beam, will produce diffraction cones of specific angular opening and intensity, which can be detected either by a diffractometer (equipped with a proportional counter) or on a photographic film. Search file manuals such as the *Powder Diffraction File* (6) simplify the comparison of the actual spectrum with the ones tabulated in the literature.

If the sample under consideration is composed of one compound only, its identification is simple and straigh forward. The task is more complex if an admixture of different compounds in different percentage is present, which produces diffraction lines all superposed. For clay mixtures, owing to the similarity of the unit cells, special techniques as glycolation or double analysis after specific thermal treatments may be necessary (see (1) and references therein; also (3)). Fortunately for our purposes, the montmorillonite group which is important to identify for its swelling properties, presents a nice line corresponding to a 15Å basal spacing which allows an easy identification, even in the presence of other clays.

As for the soluble salts, since one can guess their kind and therefore simply check their presence even in a complex sample, this method is very useful. One can establish for example if calcium is present as chloride (hygroscopic) or as sulphate (which is not), and in this case if a gypsum or anhydrite, etc.

Another useful application, apart from the complete identification of the mineralogical components, is a superficial and qualitative comparison between the spectra of a historic adobe and the soil from which new adobes are planned to be made for repairs. Gross similarities or differences can be evaluated at glance by an experienced analyst.

2.4 *pH determination*

pH is a measure of the acidity of a water solution. It is by definition the inverse of the logarithm of the concentration of hydrogen ions. In distilled water (neutral) the concentration of H^+, is equal to $1/10^7$, corresponding to pH = 7. A pH of 2 for example indicates a strongly acid solution, while pH of 13 corresponds to a strongly basic solution.

The measurement of pH for adobe can be useful because acid solutions (low pH) promote flocculation of the clay minerals from suspensions, while a high pH can lead to the formation of a stable suspension of clay (7).

There are suggestions (1) that the pH of repair materials should be within $\pm$ 2 pH units of the original adobe.

The measurement of pH is very simple. Portable pH-meters with batteries are available. Coloured strips of paper with pH indicators may function equally well on the field.

2.5 *Colour evaluation*

The evaluation of colour of adobe in a standardized way is useful especially when repairs with new adobes have to be planned. The Munsell soil colour charts are available since a long time, and allow the matching of colour with 196 different standard colour chips, arranged according to three variables: Hue, Value and Chroma. The Hue notation indicates its relation to red, yellow, green, blue and purple, and is symbolized by letters. Value notation indicates the colour lightness, and Chroma its strength; they are both symbolized by numbers.

The use of this standard procedure and its notation allows different researchers in different times to check colour variations.

2.6 *Optical and electron microscopy*

The simplest equipment which does not require special expertise from the operator is the binocular microscope in reflected light. It allows three dimensional, stereoscopic view of fine details. The adobe sample can be a fractured surface, possibly sprayed with colourless acrylic, or a section polished after impregnation with epoxy resin. The enlargement obtainable is up to 100X, although at the levels the depth of field is very low and clear images are difficult to be obtained for focusing problems. But even lower enlargements can give a lot of useful information on the microfabric of adobe such as: voids, cracks and pores dimensions and distribution, possible crystallization of soluble salts inside cavities, grain dimensions, presence of straw or, even more important, the imprints of straw long after its decomposition. I consider this optical examination an essential part of adobe investigation.

The next level of microscopic technique is the observation of thin sections (30 microns) with the petrographic microscope in transmitted polarized light. This leads to the mineralogical phase determination of the crystals present via their refractive indices measured by comparison with standard series of oils with known indices. The drawbacks are that a thin section of adobe is somehow difficult to prepare, and the analyst should be an experienced petrographer. On the other hand, valuable information is obtained, especially in the case that x-ray diffraction is not available.

The third more sophisticated level of microscopy is the scanning electron microscope (SEM) which uses a finely focused beam of accelerated electrons directed over the sample (which is normally gilded to be conductive and kept under vacuum) and slowly moving in regular lines (scanning). The secondary electrons emitted from the sample at each point are collected, and the picture of the object is then constructed by electronic devices.

The advantages of SEM are the possibility of obtaining sharp images up to 150,000X due to the large depth of field. For adobe, enlargement of 20X to 2,000X is more than sufficient. When equipped with a microprobe to obtain quantitative chemical analyses of the fine detail under examination it becomes a very useful piece of instrumentation.

Given the versatility of its applications, many universities are now equipped with SEM.

3. Causes of deterioration of adobe materials

3.1 *Water*

For once in science the simplest, more obvious answer to a problem is the correct one: by far the largest amount of damage to adobe structures is ascribable to water, especially when it is abundant and in liquid form (rain, water pools). As we have seen, clay particles in contact with increasing amounts of water, first increase their volume; then become more loose (higher plasticity) and eventually are dispersed in a water suspension. Being clay the binding agent of adobe, this effect is obviously deleterious. Wet clay becomes impermeable to water and excess rain runs on the surface, carrying suspended matter, digging preferential channels which are eroded even faster since subjected to a larger water concentration. Tensil and compressive strength of adobe are influenced by moisture content up to 200 percent (10). Therefore, particularly the bases of walls which have to support all the weight, once impregnated with water, tend to collapse. This effect is particularly evident when, due to rain and poor drainage, or to the rise of the water table level, open pools of water can be formed. In many cases one can see arches formed by the collapse of the lower part of walls. Complete destruction follows soon.

Upon drying, clay tends to contract with crack formation. Crusts can be formed due to a sort of natural sedimentation: The coarser particles are deposited first, forming a layer of very poorly adherent material. The finest particles, which take longer to sediment, constitute the upper layers of almost pure clay, severely contracting with exfoliation.

As a marginal aspect of the clay displacement, a change in colour toward lighter tones takes place, due to the fact that on vertical surfaces the platelets are now being deposited with their cleavage plane parallel (instead of orthogonal) to the wall surface, thus reflecting more light.

Finally the water movement (in liquid form) from the interior part to the surface of walls during evaporation, can transport dissoluted salts which may crystallize on the surface (causing white efflorescences often hygroscopic) or, even more dangerously, immediatly underneath of it, (it depends on the evaporation speed) causing crust detachment with their increase in volume.

It should be emphasized that even in those arid countries with very low water fall, the danger of rain can hardly be underestimated. Usually, in fact, the rain is limited to short torrential storms, which, for their violence, cause more damage than a prolonged but weak rain. Torrential rain can act upon the already weakened parts, i.e., the base of walls, by splashing effect, thus subjecting it to the action of drops coming in two opposite directions.

In conclusion, rain alone, with its macroscopic effects, accounts for most damage in adobe structures.

Rising damp is another less severe but not negligible action of water. Even when it does not produce water pools, it may produce salt efflorescences. These are limited to the very bottom of walls (40 to 60 cm) since capillarity is not a major effect in adobe, due to the large size of the pores. They affect, though, a part of the walls which is particularly weak.

Surface condensation, with cyclical contraction and expansion, may cause micro-cracks, crusts or help the detachment of performed crusts.

3.2 *Earthquakes*

In seismic regions earth movements can be even more disastrous than water. For historic monuments in adobe there is very little that could be done to prevent such natural catastrophes. For new adobe housing, reinforced blocks and better design can improve a lot the resistance to vibrations.

3.3 *Sun*

Irradiation does not affect adobe in a direct way. In combination with water may produce cracks and crusts by helping quick evaporation. If parts of walls in the shade are suddenly reached by the sun in hot climates, a thermal shock may take place (changes in temperature of up to 40°C in half an hour).

Crust detachment can be caused by different thermal dilation between the surface and internal layers, caused both by the thermal gradient and different thermal expansion coefficients of the various layers. This should be kept in mind when applying superficial consolidation treatments, which should leave dilation coefficients of the treated part as close as possible to the untreated one.

3.4 *Wind*

It can cause detachment of loose parts or be responsible for abrasion, especially if carrying suspended sand. Wind may cause indirect damage by transporting droplets of sea water (marine aerosols) leading to hygroscopic salts incrustations after evaporation. Wind can also increase surface evaporation speed on a damp wall, to such an extent that liquid water films cannot be formed on the surface. Evaporation takes place immediately below the surface, in the pores; the disruptive effect of salt crystallization is greater, creating alveoles by loss of material. The wind speed in the alveole is then further increased by the air eddy, giving rise to what is called eolic or alveolar erosion (2).

3.5 *Soluble salts*

Although the internal migration of soluble salts does not affect adobe as severely as stone or masonry, due to the larger size of adobe pores, it may cause problems. We have just seen the role of salt crystallization in alveolar erosion. If the evaporation can take place on the surface, a salt efflorescence, normally white, is formed. These salts, rather hygroscopic, help to trap humidity, with crust formation.

3.6 *Biodegradation: plans and animals*

Not only algae or lickens but also superior plants can grow on adobe structures, provided that moisture is present. Grass is common in rainy areas. In more arid climates, a few leaves of xerophiliae on the surface may be supported by several meters of large roots, which in their search for water, cause big cracks in walls. Once decayed they leave holes for preferential water infiltration.

Animal life can cause damage too: birds build their nests in adobe walls; in the Andean regions a kind of wasp digs smaller but more numerous holes for their nesting.

3.7 *Man*

Direct human intervention is sometimes responsible for the loss of historic monuments, in adobe as well as other kind. Wars are major catastrophies, unfortunately beyond our control; modern urbanizations, dams flooding entire regions, even though meant for the good, can cause the destruction of entire adobe towns. The presence of visitors in great number may be very damaging, and, if a monument should be open to the general public, special measures must be taken to insure the protection of the structure. Important archaeological sites can be damaged by illegal excavation or mere vandalism. Finally lack of maintenance has been proven deleterious.

4. Possible interventions for conservation purposes

They tend to reduce the speed of deterioration processes either by removing the causes of alteration and/or disposing of details which act as catalysts of disruption. The fact that no "final solution" is or will be available for the adobe conservation problem is never stressed enough. This is true for all materials, but particularly so for adobe, whose weak characteristics have always been counteracted with regular maintenance and extensive rebuilding. The fact that modern conservators obviously cannot act with the same freedom in rebuilding damaged parts of historic buildings, simply means that, on the long range, they are condamned. All we can hope for is to enhance their life expectancy. For this purpose some techniques have been proposed, that are reviewed here.

4.1 *Complete immediate reburial*

A rather drastic measure, to be applied to archaeological excavations which are below the ground level. It is necessary if some documentary evidence of the excavation has to be preserved for the future. A layer of salt free sand may be put first to facilitate re-excavation. A lot of damage may affect not completely excavated sites during the time lapses between excavation campaigns. This is a very serious matter, since the semi-excavated affected parts are not yet documented. Therefore temporary shelters should always be put in place. They could be very simple and inexpensive: cane or straw mats covered with mud have been proven effective.

More difficult, but necessary, is to obtain an efficient draining system because of the impossibility of digging holes or channels in parts which have not yet been excavated. Perhaps this problem should be considered when drawing the excavation plan.

4.2 *Total protection from weathering agents*

Sheds and roofing systems have been applied in many cases to protect archaeological sites. They have been proved to be effective when direct action of rain is the only cause of damage. In the presence of marine aerosol (e.g. Chan Chan, Peru) a shed facilitates condensation with further damage.

Total enclosures with transparent materials (glass, plastic panels) should be absolutely avoided, due to the establishment of a totally different microclimate and to the greenhouse effect. In every particular case a roofing project should be carefully studied to avoid results that could be very unpleasant from the aesthetic point of view.

4.3 *Partial protection*

In general adobe structures brought to light by archaeological excavation are incomplete: they are missing the roof, which was originally an essential protection.

Adobe structures can withstand the effect of rain only if they present a complete surface reinforcement, without weak, untreated parts. This can be obtained with a series of measures.

4.4 *Repairs using reinforced bricks and/or soil cement*

If part of a wall is damaged, it is better to take out the ruined bricks and substitute them with new ones.

Structural repairs should be preferably done with bricks or pieces of them if the crack to be filled is not big enough to accept a whole brick. Mud or soil cement filling should be avoided because, after contraction, they easily come apart. In my experience the addition of a minimum amount of portland cement (less than 10 percent in weight) can improve a lot the water resistance of the new blocks.

If the wall presents a section regular enough on the top, a capping can be made with one row of new reinforced adobes. If the surface is irregular, a capping 3 to 5 cm thick made with soil cement (same proportions) can be applied.

It is better to put one layer, let it dry and crack, and then apply a second layer, using a slurry which contains much less water. The capping should be well compressed, it should dry slowly (better cover it with wet straw mats for the first few days) and, most important, its shape should be convex, to avoid formation of water pools or preferential channels. If the capping is a couple of centimeters salient with respect to the vertical surfaces is better. Cracks that may appear during the execution of the capping or later on should be checked and filled, because if water can penetrate the shield, it would easily destroy the untreated original material underneath it.

Cappings have the obvious disadvantage of preventing the original part from being seen. Soil cement cappings, if not properly executed can also be very ugly. Since the new material will deteriorate as well, measures should be taken to identify it as modern; bricks could be marked with the date, for example, or small glass bits can be inserted.

4.5 *Should the new adobes be reinforced somehow?*

There is an old debate based on this question. Many people feel that repairs should be performed using strictly traditional materials. It is also true that many times, especially if the new adobes are inside the walls, they do not need to be reinforced. From the technical point of view repairs made with a material much stronger than the original one should be avoided. In fact the deterioration would continue at the connection surface and at the expenses of the original part. On the other hand, if the new material is exposed to rain (i.e. in the case of capping) and its mechanical properties are not too different from the original, I think that to be able to count on and higher water resistance is a great advantage.

4.6 *Drainage systems*

A proper drainage system should in any case be planned. Sometimes, due to the irregularity of excavated sites, this can be a difficult task. But if heavy rains are expected, drainage is so important that less important parts should be sacrified, if necessary.

4.7 *Surfaces treatments*

An effective surface treatment has to possess the following characteristics: it should confer water resistance to the mud surface. That means that the clay particles should no longer be taken apart by the action of water.

A water proofing action, in the sense of rendering the surface impermeable to water, is not necessarily needed. In effect it can have negative effects when in the wall there is water coming from other sources than its surface. In general, if the surface can maintain its original porosity an therefore "breathe" and let the internal humidity evaporate, it is an advantage.

The physico-chemical properties of the treated surface should be as close as possible to those of the untreated part. The colour, as well as the texture, should not change much for obvious aesthetic reasons. For example a glossy surface after treatment is not acceptable.

Hardness and thermal dilation coefficient should not change much as well. In particular, if the behaviour toward thermal change is very different, the treated part would come loose after a short time, a gap would be created between the treated and untreated surfaces and the whole protection would collapse at once.

As far as penetration is concerned, ideas are still not very clear. Obviously complete impregnation would be most effective, but it is in most cases technically not achievable. Therefore a weak point always remains, represented by the connection between the treated and untreated surfaces. The forces that keep together these strata are even weaker than the adobe itself, and if water can infiltrate behind the treatment, its effect can be deleterious. Particularly so if the connection between the two parts is a flat surface.

For all these reasons, those chemical treatments which end in the formation of films of materials very different from adobe, have been proved to be ineffective.

If the treated part is similar to the original adobe, a penetration of one or two centimeters can be sufficient, provided that the surface of connection is very irregular, to obtain a good keying effect.

The treatment should possibly be of easy application, even by people not particularly trained, not harmful and not excessively expensive, given the possibility of application to large surfaces.

Finally the treatment should be reversible, or at least, since complete reversibility in practical terms is seldom achievable, should not prevent future treatments to be performed, of whatever nature they could be.

The material that up to now seems to fulfill most of these prerequisites is ethyl silicate. After impregnation and hydrolysis, the alcoholic part of it evaporates, leaving a three dimensional network of silica tetrahedra, which constitutes a series of bridges between the clay particles, preventing them from becoming loose when in contact with water. The fact that all what remains in the wall of the silica ester is a framework presenting mineral characteristics, insures that the treatment is stable in time, in the sense that no further chemical reactions would take place. The physico-chemical characteristics of the adobe (colour, porosity, thermal behaviour) are almost unchanged, and only water resistance is highly enhanced. Laboratory tests (11) showed that after 24 cycles of water impregnation by immersion followed by complete dryness in oven at 110°C, the treated samples lost only 2 percent in weight, while the untreated samples of the same material completely disintegrated during the second cycle.

The penetration of ethyl silicate in the walls is high and differs according to the porosity of the surface, obtaining an irregular plane of contact with the untreated part, and a gradient of the quantity of silica remaining on place. This is a great advantage in the sense that no crust rigidly delimited from the inner wall is formed, and therefore the chances of detachment are highly reduced.

The disadvantages of ethyl silicate are that it does not possess "gluing" properties. If the wall is already deteriorated in the form of pieces detached from one another, the ethyl silicate treatment will not keep them together, but simply consolidate each separate piece. The same is true for those walls which have a preformed and almost detached crust. If one can afford to loose one or two cm of surface wall, then the crust should be removed to obtain a solid surface before the treatment. If not, as in the case of friezes or paintings, a combined technique can be applied, consisting of consolidation with ethyl silicate followed by gluing together the pieces using injections of polyvinyl acetate or similar products inside the wall (12), (13). Preexisting cracks or little holes can be used as a guide for the injections. The synthetic resin which, if sprayed on the surface would cause the formation of a film easily detachable and whose chemical composition would change in time due to the exposure to light, performs instead very well inside the wall.

Ethyl silicate can be applied by spraying in a simple way.

Conclusions

In conclusion, I would like to stress a few points:

For adobe characterization not always the more sophisticated analyses are the ones giving the more valuable information.

Among the causes of alteration rain and possibly earthquakes are the most dangerous ones (and also more obvious).

Without a careful and constant maintenance there is no hope of making an adobe structure to withstand weathering.

In case of archaeological excavations the preservation intervention should be performed as soon as possible, the ideal case being the conservator working together with the archaeologist during the campaign.

Surface treatments, although in some special conditions efficient, cannot up to now, and probably never will, garantee the safeguard of adobe structures.

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–A long list of references can be found in the quoted (9) Technical Note 934 by J. Clifton, as well as in the other referenced papers.

Notes on the Manufacture of Adobe Blocks for the Restoration of Earthen Architecture

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1.0 Introduction

The restoration of earthen architecture frequently requires the completion of existing structural elements with adobe blocks having similar characteristics.

This paper summarizes, for training purposes, the basic specifications for the manufacture of adobe blocks and illustrates the most important aspects of the process.

2.0 Distinct phases in the manufacture of adobe blocks

The manufacture of adobe requires a series of diverse operations that begin with the identification and selection of the soil, continue with its preparation and molding, and conclude with a drying period. There are many manuals and reports which describe these operations. Not all of them include every necessary operation, nor explain in detail the rationales on which various aspects of the process are based. Sections 3.0 to 7.0 of this paper attempt to summarize the basic phases of the manufacture process and to examine some of the arguments which justify the procedures frequently recommended. To do this, we have reviewed most of the important manuals and have organized a number of figures which illustrate the text and a series of photographs which show the most important phases of such work *in situ.* The latter represents a practical experience requiring the manufacture of traditional adobe for the restoration of monuments.

3.0 Identification and selection of soil

3.1 The nature of soil

From a geotectonic point of view, 'soil' is defined as the unconsolidated accumulation of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter (1). Another definition says: any naturally occurring deposit forming the outer part of the earth's crust, consisting of an assemblage of discrete particles (usually mineral, sometimes with organic matter) that can be separated by gentle mechanical means, together with variable amounts of water and gas (usually air) (2).

The variety of existing soils has necessitated the development of empirical methods for their classification and study regarding:

- identification;
- physical and mechanical characteristics;
- behaviour as construction materials;
- modification if necessary.

Similarly, the various forms and dimensions of the solid particles which constitute soils has necessitated their analysis and classification based on particle size characteristics. Through this type of analysis, soils can be divided, based on their dominant particle size, into six arbitrary categories which are:

- boulders
- cobbles
- gravel
- sand
- silt
- clay

In general the solid particles which are recognized and analyzed as 'soils' include the last four categories: gravel, sand, silt and clay.

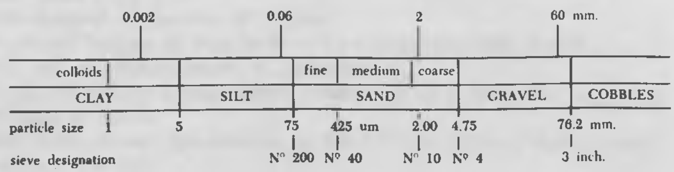
The two charts (3) which follow represent:

- the classification of soils by particle size with respect to their designation and the procedure for separating them by size and,
- the comparison of two systems of classification based on particle size characteristics; (U.S.A.) ASTM D422 and (GBR) BS 1377: 1975.

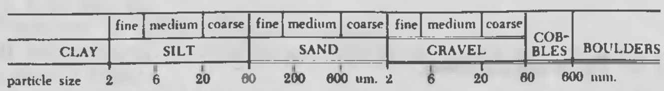
CLASIFICACION GRANULOMETRICA
CLASSIFICATION BY PARTICLE SIZE (Based on BS 1377: 1975)

Particle size (mm.)		*Designation*	*Test procedure*
> 200		BOULDERS	Measurement of separate pieces
200 – 60		COBBLES	
60 – 20	Coarse	GRAVEL	Sieve analysis
20 – 6	Medium	GRAVEL	
6 – 2	Fine	GRAVEL	
2 – 0.6	Coarse	SAND	
0.6 – 0.2	Medium	SAND	
0.2 – 0.06	Fine	SAND	
0.06 – 0.02	Coarse	SILT	Sedimentation analysis
0.02 – 0.006	Medium	SILT	
0.006 – 0.002	Fine	SILT	
0.002 and less		CLAY	

HEAD



(a) U.S.A. ASTM D422



(b) Great Britain BS1377: 1975

Soils in natural deposits are composed of different proportions of the designated solid particles; these, similarly, possess diverse physical, chemical, and mechanical characteristics which are not always suitable in a good soil for the manufacture of adobe blocks. It is, therefore, important to define the function of each solid particle in the whole of the adobe soil mix.

To *clay* is attributed the property of cohesion in the soil composition, or better, that of *'binder'* of the mix. Some of the processes related to this property of clay are discussed in point 5.2 of this paper.

The function of *silt* is not so well defined. Tests carried out on solid particles of silt characterize it as a material of poor plasticity, of marked dilatancy [1], of low cohesion, and that disintegrates easily on contact with water. Contrary to these conclusions, however, which suggest that silt is not suitable as a dominant component of an adequate adobe soil, certain researchers (5) also characterize silt as a *'binder'* material in the mix, though clearly to a lesser extent than clay. Moreover, it seems to be accepted that an adobe soil should contain equal quantities of clay and silt as binder materials in the mix (6). Taking into account these last considerations, we think that the precise function of silt in the soil mix should be better defined.

Sand, another component of adobe soil is formed of an assemblage of solid particles or fine grains produced by the disintegration of various rocks, principally quartz. This material functions as *stabilizer* of the clay and silt in the adobe soil mix. It is, thus, the sand in the mix which improves the behaviour of the clay, especially in the early phases of its preparation. It is the clay which is responsible for fractures and bulging, produced by the processes of expansion (through the absorption of water) and unequal shrinkage (by dehydration) of the block during drying. Sand functions as a filler which mitigates these reactive processes. This problem, as well as the occasional presence of *residues* (organic material, gravel, and others) are discussed later in the text.

3.2 *The evaluation of the soil*

Due to the specific characteristics of each solid particle, the proportion in which they are found in a certain soil will influence the behaviour of that soil should it be used for the manufacture of adobe. Experience demonstrates, in fact, that it is possible to produce 'better' adobes with certain soils than with others; or, in the extreme case, that with certain soils it is not possible to produce an adobe block having even a minimally acceptable degree of stability for construction purposes. It is, therefore, fundamental to define the characteristics of a good adobe soil.

[1] Property of volume increase under loading (ISRM). The expansion of cohesionless soils when subject to shearing deformation.

3.2.1. *The particle size composition of the soil*

In this regard, the existing literature presents certain differences. Following are several examples of proposed specifications for the composition of an adobe soil. These in turn are followed by the results of tests carried out on adobe samples obtained from monuments or, simply, from structures built in the past:

— The soil of *CRAterre* (7); extracted from a quarry containing no coarse stones roots nor organic earth:

+ sand	:	55 — 75%
+ silt	:	10 — 28%
+ clay	:	15 — 18%
+ organic material	:	less than 3%
+ Alkaline salts	:	maximum 0.2%

— The soil of *Proyecto PER 71/539* (8):

+ sand	:	60 — 68%
+ silt	:	10 — 28%
+ clay	:	15 — 18%
+ organic material & salts	:	maximum 0.3%

— The soil of *EBS* (9):

+ sand	:	50%
+ silt & clay	:	not less than 50%
+ organic material & salts	:	not specified

— The soil of *Adobe Codes of Arizona, California and New Mexico* (10):

+ sand	:	not specified
+ silt	:	minimum 25%
+ clay	:	in sufficient quantity for the cohesion of the mix
+ organic material	:	not specified
+ soluble salts	:	0.2 — 2%

— The soil of *NBS* (11):

+ gravel	:	little or none

+ sand	:	60 — 80%
+ silt & clay	:	20 — 40%
+ organic material	:	not specified
+ soluble salts	:	not specified

— The soil of *'Tumacácori'* (12):

+ gravel	:	2%
+ sand	:	24%
+ silt	:	26%
+ clay	:	46%
+ organic material	:	not specified
+ soluble salts	:	0.17 — 8.78% (13)

— The soil of *'Escalante'* (14):

+ gravel	:	— —
+ sand	:	18%
+ silt	:	55%
+ clay	:	27%
+ organic material	:	not specified
+ soluble salts	:	1.6% (15)

— The soil of *'Samarra'* (16):

+ gravel & sand	:	62%
+ silt	:	12%
+ clay & colloids	:	26%
+ organic material	:	[2]
+ soluble salts	:	[3]

— The soil of *'Ur'* (17):

+ gravel & sand	:	17%
+ silt	:	68%
+ clay & colloids	:	15%
+ organic material	:	[2]
+ soluble salts	:	[3]

— The soil of *'Choche'* [4] (18):

+ gravel & sand	:	7%
+ silt	:	59%
+ clay & colloids	:	34%
+ organic material	:	[2]
+ soluble salts	:	[3]

— The soil of *'Aqar Quf'* (19):

+ gravel & sand	:	14%
+ silt	:	58%
+ clay & colloids	:	28%
+ organic material	:	[2]
+ soluble salts	:	[3]

— The soil of *'Tell'Umar'* (20):

+ gravel & sand	:	32%
+ silt	:	49%
+ clay & colloids	:	19%
+ organic material	:	[2]
+ soluble salts	:	[3]

To these preceding examples could be added many others more or less representative of diverse soil mixes for adobe. Those presented will suffice, however, to attempt some generalizations.

A first consideration, often mentioned in recommendations for the proportions of particles in soils, is the preference for soils without *organic material*. The rationales for such recommendations are discussed in point 4.3 of this paper. For the present, it will suffice to say that, according to traditional practice, adobe soils should not contain organic materials or extraneous residues.

Secondly, due to the well known destructive effects of efflorescence, the content of soluble salts should be extremely low or non-existent. Maximum acceptable percentages range from 0.3 to 3%. Another extremely important consideration in relation to the presence of soluble salts concerns the layering structure of the clay particles. Some treatises dealing with the structure of soil state that clay sedimented in salt water solutions tends to develop a highly flocculated structure in comparison with those particles which sediment in fresh water. Since a highly flocculated structure generates large voids, the mix will have a low density that, ultimately, weakens the strength of the block.

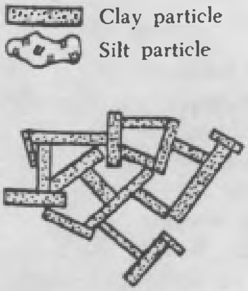
Thirdly, there is a preference for soils which do not contain gravels, fundamentally due to the unsuitable formal and dimensional characteristics of these particles as aggregates.

[2] The lack of organic material in some of the analysed samples is attributed to its decomposition and to its reaction with the mineral components of the soil.

[3] The presence of soluble salts appeared to be considerable; however, the test results were considered inconclusive.

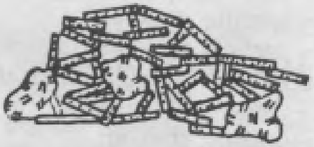
[4] Sample Nº 5. One of three.

A schematic representation of clay and silt particles combined in a flocculated structure in an undisturbed salt water deposit and, alternately, in an undisturbed fresh water deposit:



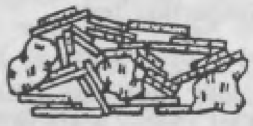
(a)

Flocculated-type structure (edge to face contact)



Undisturbed salt water deposit

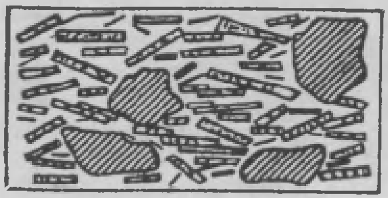
(b)



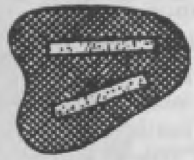
Undisturbed fresh water deposit

A schematic representation of thixotropic [5] structural change in a soil of fine particle size:

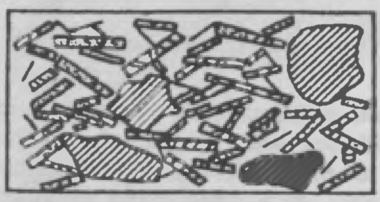
Shaded area represents absorbed water layer



(a) Structure immediately after remolding or compaction

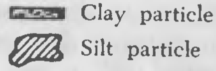


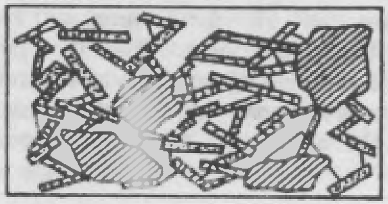
Attraction >> repulsion Water in high-energy structure



(b) Structure after thixotropic hardening partially complete

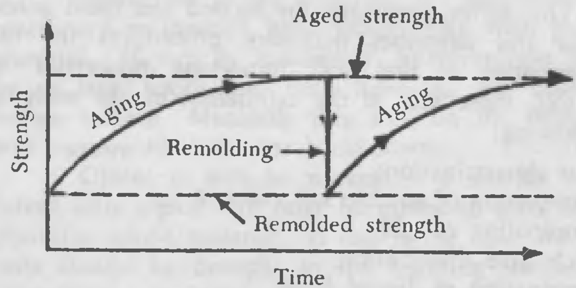
Attraction > repulsion





(c) Final structure at end of thixotropic hardening

Attraction = repulsion Water in low-energy structure



(d)

[5] Thixotropy: Phenomenon by which certain gels pass to the liquid state when agitated and are reconstituted when at rest.

Finally, as regards the proportion of sand with respect to that of clay/silt, it is difficult to make generalizations. The varied physical and mineralogical characteristics of clays diversely affect the behaviour of adobe soil mixes. It is, therefore necessary to carry out a series of tests in order to determine approximate proportions for the adobe soil mix.

3.2.2. *Tests for evaluating the characteristics of adobe soil*

The necessity for precise characterization of soil for adobe manufacture has led to the development of various procedures for the better evaluation of physical, minerological, and mechanical properties. Most of these tests consist of empirical methods derived from disciplines such as Geotechnics, Physics, and/or Soil Mechanics. Since it is not always possible, however, to count on the aid of a laboratory or, even, of the necessary equipment/instrumentation for the required tests, some of them have been simplified to provide approximate data on the characteristics of the subject soils.

Diverse publications, reports, and manuals contain detailed descriptions of all these tests. It is, therefore, unnecessary to explain them. For the purposes of this paper, we will limit ourselves to an indication of the most important references and to some brief commentary on the efficiency of the proposed methods.

3.2.2.1. *The series of NBS Technical Notes:* 934 (21), 977 (22), *and* 996 (23)

This series, especially the second and third notes, proposes and describes necessary procedures for the characterization of the most important properties of adobe soil, these are, in the estimation of the authors, the following:

- colour determination;
- determination of soluble salt content;
- determination of pH;
- particle size distribution;
- determination of *liquid limit;*
- determination of *plastic limit;*
- *X-Ray Diffractometry;*
- *microscopy;*
- determination of *compressive strength;*
- determination of *flexural strength;*
- analysis of *creep* [6].

3.2.2.2. *The Manual of Soil Laboratory Testing* (25)

Though not referring specifically to adobe, this manual contains valuable information regarding necessary equipment, theoretical foundations and detailed procedures for all tests concerning the correct identification and characterization of soils. The text specifically refers to the following tests:

- moisture content;
- Atterberg limits (liquid, plastic, shrinkage);
- sticky limit;
- linear shrinkage;
- puddle characteristics;
- swelling capacity;
- density;
- specific gravity;
- particle size distribution;
- indices of acidity and alkalinity (pH);
- content of sulfates;
- organic content;
- content of carbonates;
- content of chlorides; and
- compaction tests.

3.2.2.3 *Tests proposed in manuals for the construction of adobe dwellings: AID (26), EBS (27), CRYRZA/PREVI (28), CRAterre (29), Adobe Craft (30), and others (31)*

All these manuals contain simplified tests derived from laboratory procedures; they provide approximate methods for the evaluation *in situ* of soil characteristics. Among those tests most commonly explained are the following:

- the 'mud roll' test (for approximation of the correct proportions of clay/sand);
- the 'groove' test (verification of the water content of the mix);
- the 'bottle' test (for the approximate estimation of particle size characteristics);
- tests for *strength* and *quality control* (with the weight of a person, of adobe blocks, or with simple levers);
- *immersion* tests (verification of the permeability of stabilized adobe);
- diverse observations on the *deformations* of the mixes, etc.

A general observation concerning the efficiency of all these tests should be made here. It must be remembered that, due to the mineralogical characteristics of each type of soil, such tests could generate diverse results with samples equally suited to the manufacture of adobe. Therefore, whenever possible, the validity of these models should be verified with precise laboratory tests.

[6] Slow movement of rock debris or soil usually imperceptible except to observations of long duration. Time — dependent strain or deformation, for example, continuing strain with sustained stress (24).

4.0 Preparation of the soil

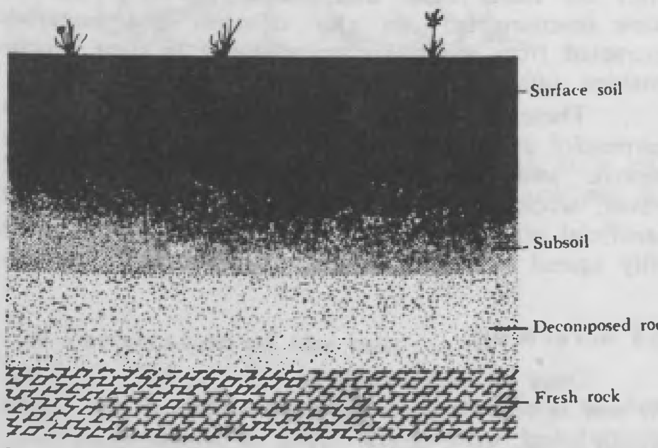
4.1 *Selection of quarries and yards*

4.1.1. *The quarry*

As discussed in the previous section, only certain soils are suitable for the making of adobe blocks. These contain established proportions of clay, silt, and sand and a low content of organic material. In addition, they must not be highly alkaline nor high in soluble salt content [7].

In general, therefore, topsoil —which contains a high proportion of vegetative material— is not suitable for adobe construction. It is rather the subsoil levels of sand and clay which, when mixed together, will provide the basis for a good adobe block (33).

A schematic representation of a soil profile of the EBS manual



MIDDLETON

[7] Alkalinity and soluble salt content are especially problematic in arid or semi-arid regions. In general, for highly durable adobe blocks, the salt content of the soil should not exceed 0.2% by weight of the soil. Since salt cannot easily be removed after the soil is quarried, tests for salt content should be done prior to extraction (32).

In this regard, it is interesting to note that the earth one finds at the top of rolling hills or ridges is more likely to contain clays, while that at the bottom will contain largely sands. The needed mixture of sand and clay could be found somewhere in between (34).

The location of the adobe quarry, therefore, will be determined largely by the availability of an adequate supply of appropriate soil. Obviously, for reasons of efficiency and cost, the quarry should be as close as possible to the construction site.

4.1.2. *Extraction*

Extraction of the soil can be accomplished by machinery or through hand labor (men with picks and shovels). If dug by machinery, however, the soil will be in large clods and will have to be broken up before mixing. Manually dug soil, on the other hand, will require little further breakdown.

Often, it will be necessary to extract two different soils which will later be mixed to form the most desirable adobe material. If this is the case, the diverse soils should be brought to the building site and kept in separate piles until ready for blending.

Some manuals suggest an extraction method which allows mixing of soils in the quarry (35). The builder first removes the layer of top soil. He then digs down the sides of the hole through both layers making his building mixture as he goes along by adjusting the quantities of each soil type he digs. Carefully done, such an extraction method could prevent extensive blending on the construction site.

It is estimated that the volume of earth dug must be 30% greater than the total volume of needed bricks (36).

4.1.3. *The construction yard*

The construction yard must be large enough to accommodate all the procedures involved in the making of an adobe block — from screening and blending of the soil through molding, drying and stacking the adobe blocks. It must be provided with an abundant supply of clear water and some type of protective structures to safeguard the blocks from rain.

It should be stressed that the organization of the adobe construction yard is critical to the success of any project. Attention should be given to the location and proximity of various functions in the yard in order to assure the most efficient use of space and time.

4.2 *Residue elimination*

Once the quarried soil has been brought to the construction yard, the first step in the preparation process is to remove all undesirable residue. These include large stones, gravel and all organic material such as decaying leaves, wood and roots. Domestic trash and other waste products such as fly ash must also be eliminated. The rationale for such a preparatory step —essential for the production of durable blocks— can be explained as follows.

In terms of coarse material such as stones and gravel, the rationale for elimination is related to the physical structure of clay. Clay particles are flat, hexagonal shapes, hydrophilic in nature. Characteristically, when lubricated with water, these plate-like shapes stack in layers creating an overlapping structure (similar to brick masonry). When subject to compressive forces, they will not break apart but rather slide past one another. The closer and more uniform the stacking (the denser the mass), the better will be the mechanical properties of the clay and, eventually, of the adobe block [8].

Stones and gravel, if allowed to remain in the soil, disrupt this stacking structure. They cause some of the flat hexagonal clay particles to stand on end, creating weakness in the clay which allow it to rupture.

[8] These are some situations in which it is desirable to have a certain percentage of non-clay particles in the mix. In making ceramic pots (especially tall ones), for example, the presence of less regular, more rounded non-clay particles provides some abrasion which allows, the clay wall to stand up (37). In this instance, the course particles prevent the clay from 'slipping' or deforming in the vertical plane.
For the fabrication of adobe blocks, however, where the clay should have maximum strength in the horizontal plane, an uninterrupted stacking structure is desirable.

Adobe blocks made with such material would have greatly weakened compressive strength. It is essential, therefore, to eliminate large stones and gravel from the quarried soil before beginning the blending process.

Organic materials are removed for other reasons. Firstly, organic soils (those high in organic matter) tend to be rather spongy. They are, thus, highly compressible and exhibit poor load-bearing properties.

Secondly, and perhaps more critically, organic materials decay through the action of bacteria, releasing acid into the soil. This decomposition renders the material unstable, increases its porosity (due to the creation of a more highly flocculent clay structure), and weakens its compressive strength (38) (39).

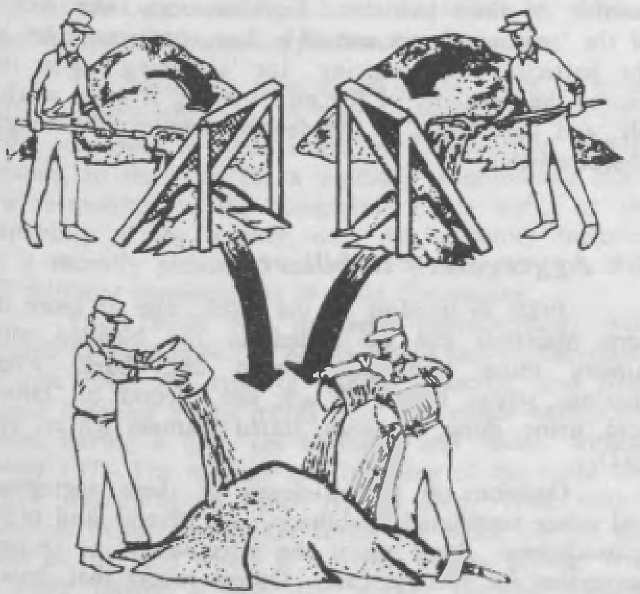
Such conclusions about the undesirability of organic matter in soil for adobe blocks may initially seem to contradict the traditional use of fibrous organic materials such as straw or camel hair in mud-brick manufacture. It has been found that such fibres have a strengthening effect on adobe which persists even after the fibres have disappeared probably due to some reactions between clay minerals and materials extracted from the fibres or produced in their decomposition (40) (41).

There is a difference, however, between such purposeful addition of organic fibre and the failure to remove what can be termed organic refuse (dead leaves, wood, roots, etc.). While the former may have beneficial effects on adobe blocks, the latter are generally agreed to substantially weaken the final product.

4.3 *Screening*

Once all undersirable residue has been removed, the soil is ready for screening or sifting. This can be accomplished with several types of simple equipment. The most typical screen is simply a rectangular wooden frame (about 2.5' x 5') on which is mounted a 0.25" — 0.5" (6-12 mm.) mesh (hardware cloth or a similar material). One end of the screen is propped up on two legs; the soil is simply dropped through the screen with shovels (42). Anything which does not pass is discarded or crushed again and rescreened.

When two different soils are to be blended, they should be screened separately and kept in separate piles. The proper proportions of each soil can then be gauged at the time of mixing.



WOLFSKILL

Using this type of manual screening, it is estimated that a man can screen 4 m^3 of earth per day (43) [9].

5.0 Preparation of the mix

5.1 *The optimum amount of mixing water*

The amount of mixing water is of critical importance in making adobe blocks. Too much water will result in a block of poor strength which will shrink considerably upon drying. Too little water will result in a soil of inadequate plasticity which will crumble when molded. Though it is impossible to specify in quantifiable terms the 'optimum' percentage of mixing water for every adobe soil, some general statements are possible.

The desirable amount of mixing water is related to the liquid and plastic limits of the soil. The *liquid limit* (LL) is defined as the moisture content (in percent by weight) at which soil passes from the plastic to the liquid state. The *plastic limit* (PL) is the moisture content at which the soil passes from the plastic state to the solid state — that is, the point at which it becomes too dry to be in a plastic condition and crumbles when worked. The *plasticity index* of a soil is defined as the liquid limit minus the plastic limit. Together these three factors provide some information concerning the dimensional response of clay to moisture.

Most simply, different clays exhibit different liquid and plastic limits (Clifton 977, Table p. 25). Thus, the type of clay will influence the amount of mixing water required. In addition, liquid and plastic limits are significantly affected by several other factors such as the presence of organic matter and the type and amounts of soluble salts (45).

As regards the plasticity index, it has been found that higher plasticity indices are accompanied by larger expansions upon wetting and larger shrinkages upon drying. According to Clifton, therefore, the closer that adobes match in their plasticity indices, the more compatible will be their dimensional responses to moisture (46).

The works of various other researchers (47) have established additional information concerning the proper amount of water needed for making adobe blocks. Schwalen, for example, found that the proper amount of mixing water depends on the proportions of clay and silt in the soil. He also found that the magnitude of shrinkage varies with clay content, type of clay, and amount of mixing water. In this regard, Webb found that drying shrinkage is not a linear function of the amount of mixing water; rather, higher water content shows *considerably* increased shrinkage.

[9] More complicated sifters have been developed which are said to be more efficient. A particularly interesting example is the power-driven barrel sifter described in *Adobe Craft* (44) consisting of a plastic garbage container which rotates on roller skate wheels. The sifter is belt driven by a pulley powered by a heavy duty hand drill motor.

Some researchers (Fenton, Webb) suggested that it is possible to ascertain the optimum amount of mixing water for each adobe soil, i.e. that which gives the highest strength and density to the block. In their own work, the NBS (48) discovered that the optimum amount of water was generally somewhat less than the liquid limit. This they attributed to the large percentage of particles in the adobe soil larger than 425 mm. which absorb much less water than clay size particles.

From the above discussion, it is clear that no simple guidelines can be given for the optimum amount of mixing water in the making of adobe blocks. Most field manuals, therefore, provide the builder with either a very general percentage range for the amount of water (from 15 — 30% depending on the manual) or with some very basic empirical tests. It is suggested, for example, that the soil is at the correct moisture content for molding adobe blocks when it no longer adheres to metal utensils (49) (50). Another simple test to determine proper consistency is to draw a stick through the mix surface; if a smooth wet indentation remains, the soil is at the proper consistency. In the final analysis, however, it is only experience which will enable the builder to judge the optimum water content.

5.2 *Blending of the soil*

One of the most important phases in the preparation of the mix consists of adding the necessary quantity of water to the selected soil, followed by blending and turning to achieve a plastic consistency [10]. Through this process, a homogeneous and plastic mix is obtained. Such characteristics ensure workability and strength. The homogenization of the mix causes the regular distribution of the solid particles and the added water in the total mass. This contributes to the necessary friction between the clay and non-clay particles and to the development of cohesive properties, the latter resulting from the structure formed by the fine particles and the water. Both factors are critical to the consistency and ultimate strength of the mix.

[10] Blending time is estimated to be at least one day, followed by a period of 'seasoning' of at least one night (51).

The so-called 'seasoning' of the blended mix permits a slow penetration of water between the clay particles which, consequently, divides them into a larger number of finer particles. Simultaneously, the weight of the 'seasoning' mix causes a slow compression of all the particles. The 'souring' (or 'seasoning') also improves the plasticity of the mix, making it more workable, and contributes to the development of its strength characteristics.

5.3 *Aggregates / stabilizers*

Prior to molding of the block, one or more diverse materials can be added to the blended mix. Among those traditionally used are: bark, wood shavings, straw, hemp, fly ash, sap, coconut oil, tannic acid, urine, dung, molasses, rotted plantain leaves, etc. (52).

Opinions on the efficiency of these aggregates and other traditional 'stabilizers' are diverse and often contradictory. Some assert the effectiveness of certain aggregates for specific cases. Others report that, based on laboratory tests, there is no considerable improvement in the properties of blocks made with some of the mentioned aggregates as compared to those without aggregates.

There are, however, at least two hypotheses regarding the function of the mentioned stabilizers. The first suggests (in the case of fibrous aggregates) a mechanical function of the aggregate during the dehydration (drying) of the block. The fibres compensate for the stresses induced by the shrinkage of the clay, thus avoiding excessive or unequal shrinkage and fractures of the block. The second hypothesis suggests organic activity which promotes the multiplication of bacteria and the formation of amino acids (thus modifying the acidity index). This process creates better conditions for the flocculation of the finest particles of the soil (53).

At the worksite, the organic aggregates should be proportionately mixed with the blended soil. Some manuals recommend mixing the aggregate with the soil for at least one day. Following this, the blended mass must 'season' for at least one night.

6.0 The preparation of the block

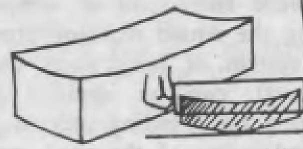
6.1 *Forms or molds, characteristics of the block, quality and efficiency*

The geometric form of an adobe block is, generally, a parallelepiped [11]. The dimensions of this solid vary according to local usage, to construction specifications, to the need for a precisely dimensioned block for restoration or the completion of a wall, to the capability of the worker, etc. An inventory included in a recently published manual (54) contains at least 33 different combinations of mold dimensions.

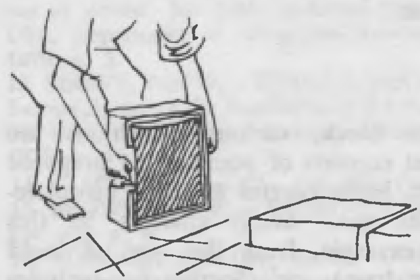
Each mold has different characteristics with regard to the number of blocks which can be fabricated at one time, the type of handle, material, and base. Some manuals group molds into two major categories: those having a base (or bottom) and those without bases (57). The method and handling of the mold will differ depending on which type is used. Thus, with a baseless mold, the worker forms the block on the surface of the yard where it will rest during drying. With a mold having a base, the worker remains standing and forms the block on a table (or pedestal) on which the mold rests. According to studies made by Programa COBE (58), the first method is more efficient, but results in a less compacted block and greater fatigue on the part of the worker. With the second method, efficiency is lower but compaction is improved and worker fatigue diminished. Whichever mold is chosen (with or without base), maximum attention must be paid to deformations of the block resulting from handling of the mold. This is especially critical in the case of the mold with base where it is necessary to turn the mold 180º in order to deposit the block on the yard surface.

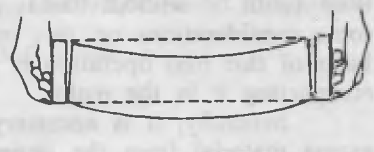
The following figures show several possible deformations due to the type of mold and its handling (59).

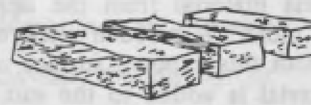
[11] Certain construction systems use blocks molded by hand creating geometric forms which are irregular or simply different from the parallelepiped (55) (56).



PARRY







PARRY

Traditionally, molds are made of wood (having sufficient strength and section to withstand continuous use and handling). Some manuals (60) suggest covering the wood with regular and impermeable surface materials (vinyl, polyethylene, latex, formica, fiberglass and other synthetic materials). The use of metallic revetment (aluminum, sheet steel) is also mentioned.

In our opinion, the traditionally wooden mold (of a single block) is not problematic. If adequately constructed and maintained, it will give excellent results. Moreover, with a wooden mold, it is possible to control the consistency of each block immediately after it is removed from the mold. It is recommended that wooden molds be soaked for the entire night preceding the molding day. It is also important to adequately lubricate the molds before molding and whenever necessary during the molding process. In this regard, some manuals recommend wetting and oiling the mold. Others suggest wetting the mold and then coating the internal surfaces with fine sand or, simply, keeping the mold wet during the entire molding process. In our opinion, the best system of lubrication (according to the type of soil used) can be decided on the basis of tests made during the molding process. It will not be difficult to modify any of the cited recommendations should they prove problematic.

6.2 *Molding*

In molding the block, various operations are distinguished. The first consists of pouring the prepared material into the mold, being careful to fill it completely and to compact the mix. Small changes in this operation result, for example, from the type of mold used (with or without base), etc. Section 6.1 includes some considerations on this point. In any case, the basis of this first operation is pouring the material and compacting it in the mold.

Secondly, it is necessary to 'level' or 'trim' the excess material from the upper surface of the mix in the mold. A wooden stick or 'rule' can be used to smooth this exposed surface of the block. The removed material is added to the mix for the following block.

Thirdly, if a better finish of the exposed block surface is desired, a final levelling can be accomplished with a trowel or similar type of mason's tool. In some cases, this operation is carried out while throwing water on the exposed surface.

Finally, the mold is emptied, lifting it (mold without base) or turning it (mold with base) so as to place the molded block on the yard surface [12].

Once the mold is emptied, the consistency of the block can be checked, noting possible deformations or fractures. Some manuals suggest adjusting the quantity of water in the mix if such problems are evident (61) (62). It is also important to check that the mold is adequately lubricated, according to the specifications mentioned in section 6.1. These problems and considerations are well illustrated in the previously cited manuals.

[12] Some manuals recommend covering the surface of the yard with a layer of fine sand to prevent the fresh blocks from sticking to the ground during drying.

7.0 Curing of the adobe block

7.1 *Drying*

Proper curing of the adobe block demands slow, even drying. Excessively rapid drying will lead to cracking of the block; damp or cold conditions will prolong the drying process. Thus, to ensure a good cure, the environment of the drying blocks must be carefully controlled. In excessively hot climates, it may be necessary to provide some type of protective covering to keep the bricks in shadow for the first few days of cure. Some manuals also recommend occasional spraying of the bricks or covering them with straw, sand, shade cloth, etc. (63). Similarly, if rainfall is a possibility, some type of protection must be provided. In general, the drying can be described as follows. After removal of the molds, the blocks are left in their original position for several days (2-5 depending on the manual) until firm enough to be handled. They are then turned on edge to expose the bottom surface and to allow more equal drying. At this time, any excess material clinging to the block can be removed with a small stick. In this position, the blocks are left to dry for another three weeks at which time curing is considered complete.

There are, of course, variations on this general process. Some manuals recommend a second turning on end after 15 days (64) to again change the ventilation of the block. This, of course, is only possible if the block has dimensional stability on its short side. Other authors also suggest that it is possible to stack the blocks allowing adequate ventilation after only two weeks of drying (65) (66) (67) (68).

The cure is completed in the stacked position. In the opinion of the authors of this paper, however, such premature stacking is not advisable since it places stresses on partially cured blocks which could lead to cracking or deformation.

7.2 *Piling*

When the blocks are completely cured (about four weeks from the removal of the molds), they are ready to be piled for use. According to traditional practice, the blocks are stacked against a central pier formed of face-bedded adobe. This method is spatially efficient and allows the worker to handle the block in its strongest position.

7.2.1. *A note on curing*

It is essential that adobe blocks be completely cured before use. Though some builders suggest laying partially cured blocks, this practice is *never* recommended. Only a completely cured block is thoroughly flocculated, has attained an acceptable moisture content [13] (and thus will not shrink further after being laid) and has achieved maximum compressive strength. The quality of cured blocks, in fact, should be checked through established tests before they are considered suitable for construction. Though these control tests are outside of the scope of this paper, they are clearly described in the cited manuals.

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Adobe Buildings
some Restoration Examples

Sergio Rojo A.

Abstract

—Some properties of raw earth used as a building material, relevant to the configuration and mechanical behaviour of structural forms, are discussed.

—Restoration examples are given, where the criterion followed was applied as a result of considering these properties.

1. Introduction *

1.1 *Need to concern ourselves with raw-earth buildings*

One-third of the world's population lives in houses made of raw-earth.

Many of the historical monuments found in different regions of the world are made of adobe.

Industrialization, by itself, has not managed to solve the housing needs of an explosively-growing population.

The vernacular traditions will continue to be the only accessible building methods for large —and, possibly, growing— groups of the world's population.

We must add to this that industrialization brings about the discredit of traditional building techniques, which are thus completely forgotten.

Another reason to concern ourselves with raw-earth buildings is the need to safeguard the cultural identity of the different peoples and to reduce energy consumption and pollution.

* This summary deals only with structural aspects of raw earth and excludes the technical precisions which were discussed during the Symposium-Workshop. These will be found in other papers of the present publication, as well as in the works listed in the Bibliography.

1.2 *Relevant properties of raw-earth from a structural point of view*

The relevant *physical* properties of raw-earth are:

—Plasticity, which makes it possible to shape earth and produce usable structural elements.
—Solidification, which allows conservation of the forms and of the mechanical properties associated with the solid state.

Both of these properties depend on the presence of small particles, of clay and on the water content. A solid element will return to the plastic state by water absorption, increasing its volume and losing its mechanical properties. By desiccation and, eventually, by pressure, it will solidify and reduce its volume.

This reduction in volume —shrinkage caused by the drying cycle— will produce cracks and mechanical damage. To maintain the material within acceptable limits, it is necessary to have larger particles, sufficient amounts of sand or to reinforce the earth diffusely, by adding vegetable (or other) fibers.

The *mechanical* properties which condition structural behaviour are:

—Compression-strength is five times greater than traction — or flexotraction-strength.
—Shearing strength is formed by a component depending on adherence and another one depending on friction and, therefore, on pressure. The latter is usually more important than the first one.

The combination of both properties produces a fragile-type of structural behaviour (as opposed to a ductile one) which is undesirable when the loads are dynamic.

Granulometric correction, compacting and physical and chemical stabilization contribute to fix the solid state throughout time, and to increase the magnitude of mechanical strength, yet do not change the structural characteristic of the material.

1.3 *Structural forms*

The following conditions depend on the physical and mechanical properties:

—Shrinkage, which takes place as a result of drying, makes it necessary to reinforce the earth or to reduce its resistance by adding sand or contraction joints.
—The unbalance between compression-strength and traction-strength will lead to structural forms which are solely —or predominantly— compressed: arches, vaults, domes, columns, walls with a vertical and static load, and others, where the result of forces is contained in the nucleus of the sections.
Alternatively, vegetable or metallic reinforcements are used to compensate for the tractional weakness of earth and to widen the range of the possible structural forms.
—The friction component in the shearing strength will make it necessary to load the sections where shearing is critical. This implies the existence of large masses whose inertial reaction to seismic movements is undesirable.
—Fragility makes it necessary —in structures built in high seismic-risk areas— to use reinforcements and to carefully choose the structural shapes, in order to produce ductile-type failings.
This will also lead to look for the most resistant redundance which the shape will allow.
We must emphasize that, except for the loss of the solid state, due to the absorption of water, all the other properties listed are common to the different forms in which raw earth is used, as well as to brick masonry, stone rubble work, ashlar stone masonry and concrete (not reinforced).

2. Some restoration examples

Comments follow on the structural and design criteria applied in four monuments where I acted as structural consultant.

These monuments are:

—The Church of San Francisco de Curimón, Chile (1972).
Architect: Rodrigo Márquez de la Plata.
—The Museum of San Francisco, Santiago, Chile (1974).
Architects: Raúl Irarrázabal and Exequiel Fontecilla.
—Tower of the Church of La Merced, Rancagua, Chile (1982).
Architect: Mario Pérez de Arce A.

—Tower of Hacienda Mendoza (Monasterio Benedictino), Rengo, Chile (1983).
Architects: Raúl Irarrázabal and Associates.

2.1 *Church of San Francisco de Curimón*

The nave of the church was built in 1737, and the tower (the third one) between 1860-1890.

The tower is made of wood and is totally independent from the nave. It suffered extensive damage during the earthquake of La Ligua, on 28 March 1965. Part of the south wall (13 m.) collapsed and several buttresses were detached from the north wall.

At the time, the roof was lightweight, made of ondulated galvanized steel. The adobe walls, for an 8 x 44 m. interior free floor plan, were 9.50 m. high. The section of the south wall which collapsed did not have any buttresses.

The wall which collapsed was rebuilt and the lacking buttresses were added. The detached buttresses were connected to the wall, by locking the adobes and introducing several oak chains, placed throughout the height.

The lightweight roofing was substituted by a heavy one, made of curved tiles, stuck with mud. The height of the walls was lowered —except in the choir part— to 7 m.

These two operations allowed to regain the original design of the nave.

Comments

—The colapse of the central part of the south wall, far from the interlocking corners, was due to the lack of buttresses.

These have a double function: on the one hand, they are equivalent to a "widening" of the wall, reducing its slenderness; on the other hand, they constitute localized weak points, which can be repaired.

The history of the buttresses in the north wall explains the above: they were torn at the point of connection with the wall but, when breaking, they dissipated energy and, probably, allowed the wall itself to survive the destructive phase of the quake, which has a limited duration.

—The advantage or disadvantage of a heavy roof calls for some comments. Evidently, for a free-standing wall, which is not part of the wall-system, the existence of a considerable mass at the top of its height is clearly unfavourable.

The situation is less clear if the existence of said mass —and the rigidities and links associated with it— have the capacity to integrate that wall within a system having greater redundance.

A cover of ondulated galvanized steel, tightly screwed to the wood roof structure has a significant capacity to act as a diaphragm. Nonetheless, it can not materialize the restriction of the top part of the wall, because of lack of weight.

A roof made of tiles and mud over a continuous, wide planking, properly nailed to the legs of the roof structure, constitutes a good diaphragm and forms a box where the walls which are momentarily in a perpendicular direction to the seismic movement receive support at the top, at the expense of those which have a parallel direction and, therefore, resist easily.

The link at the top of the wall can be materialized through the shearing strength which is increased by the pressure caused by the weight of the roof.

Although some slipping in this link might occur, there is still an advantage to be had as a result of the energy dissipated.

—Reducing the height diminishes the slenderness of the walls and reduces the probability of overturning. Although—for a specific earthquake— it cannot be demonstrated that less slenderness implies greater overturning safety, this is undoubtedly so for the family of seisms.

2.2 *Museum of San Francisco de Santiago*

This church, the oldest in Chile, was built between 1572 and 1618.

The cloister, which houses the Museum, was built in the 17th century and recently adapted to museum purposes.

The restored part is two-storeys high; it has an aisle 8 m. wide, plus a corridor 4 m. wide. It is 70 m. long and 9.70 m. high.

The walls, made of adobe, are 1 m. thick.

The wall adjacent to the street was noticeably out-of-plumb in all its height.

Following criteria developed in previous projects, we decided to accept the inclination of the wall for the first floor, but not for the second storey.

The second-storey wall was torn down and replaced by *adobillo*, i.e., a partition-wall made of oak posts, filled with adobes laid on edge, with diagonal wiring and plastered with mud (*polvillo*).

Furthermore, other existing transversal *adobillo* partition walls were linked to the structure, and the roof was rebuilt. It is made of curved tiles over a traditional wooden structure known as *par y nudillo*. The rafters and beams were carefully designed and a reticular diaphragm was added in the horizontal plan of the tie-beams.

Comments

— The out-of-plumb wall did not show any local damage. Leaning may have several causes:
The most probable one is, simply, differential settlement on the ground outside, with regard to the inside part. Three-hundred and fifty years of weathering and traffic on the outside must have resulted in greater consolidation.
The inside wall —between the aisle with the series of rooms and the corridor— where ground-conditions are similar on both sides, is totally plumb.
In other cases, leaning is due to the thrust of the rafters, faultily connected to the tie-beam. In yet others, it is due to permanent deformation of the walls —or of the foundations— of a seismic origin, caused by the crushing of the material in the support-base area. It can also be due to a deterioration of the base, caused in turn by the presence of superficial water.

— Safety of two-storey walls in the event of a seism is precarious.
For this reason, the greatest efforts were made to increase the integration of the structural whole and, therefore, its mechanical redundance.
The partition walls made of *adobillo* are an example of structural elements where one can obtain a ductile response to the dynamic loads, thanks to a combination of the mechanical properties of wood and raw earth.

2.3 *Tower of the Church of La Merced, Rancagua*

This is a small tower, built in the 18th century. Its floor plan is small, 3 x 3 m. free span, and it is 12 m. high.

Its four walls are made of adobe; they are 1.20 m. thick.

It was in excellent condition until someone, clumsily, made an opening for a door next to one of the corners.

This alteration —of recent date— produced breakage in the wall "as if the opening was trying to centre itself in the wall".

Repair interventions consisted in closing this eccentric opening and reopening another, previous one, which was centred in one of the other walls.

Reopening the old door did not produce any weakness because, from a structural point of view, it was always "open", although a part of the wall made of piled adobes blocked the way through it.

The damaging opening was closed using bricks and a mortar binding made of Portland cement. A final adjustment was made using expansive mortar. In a certain sense, this meant the foundation-level and foundation-top were raised, until they were in contact with the adobe wall.

Although from the point of view of mechanical homogeneity it would have been ideal to close the opening with adobes, this was impossible to do in practice: the "patch" wall settles, due to shrinkage caused by drying, and stops acting as support for the wall which is over it.

By the same token, lateral interlocking is destroyed and the whole patch becomes detached.

To fill in the opening with brick masonry, parallel brick piles were made. The lateral interlocking effect was substituted by using horizontal reinforcements made of welded wire mesh.

Steps were built on the contact face to receive the load of the uper weight on the horizontal planes, trying to follow as closely as possible the shape of the total opening, i.e. the original door plus the additional opening, caused by breakage or failure.

Comments

The damage ensued demonstrates the wisdom of recommending that openings made in an adobe wall be centred, or at least be placed away from the corners.

Under static conditions, the load of the weight —a considerable one in this case— tends to produce (due to the lack of symmetry in the wall) a horizontal slipping of the lintel with regard to the floor, on the side of the opening.

This slipping increases the pressure in the area of the wall which is next to the opening on the side of the larger wall.

Under seismic conditions the problem increases because the larger wall, which is more rigid, takes a percentage of the horizontal load exceeding that which would correspond to a simple distribution of that load in function of the relative areas.

The free end of the larger wall is the critical area, and this is, precisely, the one that suffered damage.

Finally, the corner area in a tower such as this is the most valuable one from a structural point of view, for it is composed of two interlocking walls.

A poorly-placed opening destroys this valuable element.

2.4 *Tower of the Hacienda Mendoza, Rengo*

This XVIIth century tower, possibly built after 1655 was used both for representative functions and as a watchtower.

It has a 6 x 6 m. free-span ground plan and is 12 m. high. Walls are made of adobe, 1 m. thick and it has floors placed at three and nine metres.

It is perfectly conserved, due to its excellent construction. The floors interlock the walls securely and, apart from the floors, it has a number of intermediate oak chain reinforcements.

Intervention was necessary in order to add some new openings and a third floor, placed at 6 metres.

These changes were necessary because of the new functional use: the tower is now part of the Benedictine Monastery for Women, Our Lady of the Assumption.

The new openings are small, strictly centred and framed with oak.

The new floor will improve the blocking-up of the walls.

Comments

No negative comments.

We should emphasize the excellence of its construction; the symmetry of design and the absence of weak or critical points.

The static pressure in the walls is close to 2 kg/cm^2 and dynamic compression —for a seismic design according to Standards— does not exceed the former in more than 50%. This is due to the lack of slenderness in the total structure.

The floors (mezzanines) do not represent more than 1,3% of the total weight of the tower. We emphasize this situation because it is usual in adobe and quite different from the one existing in concrete or steel structures.

In an adobe tower (or one built with raw earth in any form) with considerably thick walls, it is not realistic to suppose masses concentrated at floor levels to study the structural response to seismic loads.

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now standing, and a third floor, placed at 6 meters.

These changes were necessary because of the functional use the tower is now put to [illegible] the [illegible] [illegible] framed with [illegible].

[illegible]

The [illegible] strengthens the [illegible], [illegible] the [illegible] of [illegible].

The [illegible] pressure in the walls in [illegible] and dynamic compression — for a [illegible] design, according to [illegible] — does not exceed [illegible] to more than 10%. This is due to the lack of slenderness in the final structure.

[illegible] of the total weight of the tower. We considered the [illegible] used in [illegible] and [illegible] different [illegible] and [illegible] in [illegible].

In an [illegible] for one [illegible] with the same [illegible] such considerably thick walls, it is [illegible] floor [illegible] to [illegible] the structural response to seismic loads.

Bibliography

[illegible] Church [illegible] Armenia [illegible]

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[illegible] demonstrate the [illegible] by recommending that openings made in an [illegible] be centred, or at least be placed away from the corners.

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The [illegible] the passage in the area of the wall [illegible] of the [illegible] the size of the larger wall.

Under seismic conditions the [illegible] because the larger wall, [illegible] percentage of the horizontal [illegible] would correspond to a single [illegible] of the wall in function of the [illegible] area.

The [illegible] end of the larger wall is the critical area, and that is, [illegible], the [illegible] damage.

[illegible]

4.4 Tower of the Church of [illegible]

This [illegible] 1955 [illegible] and [illegible]

[illegible]

It is [illegible] construction. The [illegible] walls [illegible]

Assessment of Structural Faults and Monitoring of Structural Movements in Adobe Buildings and Ruins

Todd Rutenbeck

The assessment of structural faults in adobe structures normally begins with a visual inspection and a study of the structural history. Locating structural cracks and deducing their probable causes is essential. A plumb bob will help in locating severely out-of-plumb wall sections, and profiles of the worst sections can be plotted to determine the likelihood of failure. Sagging beams, floors, or roofs indicate structural movement and possibly weakened structural members. In addition to obvious current structural defects, conditions likely to cause future problems should be observed. Problems with surface drainage, soils, vegetation, moisture, animals, and roof drainage are a few examples. Structural history items such as dates of known seismic activity, sources of vibration, dates of past repair work or major damage, data from past structural studies, and photographs showing past structural condition are important. Signs of weakened or moist adobe along with signs of damage from current building use should be observed. Most important, however, are signs of recent change in the structure. Pieces of plaster or adobe that have recently fallen, cracks that have become wider or longer, and new structural cracks all indicate current structural movement.

Unstable structural elements will fall into two general categories: (1) those whose geometry or material strength is so unstable that small increases in loading could cause instant collapse, and (2) those having defects that are slowly increasing and may lead to collapse in the future. Items such as crumbling adobe blocks, detached plaster, severely leaning walls, broken beams or columns, and loose adobe or brick could be included in the first category requiring immediate repair work. Items in the second category are more difficult to deal with. Because of the cost of repairs and because of preservation considerations, it is necessary to separate apparent structural defects from actual structural defects. The wall that leans slightly may tilt more each year until it fails. It may, however, have been built out-of-plumb and not moved since, and thus be in no danger of failure. Cracks in adobe walls or domes may widen each year due to foundation defects and eventually lead to failure. They could also be due to temperature or moisture changes that are seasonal, or due to shrinkage or foundation settlement that took place immediately after construction, and thus pose no structural threat other than leaking water. Vibrations from railroads, highways, or sonic booms can damage structures, but in some cases they are harmless. Such considerations often lead to starting a structural monitoring program to measure gradual movements and determine which apparent defects are actually moving toward failure.

Structural monitoring can be a very valuable technique for evaluating adobe structures, but it sometimes fails due to poor planning. Frequently instrumentation is installed in a structure with no clear purpose. There must be a definite preservation decision that the data will help to decide. For example, seismographs are frequently installed in historic structures where damage from traffic vibration is suspected. Several years of data gathering takes place to record the intensity and duration of vibrations loading. It then becomes apparent that while the level of seismic loading has been determined, no one knows if this vibration intensity is sufficient to cause damage to the structure. What was actually needed was a concurrent measurement of structural damage such as increasing crack width that could be correlated to levels of seismic loading. Then a decision to limit vehicle size to stay below the critical vibration level could be made. Other problems in planning monitoring programs include a false sense of security from monitoring a structure that is likely to fail instantly, monitoring when the decision to repair the structure has already been made, and using instruments of insufficient accuracy. For example, suppose that the width of a crack between a badly leaning wall and an abutting wall is to be monitored. If plotting the profile of the leaning wall indicates that the wall is already at the balance point, it is likely that the wall will fail instantly from a single event such as vibration or high wind loading. Monitoring may show no gradual changes in crack width and give a false sense of security in this dangerous situation. If, however, the top of the wall must tilt out several millimeters before it is in danger of falling, monitoring would be appropriate. Even in this case the monitoring effort would be wasted if the decision to build buttressing walls had already been made or if the monitoring was done with insufficient accuracy to predict movement trends before the critical angle of tilting was reached. Only a well planned monitoring program with definite goals and appropriate instruments will be useful in making preservation decisions.

The purpose of structural monitoring, then, is to detect gradual structural movements that can lead to collapse. A well designed monitoring program allows definite decisions to be made based on the results. If no progressive movements are found, the historic fabric can be left unaltered. If progressive movements are detected, stabilization work must be carried out in time to prevent collapse. It is therefore necessary to be able to distinguish between progressive movements that will lead to failure and seasonal changes that are harmless. It is also necessary to know how much movement can be tolerated before failure. This determines the needed accuracy of the instrumentation to be used.

Structural movements, such as crack width change, wall tilt, deflection, and foundation settlement are usually plotted as movement versus time. Thus, in monitoring a structural crack, it is not necessary to measure the existing crack width. A gage is installed across the crack and the reading on the gage is recorded. This initial reading is subtracted from each subsequent reading to determine the change since gage installation. These changes in crack width are then plotted versus time in days. The fluctuations that this plot shows are composed both of seasonal changes and of progressive movements. If only seasonal changes are occurring, the plot would fluctuate above and below the zero movement line, but after a year of data plotting the total change would still be approximately zero. If progressive movements were taking place, the plot would continue to move away from the zero line. The seasonal movements would cause variations in the plot, but the general trend in one direction would be apparent.

Seasonal variations have two causes. The first is composed of actual changes in the structure due to seasonal or daily changes in loading, temperature, and moisture. The second is due to changes in the instrumentation. These include thermal expansion and contraction of the instrument and its mounting brackets, reading errors, and instrument inaccuracies. There is a tendency when first starting a monitoring program to spend too much time on instrument seasonal variations. Computing the thermal expansion of the brackets and the instrument, and applying temperature corrections to electronic gages and their readout devices, is seldom necessary. As data are plotted, the difference in progressive movements and seasonal movements becomes apparent. Since the main purpose is to detect progressive movements, it is not normally necessary to separate the two types of seasonal movements. The instruments used, of course, should have as small a variation with temperature as possible, but once the installation is completed, it is seldom necessary to compute these variations.

Determining how much progressive movement can be tolerated before collapse occurs is a function of structural geometry. A vertical crack in a free-standing wall could widen indefinitely without the danger of collapse so long as the wall segments remain vertical. If a free-standing wall segment is tilting as a whole, it is easy to compute what degree of leaning will cause it to fall. Most structural faults are not so easily analyzed and most predictions of how far movement can progress before failure are merely estimates. Even in the simple case of a long free-standing adobe wall that is leaning dangerously, the idealized computation of the amount of movement necessary to cause failure will not exactly represent the wall. The wall is stable as long as the center of mass of the wall does not tilt beyond the center one-third of the wall's base. At this point, tensile stresses develop, and adobe with mud mortar has little resistance to tension; however, the wall may not fall. As tensile cracks develop, the wall may bulge and change its shape. Some segments may lean beyond the balance point (when the center of mass is above the outer edge of the wall base) without failing merely because adjacent, more vertical sections of the wall provide support to the leaning sections through friction between the adobe blocks. Thus, most estimates are on the conservative side, treating a failing section as if it were free-standing and ignoring the support of adjacent sections which is difficult to compute.

The needed instrument accuracy depends on the estimated amount of movement that will take place before failure. If a movement of only ten millimeters could cause failure, an instrument accurate to 0.01 mm. would allow 1000 units of movement before failure, thus allowing gradual movements to be observed before failure. An instrument with an accuracy of 5.0 mm. would allow only two units of movement before failure, not enough to detect gradual trends.

Monitoring efforts often fail from lack of accurate instruments. Glass slips glued in place across cracks or measurements taken with a ruler between two pencil marks often yield useless results due to low accuracy when the use of a $60.00 mechanical dial gage could have given results accurate to 0.01 mm. This is a small cost compared with the personnel costs involved in taking and analyzing the data.

Instrument costs vary widely depending on the needs of the monitoring project. Crack width and deflection can be monitored accurately using $60.00 mechanical dial gages provided that it is possible to get to the gages periodically to take readings. If scaffolding or manlifts are necessary to reach the gages, it may be cheaper in the long run to install $700.00 electronic gages that allow a remote readout. Electronic gages also allow automatic electronic recording of data in cases where continuous recording of data is needed.

Soil and foundation settlement can be detected with a precise surveyor's level. While initial costs of precise leveling equipment may be about $9000, there is little additional cost for the purchase of brass monuments needed at each site for reference points. Thus, once the equipment is purchased, it can be used at numerous sites at little additional cost. Such equipment (consisting of a precise level with optical micrometer, tripod, and invar rods with rod stands) reads elevation directly to 0.1 mm. with estimates to 0.01 mm. In structural monitoring work, closing errors of less than 0.20 mm. are frequently obtained.

Variations in wall tilt can be detected by several methods depending on the accuracy needed. Wall profiles can be plotted periodically using two plumb bobs hung one on either side of the wall a known distance apart. Comparing profiles could then detect any large changes in tilt. More accurate readings can be obtained by fabricating simple plumb bob brackets. The brackets are permanently attached to the wall. The top bracket holds the string in an exact location. The plumb bob is suspended from this string, which extends below the lower bracket. The lower bracket has a reference surface for measuring the distance between the string and the bracket with machinist's calipers. Plumb bob brackets are capable of a reading accuracy of about one millimeter. Electronic tilt meters give much improved accuracy, but cost about $1000 each.

While accuracy, cost, and access are the most important factors in choosing instruments, there is an additional important factor: the skill of the data gatherer. In many cases the person taking the readings is not technically oriented and good results depend on using instruments that are easy to read without error. For example, determining wall tilt with plumb bob brackets requires considerable skill to estimate the center of the string that always swings slightly and skill in reading the calipers. A tilt meter would give a digital readout that can simply be written in a data book. For crack width, the dial gage is usually easily read, but there is less chance of error with the digital readout of an electronic gage. Remote readouts also reduce the chance that the gage installation will be accidently disturbed. Thus, the ease of taking accurate readings is a consideration. Fortunately, however, most occasional reading errors are similar to seasonal variations: they become apparent as the data are plotted. It would be almost impossible to make reading errors consistently in a manner that would indicate progressive movement when none exists.

Properly used, the monitoring of structural movements in adobe buildings and ruins can help in assessing apparent structural faults. While it cannot warn of instantaneous collapse, it can warn of structural movements that gradually increase toward collapse. By determining which apparent defects are actually dangerous, and which are harmless, structural monitoring can prevent unnecessary modifications of historic fabric.

A Conservation Survey of Adobe Buildings *

Anthony Crosby

In this presentation I will emphasize a logical way of looking at an adobe building in order to determine the problems, or the effects, which result from the processes of deterioration. I will begin by discussing the process of examination, then will show specific examples of several systems to look for specific answers to questions concerning the processes of deterioration.

The conservation survey of an adobe building or structure is, simply, the process necessary to determine the causes of deterioration. Once the causes are determined they can be either eliminated or accepted if elimination is not possible or practical. The important word is "cause". While the actual visible deterioration will need to be repaired — or it may become the cause of further deterioration itself, the repair without addressing the cause will not be long-lasting. The actual process may also be interesting and in some cases necessary to be able to determine the cause, but a knowledge of the process without eliminating the cause will not result in a long term solution.

The most logical way to determine the causes of deterioration is to approach the survey by looking at the visible signs of deterioration and then going back through the process to the cause. Another equally important way is to look for potential causes. As an example one would look for the actual causes which resulted in basal erosion. The investigation may determine that the cause is an excessive amount of rain water splash, and that there is no surface runoff or

* Abridged version.

capillary moisture problem. In another location the investigator is aware of an extremely high water table. The high water table is a potential cause of a serious problem which should be investigated. Any survey should include looking for both the actual visible deterioration and its causes.

The subject of the survey:

A. Deterioration, the results of problems:

1. Basal erosion
2. Surface erosion
3. Cracks and bulges
4. Slump or creep
5. Upper wall displacement
6. Collapse

B. The problems, or causes of deterioration:

1. Running water
2. High wind
3. High water table
4. Excessive ambient relative humidity
5. Concentrated rain water
6. External loading

The methods for determining the results and the problems can be extremely complicated and technologically advanced, such as microwave and laser technology. Some others are less sophisticated but can also be expensive or otherwise unavailable. However, the results of much of this type of equipment can be replicated to some degree by techniques which are more ordinary. Probably the most important tools are those such as plumb bobs, levels, probes, and thermometers which are available to most anyone. But even more simple is the investigator who has a comprehensive understanding and respect for the material. It remains to be seen, but this most simple tool may be more rare than the most technologically advanced.

C. Causes (Processes)

What are the actual processes which result in such things as basal erosion, wall collapse, cracks and bulges? What actually causes these results?

1. *Causes of basal erosion*

a. Tunneling by rodents
b. Wet/dry cycles
c. Freeze/ thaw cycles
d. Splash
e. Hydration/dehydration of soluble salts

2. *Causes of surface erosion*

a. Wind driven abrasives
b. Running water
c. Insect activity
d. Freeze/thaw cycles
e. Wet/dry cycles

3. *Causes of cracks, bulges and leaning*

a. External loading
b. Internal wall moisture
c. Increased compressive loading

4. *Causes of the failure of protective surfaces*

a. Same as surface erosion, above
b. Internal moisture

5. *Causes of wall collapse*

a. External loading
b. Wall moisture
c. Decreased bearing area

6. *Causes of upper wall displacement*

a. Wet/dry cycles
b. Wall moisture

Several of these processes such as wet/dry cycles, freeze/thaw cycles, and internal wall moisture occur more often. Others seem to be problems in fewer cases.

D. Explanation of the Processes

1. *Wet/dry cycles*

a. Associated with soluble salts
b. Associated with types of clays
c. Number of cycles, length of cycles, important, but difficult to access

2. *Freeze/thaw cycles*

a. Dependent upon moisture
b. Dependent upon temperature

3. *Capillary effect*

a. Critical moisture content
b. Dependent upon a source
c. Mechanism

4. *Internal wall moisture*

a. Internal condensation
b. Capillary condensation
c. Upper wall leak
d. Effects mechanical properties

5. *Running water*

a. Surface wash
b. Increase moisture content

6. *Increased loading*

a. Reduced loading area

E. Actual Sources

1. High ground water table
2. Inadequate drainage
3. Leaking pipes
4. Rodents
5. Insects
6. Leaking roof, gutters, etc.
7. High ambient relative humidity
8. Earth movement, lateral force

Of these eight common sources of adobe deterioration, five are directly related to the presence of moisture. Four of those five could be simply grouped as the one common source, free water.

Summary

These are some of the more common causes which initiate a process that results in visible deterioration. We have not talked very much about corrective measures. Some are obvious. If the upper portion of a wall becomes saturated because of a leaking gutter, then repair the gutter. The solutions to problems of high water tables, improper drainage, or the lack of a waterproof foundation are not as obvious and are often not as simple, either. We will be discussing solutions during other sessions of this conference.

One more word in closing. It has been said before, but it is important to repeat. To be able to identify deterioration, to look for problems, and to search for solutions, the most important tool that anyone can have is the knowledge, or more appropriately, an understanding of the material; an understanding of its advantages and disadvantages. An understanding that will lead you to know which processes of deterioration can be stopped and which ones simply have to be accepted. It takes an understanding of adobe to know that certain visible deterioration should be accepted and hopefully managed, rather than eliminated.

Earthquakes and Adobe Structures

Julio Vargas Neumann

1. Introduction

The first buildings made by man were made of earth; still today, in many parts of the world, earth is the basic building material.

Edifices built with earth have a series of advantages and disadvantages, as do those built with any other material.

Some of the advantages are:

a. They are simple to build.
b. They are economical.
c. They have good thermal and accoustic isolation.
d. They can be built without energy consumption.

The major disadvantages are:

a. Durability is precarious (subject to erosion, effect of water, etc.).
b. Fragility in the face of natural disasters (earthquakes, floods).
c. Some interior space is lost, due to the thickness of the walls.
d. Socially, they are often not accepted.

In the industrialized nations, modern technology has developed new materials during the last decades. However, less efforts have been made to solve or control the deficiencies of primitive or natural materials used in the Third World.

A review of the advantages and disadvantages of earth as a building material leads us to conclude that the advantages are increasingly important in today's world, while the disadvantages can be overcome with the help of the new technical developments and of state-supported educational programmes.

2. Earthquakes

The earth's crust is divided into some 20 plates which displace themselves over the earth's surface and interact with each other. In the regions where these plates meet, most of the seismic energy of the world is dissipated. Nonetheless, in other parts of the globe, faults in the earth's crust produce earthquakes as well.

When an earthquake takes place, a dynamic movement is produced at the base of a building; this induces vibrations throughout the different parts of the edifice. Engineers can estimate the amplification levels of these vibrations in terms of displacement, velocity and acceleration, and thus design the buildings adequately. Structures must be prepared for this type of movement; this means one must first know the dynamic behaviour of the building in order to produce a correct design.

3. Seismic Behaviour of Adobe Buildings

In general, the simplest way to represent or idealize a structure with vibration at the base is by an oscillator in the shape of an inverted pendulum. (See Fig. 1). We are imagining the mass of the building concentrated and connected to the ground by a hoop which would represent its flexibility, having a certain degree of shock absorption. This equivalent model would undergo a movement at the base — this we would also represent, in its simplest form, by the registration of an earthquake, such as the one seen in Fig. 2-a. This registration produces movements in the mass which, if measured, would give the line found in Fig. 2-b. It is easy to see that this last movement depends on the magnitude of the mass, the flexibility of the hoop, its shock-absorbing capacity and naturally, on the registration, of the earthquake which originates the movement.

The result of the vibration may or may not produce damage in the model. This depends on the strength of the hoop as well as on a basic concept: its ductility —that is, its capacity to deform itself in the inelastic range —which is when it actually dissipates energy.

A good seismic-proof design involves a series of concepts simultaneously. Trying to sum them up, we

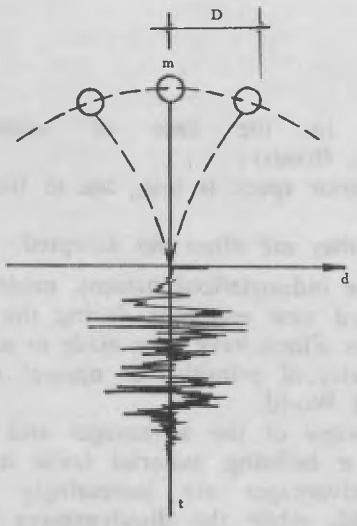

Fig. 1. Simplified dynamic model.

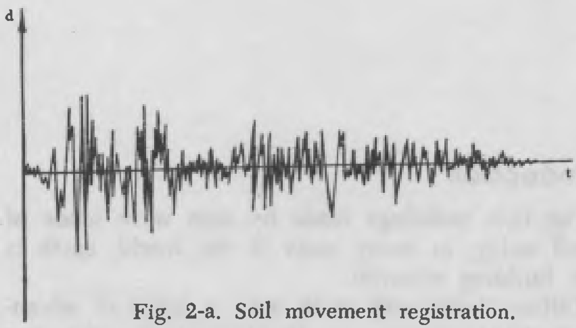

Fig. 2-a. Soil movement registration.

Fig. 2-b. Structural mass movement registration.

might say that the following are the characteristics required in a building:

— Lightness, so as to diminish the mass and, therefore, the forces between the different elements.

— Absence of critical points of effort-concentration. This is obtained through adequate architectural design which supposes:

· A symmetrical distribution of the different elements.
· Uniform density of walls and elements.
· Continuity in the shapes and volumes.
· Uniformity in materials, rigidity and ductility.
· Adequate connections, which will guarantee the possibility of ductile movements.
· Sufficient strength (resistance), so as to withstand the thrusts.
· Limited deformability.

We will point out two types of earthen buildings and analyze their performance:

— Buildings made of masonry (adobe and *tapial*).

— Continuous systems (wood or cane with mud — "wattle and daub").

3.1 *Masonry Buildings*

a. *Massive masonry*

This type was widely used in antiquity to build monumental-type structures, such as temples and fortresses. On the coast of Peru, the Fortress of Paramonga, the Temple of the Sun at Pachacamac, Puruchuco and others are examples of this type.

The large dimensions of their principal elements make them invulnerable to earthquakes. In general these buildings have great rigidity and therefore the vibrations they undergo are practically the same as those in the foundation-ground, i.e., the amplifications of the movement, a characteristic structural response, are absent.

In these structures the most acute problem is their durability, and not precisely the seismic problem. Pachacamac, for instance, built with adobes and mortar of the same quality as the block, is an example of seismic resistance due to its structural shape. The quality of the adobe and the mortar is rather low; the ground has a high content of sand and little plasticity, due to lack of sufficient clay. Shear resistance is very poor in this type of masonry. A proof of this is that the slender elements of the masonry have practically disappeared, and even those recently restored (Temple of the Moon) are severely cracked. Use of this material is due to the location of this monument, near the ocean, in a sandy, desert area.

b. *Slender masonry or wall-type elements*

Ancient buildings (pre-Inca or Inca) built with these elements have generally disappeared, as a result of earthquakes. Those left standing have withstood the centuries either because they were buried or because their slenderness was limited, i.e. the relation between height and thickness was not too high. Colonial adobe buildings belong to this type of masonry.

We can distinguish two sub-types within this group:

— Linear walls or enclosures.

— Buildings with walls at right angles from each other, orthogonal walls (houses and other buildings).

The seismic behaviour of linear walls is interesting. The first concern is overturning. However, under dynamic action the walls vibrate transversally but not in a uniform manner, i.e., while parts of the wall tend to collapse toward the left, others tend to collapse toward the right, forming a sinusoidal wave when seen from above. This undulation produces vertical cracks which divide the wall in parts, and if the movement persists, some of them, and eventually all of them, collapse.

The dynamic stability of the walls to overturning is a matter of special interest. A study has been undertaken in order to define the characteristisc of said process. Because earthquakes have impulses that change direction in fractions of a second, and the wall has a strong rotational inertia, it is not easy to produce the collapse of a part of the wall.

The results of this study will allow us to find out how severe an earthquake the Inca or pre-Inca enclosures, still standing today, are able to endure. Thus we would be able to find out the uppermost limit for the earthquakes which have taken place from pre-Columbian days to the present. This information will be very valuable for the studies on Seismic Risk which are carried out for huge works of infrastructure, such as Nuclear Plants, Hydroelectric Power Plants, etc. which must be built taking into account earthquakes with long periods of recurrence (100 years, 200 years, etc.).

The seismic behaviour of adobe buildings with walls that meet each other is even more complex, and it is not possible to idealize this behaviour in practical terms.

Because of the fragility of the material, the disorderly vibration of the walls —each one having different dimensions and support-conditions— produces flection loads and shearing loads which generally concentrate where the walls meet.

Once vertical cracks appear where both walls meet, each one of them vibrates separately, as in the case of linear walls; what differs is that normally, they collapse toward the outside due to interaction between them.

Secondarily, some shearing cracks of a diagonal type also appear. Their critical paths preferably follow lines near the corners of windows and other openings.

It is essential to know these types of faults when re-constructing, as well as when first building an edifice. It is crucial to adequately treat the meeting-place of walls, as well as corners, and all openings.

Another critical area in adobe buildings is the place where the roof meets the walls. The weight of the roof concentrates horizontal thrusts in the upper part of the wall when an earthquake occurs. This produces partial faults or overturning of the walls, which in turn brings about the collapse of the roof.

Thus, it is possible to conclude that a basic factor for the stability of adobe buildings is the relation between height and thickness (width).

The size of openings and their place in each wall (they should be small and centred), as well as the shape of the floor-plans (rooms should tend to be square), are other important factors.

The only way to get the different walls of a building to work together and not separately, and to notably increase their stability, is to use reinforcements made of ductile materials (wood, cane, wire, etc.). This is as true for new buildings, where it is easier to place them, as it is for existing ones, where these reinforcements can be placed exteriorly.

3.2 *Continuous Systems*

These are buildings where wood or cane are used as structural elements and which use earth to create enclosing elements (walls and roofs).

The seismic behaviour of this type of building can be very adequate if an integral and flexible behaviour is achieved. This depends on the quality of the connections, which constitute the critical points.

It is important to reduce as much as possible the weight of the earthen components and make sure of the durability of the wood or cane.

4. Research Studies Undertaken at the Catholic University

The Department of Engineering at the Catholic Pontifical University of Peru has carried out several research studies dealing with adobe and earth constructions. The titles of these published studies are listed in the Bibliography (see last page of this paper). We will briefly describe their content here:

Reference 1

Fot the first time, the static test method for structures was used with natural-size structures placed on a leaning platform 4 m x 4 m. A series of structures with 4 meeting walls 2.6 m x 2.6 m x 2.4 m high (with no roof) and with a variable number of openings and different reinforcement elements, were tested on this platform whose inclination could simulate horizontal static accelerations, which were 23 to 42 per cent of the acceleration of gravity.

Reference 2

Basic information was obtained on various elastic parameters which are interesting for buildings made of earth. This was done through different tests: cubic and prismatic compression test, flexo-traction (a Brazilian test) diagonal compression test, shear, flection in walls, overturning, etc.

Reference 3

Ductility was sought by using cane reinforcements, and the data for shear resistance and others was revised, continuing the experiments begun in Reference 2. Information obtained will be used to make proposals for the National Building Code. Good levels of ductility were achieved. See Fig. 3.

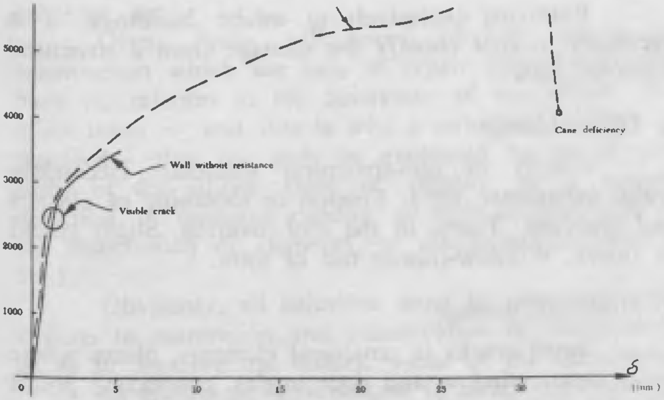

Fig. 3. Ductility in wall reinforcements (Cane mesh). Monotonic load.

Reference 4

This programme was carried out in coordination with the Engineering Institute of Universidad Autónoma de México. Its aim was to corroborate the sharp differences existing between the Peruvian and the Mexican tests for shear-resistance in masonry. These differences are negligible where individual adobe bricks are concerned.

Reference 5

Through a study of variations in the constitution of the mortar and the adhesion techniques used in masonry, the aim was to explain the differences registered, which are due principally to the adhesion of the mortar to the block.

As a result of this study, a classification of different mortars was proposed, in view of establishing standards and norms.

Reference 6

The direct shearing test, which is part of the current Adobe Norm (*Norma de Adobe*) was perfected. The cyclical behaviour of adobe masonries was studied; this allowed evaluation of the dissipation of energy inherent to internal friction. This information is useful when applying the Seismic-Proof Norm to adobe buildings.

Reference 7

With support from AID (Agency for International Development), a research project was undertaken to study appropriate soils for building with earth. The reasons of their appropriateness (or lack of it) were considered.

A good soil must have adequate plasticity, and, at the same time, adequate granulometry.

Adequate drying conditions for blocks and mortars, and the control of cracks by adding sand (and straw) are crucial, in order to obtain resistant masonries.

The diagonal-compression test of a small wall 60 x 60 cm. (made of adobes and joining elements) is the best way to ascertain the resistance of masonry.

A lab test, which allows optimization of the composition of the soil (using sand mixtures) is shown in Fig. 4. Here, resistance to compression Sigma m is related to the IP-Alfa Parameter, the product of the Plasticity Index, IP, and the quotient between the weight of the soil which passes through the 40 wire-meshes and the total weight.

It can be observed that there is an optimum range for IP-Alfa, which does not occur for other parameters.

When sand is not available to modify the granulometry of the soil, it should be used to control cracking. It can be used up to 4 or 5% in weight. (See Fig. 5).

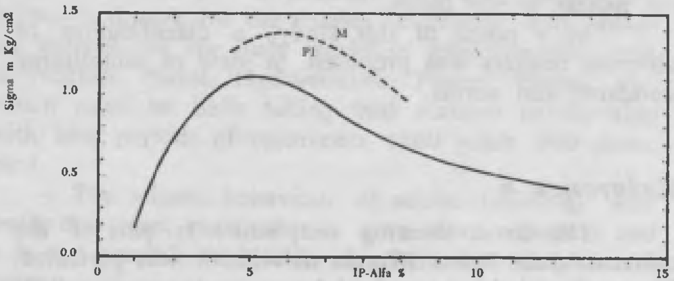

Fig. 4. Wall resistance vs IP-Alfa.

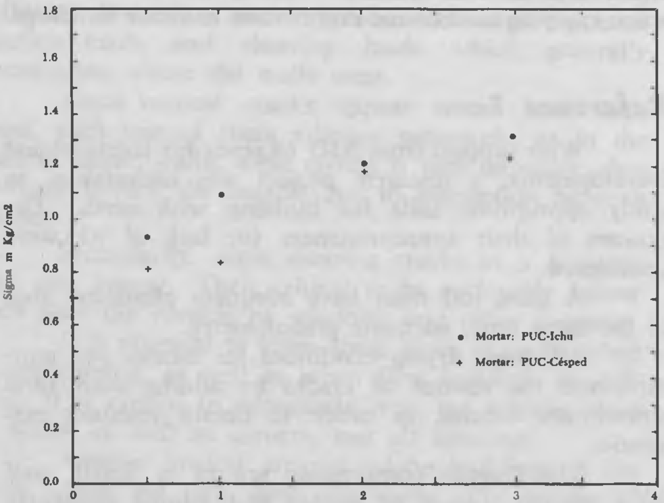

Fig. 5. Masonry resistance vs straw content in mortar. Mortar: PUC-Straw: 100-C.

5. Evaluation and repair of damages

The repair of faults produced by earthquakes, unlike other faults, requires a careful analysis of their cause, and not only the type of repair which will give them back static stability. One must give the whole edifice the dynamic stability it did not possess (since it failed).

In other words, the philosophy underlying repairs consists in assessing the cause and magnitude of the faults, in order to repair them and, additionally, to modify the structures in order to make them seismic-proof in view of future earthquakes. One must not only repair the local fault, but design a global anti-seismic behaviour for the building, which will prevent future faults.

We can summarize this process of assessment and repair as follows:

- Classification of the damage.
- Structural analysis of the damaged building.
- Interpretation of the cause of the faults.
- Designing a reinforced or modified building.
- Follow-up and evaluation of repairs.

Referring exclusively to adobe buildings, it is necessary to first *classify* the damage from a structural point of view:

a. *Light damage*

Cracks in non-structural elements (secondary walls, ornaments, etc.). Erosion or loosening of plasters and stuccoes. Faults in the roof-covering. Slight cracks in floors. Window-frames out of joint.

b. *Moderate damage*

Small cracks in structural elements, places where walls meet, window and door angles, connecting points between lintels and walls, connecting points between roof (beams) and walls. Superficial erosion of walls. Loosening of secondary elements in the roof system. Walls slightly out-of-plumb. Large cracks in floors. Displacement of door and window-frames.

c. *Severe damage*

Cracks in the structural elements; partial detachment of walls and roofs. Walls severely out-of-plumb. Faults in the main roof-beams. Differential settlement of foundations; severe erosion in walls.

Structural analysis must take into account several aspects:

- The quality of the masonry.
- Reinforcements (existence and types).
- Location of resistant elements.
- Idealization and evaluation of thrusts.

This information makes it possible to interpret the cause of faults, after examining their location and type.

It is probable that there will be a coincidence as to which elements undergo stress in theory, and what in fact happened. This will require an analysis of the existing resistant elements, in order to modify the concentration of stresses.

If there is no coincidence, other explanations for the faults have to be sought; the quality of materials should be analyzed, as well as the details of connections between elements, the reinforcements placed in the different elements, as well as the local concentration of stresses in short columns, poorly-placed openings, etc.

Often, faults will reveal obvious defects in construction which are easy to repair individually and have no relation to the behaviour of the whole. But other times — and this is why a structural analysis is required — they can only be explained by an integral study of the edifice (lack of rigidity in a certain direction, or torsional rigidity, or high eccentricities in the distribution of elements, or discontinuous rigidity, etc.).

Obviously, all solutions must be consulted with experts in restoration and conservation of monuments, so as to preserve the historic value of the monument.

In ending, it is important to stress the need for a follow-up, in order to assess the repairs and to decide on their adequateness in future cases.

6. Prevention vs repair

Important efforts are made today to create an awareness of the need to establish preventive measures in view of natural disasters, such as earthquakes, floods, hurricanes, etc.

Monuments should be looked after in a very special way, for they represent our historic and cultural heritage.

Preventive measures in view of earthquakes, which include evaluation and eventual repair of buildings in order to make them seismic-proof are required. Unfortunately, this task is often ignored. Thus it seems logical, after what we have just stated, that general restoration interventions should include experts in seismic-resistance within the interdisciplinary team of specialists. In this manner, the potential permanence of the monument is significantly increased and —equally important— the cost of repair interventions is lowered, for it would be much more expensive to repair this building after an earthquake has occurred.

To think that a building is strong because it has endured a number of earthquakes is as erroneous as it would be to assume that a patient who has undergone several heart attacks is presently in excellent health.

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Investigation of the Long-Term Effectiveness of an Ethyl Silicate-Based Consolidant on Mudbrick

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Introduction

The five thousand year-old mural paintings at Teleilat Ghassul, Jordan, are on a support consisting of sun-dried mudbricks, about 13 cm. in thickness. One of these, found in 1977 to have been broken into 33 major pieces and many fragments, was restored, consolidated, and reassembled in a mount suitable for installation in the Amman Museum. The details of the technique employed have been fully reported by Schwartzbaum, *et al.*, at the Third International Symposium on Mudbrick Preservation.[1]

The chemicals employed were as follows: the paint layer was strengthened by the application of a 7% solution of Paraloid B72 in acetone, and detached areas were treated by injecting 15% Paraloid B72 between the strata. Small fragments along the fractured borders of the pieces were glued in place with 50% Vinavil (a polyvinyl acetate emulsion). It was next necessary that the mudbrick support of the paint layer be consolidated and strengthened so that it would resist damage and attrition through handling in the process of reassembling and mounting the pieces. This was done by placing the mudbrick surface opposite the paint layer in a shallow pool of a 50% solution of Wacker Stone Strengthener H in toluene. The mudbrick absorbed the impregnant through capillary action, and when it was judged to be fully saturated, the piece was covered with aluminum foil to retard evaporation, and left to cure for three days.

The requisite degree of strengthening of the previously very friable mudbrick did occur, and this contributed significantly to the trouble-free manipulation and mounting of the pieces to reconstitute the total mural.

Although the use of this ethyl silicate-based consolidant served its primary purpose, it remains to be determined what the long-range effect will be.

The treatment of this mudbrick was completed in 1979, and several specimens of both the untreated and treated material were retained for future study. Consequently, at the present time we have available samples of the treated mudbrick that have aged under ordinary indoor ambient conditions for 4 years, as well as untreated specimens of mudbrick from the original source which can be given the same type of impregnation in order to produce freshly consolidated samples as comparison standards. The present paper reports the results of such a study, i.e., determination of the effect of 4 years of normal aging on the composition of the silicon ester-based impregnant.

A. Properties of the Teleilat Ghassul Mudbrick

The mudbrick from Teleilat Ghassul consists principally of quartz pebbles ranging from 0.1 to 2 mm in dimensions, calcitic skeletal debris 0.01 to 1 mm in dimensions, and clay particles in the size range 0.002 mm and below. It is the clay component that serves to bind the mud together when a brick is fashioned. When wet, the clay absorbs water intramolecularly and swells; as the mud dries, the clay particles are drawn together into close mutual contact by surface tension forces, and when dry, they are hold to each other principally by the Coulomb forces arising from hydrogen-bonding between the —OH groups on adjacent particles.

It is these —OH groups on the surfaces of the tiny clay platelets that are responsible for the interaction with the silicon ester-based consolidant, and that causes the consolidant to cross-link adjacent clay particles into a three-dimensional network. The molecular nature of this cross-linking is illustrated in Figure 1.

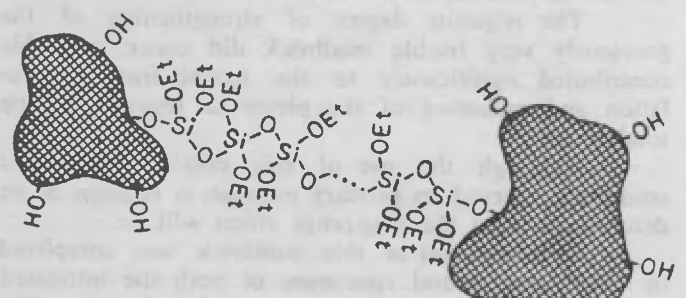

Figure 1. Illustrating the molecular mechanism by which two particles of clay are cross-linked through the hydrolysis and condensation of ethyl silicate.

Thus, it is the clay content of this mudbrick that is of crucial importance for the initial success of the consolidation treatment.

Measurements were made of the volume of the silicon ester formulation that is imbibed by the mudbrick through capillary rise from a shallow pool of the liquid in which a sample of the solid is placed. It was observed that a 23.29 gram specimen of the untreated Teleilat Ghassul mudbrick imbibed, by capillarity, 3.54 g of the Wacker H solution (density = 0.9 g/ml) in 45 minutes, and 4.01 g in 2 hours. The latter value corresponds to a porosity of 19%, i.e., 19 milliliters total volume of accessible pores per 100 grams of the solid.

B. Analysis of Siloxane Composition

Our analysis of a batch of Wacker H solution which had been stored in an unopened bottle for about two years, shows the composition to be: 15% solvent (principally toluene), 35% methyl triethoxysilane (monomer + dimer), and 50% tetraethoxysilane (monomer + dimer).

This mixture of silicon esters reacts with moisture or reactive —OH groups by undergoing hydrolysis and condensation. For an explanation of the nature of these reactions, and the factors affecting their rates, see Reference 2.

As these reactions proceed, ethyl alcohol (= ethanol, C_2H_5OH or EtOH) is released; one molecule of ethyl alcohol being liberated for each ethoxy group that is hydrolyzed. These hydrolysis reactions occur stepwise, and the —OEt groups react in a statistically random fashion.

The general features of the sequence of reactions are summarized in the following equations:

Monomeric Species:

$$(EtO)_4Si + \sim OH \rightarrow (EtO)_3SiO\sim + EtOH$$
$$(EtO)_4Si + H_2O \rightarrow (EtO)_3SiOH + EtOH$$
$$(EtO)_3SiOH + H_2O \rightarrow (EtO)_2Si(OH)_2 + EtOH$$
$$RSi(OEt)_3 + H_2O \rightarrow RSi(OEt)_2OH + EtOH$$
$$RSi(OEt)_2OH + H_2O \rightarrow RSi(OEt)_2(OH)_2 + EtOH$$

⋮ ⋮

etc. etc.

Condensed Species:

$$(EtO)_3Si\text{-}O\text{-}Si(OEt)_3 + H_2O \rightarrow (EtO)_3Si\text{-}O\text{-}Si(OEt)_2OH + EtOH$$
$$(EtO)_3Si\text{-}O\text{-}Si(OEt)_2OH + H_2O \rightarrow HO(EtO)_2Si\text{-}O\text{-}Si(OEt)_2OH + EtOH$$

.
.
etc. etc.

Measurement of the total amount of ethyl alcohol released (or, alternatively, of the residual quantity of ethoxy groups) during the curing or aging of the impregnant is thus an indication of the degree to which hydrolysis has occurred. That is, if an average of only one of the ethoxy groups of each silicon ester molecule has been hydrolyzed, there would be observed one mole of ethyl alcohol per gram atom of silicon. If the hardening effect involves the formation of long polymer chains of diethoxysiloxane, such as that depicted in Figure 1, the molar quantity of ethyl alcohol liberated would be close to 2.0 X the molar quantity of silicon ester originally introduced into the stone.

If substantially all the ethoxy groups have been hydrolyzed, the silicon-containing species remaining in the stone would consist of silicic acid, $Si(OH)_4$, and its polymers (the end product of the dehydration of these polymers is silica or quartz, SiO_2); $CH_3Si(OH)_3$ and its polymers; and various condensation polymers, such as that shown in Figure 2. In this case, the molar quantity of ethyl alcohol released would be 4X the tetraethoxysilane content, plus 3X the methyl triethoxysilane.

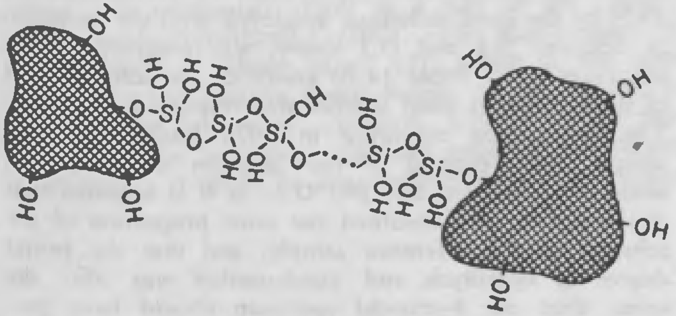

Figure 2. Molecular structure of a possible product of the Hydrolysis of all the ethoxy groups from a silicon ester consolidant. Note that two –OH groups on the same atom tend to undergo dehydration reactions.

Taking into account the composition of the Wacker H formulation used in the present work, we calculate that complete hydrolysis of 1 gram of this material would yield 0.71 grams of ethyl alcohol, and no ethoxy content would, of course, be left in the solid.

Hydrolysis to the stage of the linear polymers shown in Figure 1, i.e., diethoxysiloxane from the tetraethoxysilane, plus methyl ethoxysiloxane from the methyl triethoxysilane, would yield 0.40 grams of ethyl alcohol for every gram of the Wacker H formulation, and the ethoxy content left in the solid would correspond to 0.31 grams of alcohol.

Hence, analysis for released alcohol, or for residual ethoxy content, can show the average composition of the silicon —containing metal-organic products present in the stone— either immediately after the initial cure, or at any subsequent time. If such analyses show no change in composition with time, the impregnated stone may be considered to be stable. If the composition changes with the age of the impregnation, this may be a cause for concern (though not necessarily, as will be discussed later).

C. Method of Determination of Residual Ethoxy Content

A convenient and reliable method of determining the ethoxy content of a specimen consists in fully hydrolyzing those groups, and recovering the resulting liberated ethyl alcohol. Our procedure is as follows.

The quantity taken of the substance to be analyzed should be such as to contain not less than 1 gram of the silicon ester or its equivalent in hydrolysis and condensation products. For the proportions of reagent, dimensions of apparatus, etc., we employ, the sample, if a liquid should not contain more than 10 grams of silicon ester; if a solid, such as impregnated stone, the sample weight should not exceed 50 grams.

The weighed sample is placed in a 500-ml single-neck flask; 50 ml of 9 M H_2SO_4 are added; and the flask is tightly stoppered. If impregnated stone is being analyzed, it is first reduced to a fine powder. The mixture is allowed to stand, with occasional swirling to mix the contents and insure contact of the acid with all solid particles, for at least 6 hours. If much alkyl alkoxysilane is present, the acid will not wet the sample easily, and the mixture should stand for one or more days to permit the acid to break through the hydrophobic barrier.

When it appears that the sample has been thoroughly wetted by the acid, and has been kept thus for at least 6 hours with occasional mixing, the flask is connected by a short adapter to an efficient condenser, and the ethyl alcohol is distilled over into a suitable receiver, e.g., a 20-ml graduated flask. Glassware with close-fitting ground glass joints is used for all set-ups.

The temperature of the distilling flask vapors is monitored, and the condensate is collected until the still head vapor temperature is 110°C. Under these conditions, the condensate contains substantially all of the ethyl alcohol, plus some water. Its weight is measured, and its alcohol content determined by measuring the refractive index ($nH_2O = 1.334$; $nEtOH = 1.361$; mixtures interpolate linearly in terms of weight percent). In this fashion, a quantity of ethyl alcohol as small as 0.1 gram can be estimated with a precision of ± 0.02 gram.

D. Experimental Results

1. The untreated Teleilat Ghassul mudbrick was allowed to absorb the undiluted Wacker H solution by capillarity. When substantially saturated (taken to be after about 2 hours of imbibition) its weight had increased by 17.2%. It was wrapped in aluminum foil and allowed to cure for 3 days. The Al foil was then removed and the specimen was allowed to airdry for 1 day. At the end of this period, the weight of the specimen was found to be 10.7% more than before the impregnation; i.e., the imbibed material had decreased in weight by 37.8%. This weight loss is due to the evaporation of the solvent plus the ethyl alcohol that had been produced by the reaction of the silicon esters with $-OH$ groups in the solid during the curing period.

Correcting for the proportion of solvent, this weight loss corresponds to the release of 0.27 grams of ethyl alcohol per original gram of mixed silicon esters. Calculations based on the proportions of the several silicon esters in the original consolidant solution, and the stoichiometry of the reactions, lead to the result that after the initial 3 + 1 day curing period, the average degree of hydrolysis of the silicon esters was 1.14 ± 0.05 molecules of ethyl alcohol released per Si atom.

Since this is an average, it means that there is a distribution of hydrolyzed species, including large proportions of those with only one or two ethoxy groups reacted per original molecule. This shows that the initial consolidation effect is due to the formation of mostly short siloxane chains, i.e., oligomers, rather than long-chain polymers.

In addition, it shows that after the initial curing the consolidant still retains intact a substantial proportion of its original ethoxy groups. Thus, the initial consolidation is produced by that portion of the silicon ester molecules that have hydrolyzed and condensed into ethoxysiloxane chains of the type shown in Figure 1 (and not into those of the type shown in Figure 2).

2. The analysis based on weight loss was checked by analyzing the 3 + 1 day cured specimen for its residual ethoxy content, employing the H_2SO_4 hydrolysis and distillation procedure described in Section C above. Using the data of Section D.1., the theoretical amount of ethyl alcohol that should be recoverable from the partially hydrolyzed silicon ester mixture in the mudbrick specimen is 0.77 grams per 1 gram of the cured impregnant. The actual amount recovered was 0.66 ± 0.08. This appears to be reasonably satisfactory agreement.

3. A sample of the Teleilat Ghassul mudbrick that had been impregnated with the Wacker H formulation in 1979 by the same technique employed with the specimen of Sections D.1 and D.2 above, was analyzed for its ethoxy content. From 14.20 grams of the solid, a total of 0.76 grams of ethyl alcohol was recovered.

The formulation employed in 1979 had one-half the silicon ester content of the solution used for the analyses of Sections D.1 and D.2. If it is assumed that this specimen had absorbed the same proportion of the solution as the reference sample, and that the initial degree of hydrolysis and condensation was also the same, then the 4-year-old specimen should have produced, upon complete hydrolysis by H_2SO_4, an ethyl alcohol yield of 0.5 (14.20/23.29) (0.77), or the equivalent of 0.23 grams per gram of silicon ester oligomers.

The actual amount of ethyl alcohol recovered was 0.11 grams from the equivalent of 1 gram of silicone ester oligomers assumed to have been originally present i.e., less than half the theoretical amount if no hydrolysis had occurred after the initial cure.

E. Conclusions

The experimental data show that the consolidating and strengthening effect produced initially by silicon esters in Teleilat Ghassul mudbrick involve the formation of oligomers that have a large proportion of potentially reactive ethoxy groups still present.

A 4-year-old specimen that had been stored in a normal indoor environment has a smaller ethoxy content than is expected based on the analysis of freshly treated brick. This indicates that hydrolysis continues to occur during long-term aging; it also shows that the reaction is quite slow.

An estimate of the time required for the hydrolysis to be complete, e.g., to reach the stage shown in Figure 2, cannot be given at this time with much confidence, because of the assumptions that would have to be made (e.g., that the rate of reaction is constant, independent of the degree of hydrolysis and condensation; also, that the initial reaction is not sensitive to the solvent concentration; etc.). It does appear, however, that the degree of hydrolysis probably does not change much during the first several years of aging.

Furthermore, it is not yet clear whether the slow, progressive increase in the degree of hydrolysis during aging will necessarily result in a loss of the consolidating and strengthening effect. The glassy stage of condensation of silicon esters (*2*), which is the form present in the initially cured liquid, as carried out *in vitro* in the laboratory, gradually crumbles to a fine powder as the hydrolysis reactions continue on toward completion. It might be assumed that something similar would occur with impregnated stone, but we do not have any objective evidence on this score. That is, it is not yet known whether this phenomenon occurs also when the oligomers have been formed in the intergranular spaces of a stone or mudbrick.

There is reason to believe, however, that if the consolidating effect weakens and dissipates upon prolonged aging, due to the ongoing hydrolytic reactions, the residue left in the stone will not interfere with a re-introduction of silicon esters to regain the consolidant effect.

One caveat should be stated: it is not yet known whether or not stresses are generated in a stone as the initially formed oligomers undergo further reactions. It is known that the increase in degree of hydrolysis is accompanied by a decrease in volume of the xiloxane moiety.

The present investigation is, therefore, only a preliminary exploration of questions that are of prime concern for the long-term safety and stability of silicon-ester-impregnated solids. An appropriate analytical procedure has been developed, and some insights into the hydrolysis and condensation behaviour of a particular silicon ester mixture have been gained. Further studies are needed with other types of stone and mudbrick, and over additional aging periods.

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Conservation of Structures and Adobe Decorative Elements in Chan Chan

Ricardo Morales Gamarra

This paper analyzes the conservation problems related to the structures and high-relief ornaments in the archaeological complex of Chan Chan (XIIth-XVth centuries A.D.) located near Trujillo, in La Libertad, Peru.

For a better understanding of the topic, we deal with the causes of alteration, the building techniques and how reliefs were made, the criteria used in restoration and the treatment applied.

Causes of Alteration

We will examine here the causes of alteration specific to Chan Chan, which occupies 18 sq. kilometres. We divide them into two groups: intrinsic causes (geo-topographic situation, nature of the soil and inherent defects in construction) and extrinsic ones (climate, physical and chemical phenomena, etc.). We do not include socio-economic factors, for we concentrate on technical aspects. One should bear in mind that these causes are all interrelated.

The alluvial terrace presents the following characteristics: slight orographic inclination (10 to 15 m. above sea-level); high salinity (over 7.5 pH) soil texture varying from sandy to very sandy; good electrical conductivity, high phreatic level (2.60 metres/average) and proximity to the sea (1,000 metres, approximately).

As additional information, it is interesting to note that the lands south of Chan Chan were known in the last century as "Los Gramadales", because *gramalote (Panicum purpurescens)* grew abundantly in them. This plant needs humid soil and does not tolerate prolonged dryness. In sum, the soil is humid, saline and has little clay. If we add that it is generally agreed that the adobes were made with materials found in the area, we can understand why chlorides and other salts are found, in varying percentages, in most bricks. These salts are activated by humidity and by the salts in suspension brought in from the ocean by the wind. It is thus important to recognize the negative action of the climate; this constitutes the most dynamic factor in all the degradation cycle.

The climate in Chan Chan does not correspond to its geographic location: the cold waters of the Humboldt current bring a modification to the climate and geography of the north coast of Peru. Thus, summer is warm, with little or no rain and dry, while winter is temperate, misty and with a special type of rainfall.

When the warm waters of the "El Niño" current appear, the climate is substantially altered. Temperature rises and remains high during several months, and rains are torrential. This causes serious floods, as was the case in 1983 and in previous years (1701; 1720; 1728; 1858; 1891; 1925 and 1972).

Normally, temperatures are highest between January and March (27°C mean maximum). Relative humidity is the lowest (81% mean maximum) and wind is predominantly S. and S.E. (11 mts./second, mean maximum). Rains are scarce and fall usually around Holy Week. We do not have official data for rainfall; however, we refer to Paul Coremans, who gives 38 mm. per year for Lima and somewhat higher for the north coast. Zoltan Zsabo indicates an average of between 0.025 and 50 mm. per year for the north coast of Peru. In 1983, the hours of rain totalled 36; the rainfall of 12 April lasted 55 minutes and averaged 7 mm.

Between July and September, temperatures are the lowest (14°C is the mean minimum). Relative humidity is the highest (86% monthly mean); wind is predominantly S. and S.E.E. (12 mts./second, maximum mean). Rainfall is almost absent — there is a type of fine mist called "garúa".

This climatological information is basic to understand the mechanics of what affects the adobes and to give the necessary solutions. The joint action of these phenomena ("weathering") causes serious damage in the structures. Nocturnal moisture softens the surface of the bricks and activates the salts; insolation causes contraction, due to sudden drying of the surface and produces saline efflorescence. Wind brings salts in suspension (sodium chlorides) as well as sand from the ocean; thus it becomes a highly erosive element which also destroys the loose crusts in the upper part of the walls. Finally, rain washes out surfaces, due to the fragility of clay; it increases the weight of projecting decorations, causing their collapse and forms pools that seep into the foundations, causing the collapse of walls and the loosening of the reliefs.

For these climatic reasons, we reached the conclusion that consolidation work should not be carried out between July and November, especially because of the humidity and the activity of salts. We also concluded that roofs and covering are not an integral answer to the problem of rain, for the concentration of water in specific areas requires appropriate drainage. To come up with an adequate drainage system we must consider the underlying structures which we wish to conserve. That is, the solution must include collateral actions. On the other hand, protective cappings also cause rapid moistening and salinity in the top of the walls due to lack of sunshine.

The permanent erosion caused by wind is helped by the flat profile of the alluvial terrace. This is why planting a protective barrier of trees (small, medium and tall) has been proposed.

This barrier would also indicate the start of the Intangible Area and would help modify the climate.

We will now discuss some of the dangers caused by salinity in Chan Chan. (These are the conclusions of a test carried out by Miss Noemí Rosario Chirinos, a chemist working for the INC).

Samples were taken from Ciudadela Tschudi. Eleven came from Temple Nº 8, oriented towards the ocean. The average for chlorides here is 0.84% and for sulfates 0.79%. The second samples were taken from the Temple known as "Pelícanos Estilizados", located with its back to the ocean. The following results were obtained:

Salts	Samples Adobe	Plastering	Head of the Wall
Chlorides	0.21%	0.22%	0.54%
Sulfates	0.05%	0.09%	0.04%

This gives us two well-defined situations: 1) The location of the structures in regard to the sea and wind determines the concentration of salts, which varies according to the height and movement of the underground water (phreatic level); 2) The concentration of sulfates is equal or higher than 0.1%, which Muni Kendam gives as a minimum before considering them damaging in adobe monuments.

Building Methods and High-Reliefs

Chimu architecture is characterized by the exclusive use of adobe and cotton as building materials. Stone was also used for the large foundations and gravel mixed with clayey mud for the upper foundations.

This mix (gravel and mud) was used for the large-type *adobones*, which we find in the tall outside walls (Ciudadela Rivero) or in the funerary chambers, where they function as lintels in the tombs. They are trapezoidal in shape, which helps to place them in the structure.

Adobes are predominantly rectangular in shape, although some trapezoidal ones exist. Their size depends on their location in the structure; that is, the larger ones are placed in the lower parts of the walls and the smaller ones on top. These adobes, in Kolata's opinion, maintain a certain proportion, between height and width in any of the sizes. This researcher adds valuable information: when adobes were made, different forms or molds were used, including multiple-forms. Garbage was used in making them (as well as for filling in the structures). Evidently this suggests a certain deficiency which, compounded with the use of saline local earth makes these adobes more fragile than is usual.

Adobes are placed on the wall in a way that specialists have recognized as seismo-resistant; that is one row is placed head down the next facewise. It is interesting to note that the mud mortar does not join the sides of the adobes; there are empty spaces (of varying width) between the bricks. This allows a certain elasticity during earthquakes. However, we must recognize that this type of structures also allows rainwater to filtrate, causing crumbling or dripping of the mud.

The perimetric walls have a trapezoidal shape — some are as high as 12 metres. The inside walls are smaller and have geometric designs, such as lozenges or chess-board patterns. In this last case, reeds or other vegetable materials are used for horizontal support. Their decay, due to insects and to the excess weight of the mud having absorbed water, causes problems and loosens the adobes.

The plasterings and decorations are highly plastic — they contain an average of 18% clay (while in the adobes the percentage of clay is 12%).

These reliefs and decorations are made after plastering, taking advantage of the plasticity and malleability of the clay. Once the mortar is applied on the plastering, the relief is shaped by excision; to complete the ornamentation, incisions are then practiced on them. Finally, the surface is polished and painted in different colours.

Technical Criteria Used

Our intervention followed certain criteria; we will list the most important ones:

a. Stop the factors of decay and consolidate the structures.

b. Avoid restoration which seeks formal repair of the monument or its scenographic reconstruction.

c. Additions are justified only for reasons of structural stability, distribution of rainwater at the top of the walls, reinforcement or protection.

d. The above requirements have to be satisfied prior to other considerations which take into account the tourist value or artistic aspect of the monument, for these last considerations are both subjective and controversial.

e. The relativeness of the concept of "reversibility" must be considered, due to the nature and treatment of adobe. In the case of adobe, many products are irreversibly applied, because of the mechanics of the applications itself.

Restoration Treatment

We believe that, in principle, there is a technical order to be followed when treating a structure. This order may change, according to priorities which depend on its condition. Isolated intervention, in any of these stages, does not guarantee integral results. The order —in our judgement— should be as follows:

a. Structural reinforcement.
b. Protection of the top part of the walls.
c. Consolidation of plasterings and reliefs, as well as fixation of the colour.
d. Total drainage.

Structural reinforcement has been directed, principally, to replacing missing adobes in the walls where there are holes, cracks or loss by crumbling. It also has meant changing adobes attacked by salinization and putting in new ones, or re-using original adobes.

In the case of the perimetric Tschudi wall, rows of new adobes (reinforced with lime) have been placed in the upper sections, to protect original adobes from weathering.

In other cases, parts of decorated walls which have slipped and are in danger of collapse have been placed elsewhere. Automobile jacks and mud mortar were used to secure them.

The use of wooden keys (using carob or similar wood) has had good results for consolidation and reinforcement of crumbling areas.

One of the most critical questions in the conservation of adobe archaeological monuments is the protection of the top part of the walls. Interventions seek to avoid loss of height of the wall, as well as drippings and grooves which affect both the reliefs and plasterings and the structural stability of the walls, due to rainwater filtration through the cracks.

Experiments in restoration, following this treatment, were begun only in 1977 in the area known as "Ciudadela Tschudi". Several UNESCO experts, among them Giacomo Chiari, Rodolfo Vallín and José María Cabrera provided suggestions and valuable advice for this experimental project.

The main idea was to apply a stabilized capping in these areas. The type of mortar suggested by Mr. Chiari was soil-cement (earth-sand-cement). But considering the salinity, humidity and the incompatibility of this material with saline earth, we decided —as an alternative— on the use of lime. Subsequently we added to this lime-soil solutions of Primal AC-33 (acrylic emulsion) at 10 and 20% in water, trying to find a better formula against weathering.

We took into account the cost and the apparent rigidity of this method, and proceeded to carry out tests using three types of sand and earth mixtures (2: 1; 2.5: 1; 3: 1 vols.). We added lime to some and cement to others, in percentages of 2.5; 5; 7.5; 10; 15; 20:. The criteria for evaluation were: colour, endurance against drops of water and superficial hardness. The test which gave the best results was lime at 10% in the three cases, although the whitish colour produced was always a problem.

We insisted on the use of plastic substances due to the failure of soil-cement and the relative endurance of soil-lime in prolonged exposures. We needed a stabilized capping whose endurance to weathering would justify the investment and would guarantee effective protection.

At first, this capping was applied following the original shape of the top of the walls; however, we observed, during some rains, that there were difficulties, in the distribution of the water and that the danger of gullies subsisted, due to the intensity of the rains which surpassed the capacity of absorption of the capping.

This led us to find another solution: to incline the top of the wall towards the side of the wall with no decoration. Evidently this alters the look which we were accustomed to see, but it does not imply a formal reconstruction of the treated area.

This solution was applied in the area of "Arabescos", Ciudadela Gran Chimú. The heavy rains of the summer of 1983 supported our thesis. The reliefs in the first sector did not suffer at all, while a stylized pelican in the second sector was affected by the gullies formed.

We did not use lime in these cappings: the mix used was coarse sand and earth (2:1 vol.) and polyvinylic acetate at 5% in water.

Capping should be applied following these steps:

a. Elimination of superficial crusts and of humid-saline earth found under them.
b. Filling of cracks and holes with an earth-sand mortar (1:2 vol.).
c. Consolidation of adobes, using Mowilith DM-1H at 5% in water, after having wetted the area with water-alcohol (1:1 vol.).
d. Addition of adobes (new or old) to form a slant or inclination at the top of the wall, leading away from the decorated side.

In the case of walls having decorations on either side, a concave roof covering was made with cane. This permitted the water to flow towards a ramp, built next to the structure. These elements are totally reversible, as is the capping. This solution was suggested by Ismael Pérez.

e. Application of a mortar of coarse sand and earth (2:1 vol.). The cracks caused by drying will help the stabilized capping to adhere better.
f. Use of the stabilized capping, as mentioned. This mix must not be too watery, to avoid cracks. The first layer must be applied with a spatula, for better adherence, and then the hand should be used, to avoid surfaces with too much polish.

The torrential rains of 1983 have shown us two things: first, the strength of the capping, its ability to absorb water and to dry without cracking; second: that there is a critical problem in its adherence to the wall. Because the wall is not located with a waterproofing consolidant, it is affected by water. Thus, we believe it necessary to use a silicate, or a similar product.

A second aspect in the conservation of Chan Chan is the treatment of plasterings and high-reliefs. The exceptional aesthetic quality and the testimonial character of these decorations conditions all restoration action, for the treatment of the plasterings and decorations is linked to the supporting structures.

This link between support and relief-decoration conditions the treatments applied at the following levels:

a. Consolidation of the clayey structure of the plastering and relief-decoration.
b. Adherence of the plastering to the wall.
c. Adherence of the relief to the plastering.

A series of tests have been carried out, namely the application of chemical substances of a plastic nature on the surfaces of plasterings, reliefs and even on the adobes themselves. The products used were: Primal AC-33 (acrylic emulsion); Mowilith DM-1 H (polyvinylic acetate); Paraloid B-72 (copolymerous acrylic); Bedacryl 122 X (metracrilate); Calaton CB (soluble nylon). These solutions have not had the desired results, although the percentages used were very low (5% maximum). After two years, we find cases of exfoliation, due to the humidity contained in the structure or because of the orientation in regards to the ocean. Moreover, the plastic film formed makes future applications difficult.

However, the adhesive action on the plastering, as well as between the plastering and the supporting wall (that is, its application *in depth*) presents no exfoliation problems.

We have used, with good results, ethyl silicate 40, combined with ethyl alcohol at 96% and hydrochloric acid. Giacomo Chiari first introduced this treatment in Peru in 1975 and we have followed his steps. Application of this substance, however, still leaves some specialists skeptical, due to its irreversible character and the fact that it causes structural alteration of the adobe. However, considering the results obtained, we believe that —to the present— this product is the most appropriate one, due to its waterproofing capacity as well as because it gives good consistency to adobe and produces minimal alteration of its colour.

To give an idea of its waterproofing capacity and consistency, we will report a simple test. We plunged two specimens of reliefs in water, one untreated and the other consolidated by immersion, with ethyl silicate 40. After ten minutes, the first was totally destroyed, keeping only the superficial crust. The second specimen endured four hours, unaltered. It was then placed at a temperature of 52°C (it dried in sixteen minutes) and then was immersed four more hours. It showed no signs of alteration after this treatment.

Certain requirements have to be met when applying ethyl silicate:

a. Quality of the ethyl alcohol: it *must* be 96%.
b. Wind or air currents which accelerate the normal evaporation of alcohol must be avoided. Evaporation

is slowed down by covering the area with plastic, for a period of 5 to 7 days.
c. A high degree of humidity (both contained and atmospheric) must be avoided, for it impedes polymerization of the consolidant.
d. The surface to be treated must be cleaned of any particles adhered to it, as well as of dust. Cleaning must be thorough and should respect original forms.

Faced with the problem of adhesion between the plastering and the wall, and between the relief and the plastering (which is not solved by this product) we decided on the use of Mowilith DM-1H or Primal AC-33 at 3 or 5% in water, as we have previously explained. The voids or pockets which are eventually formed between these layers are filled in with aqueous mixed of earth and fine sand (1:2 vol.) and lime at 10%. Naturally, the area to be treated is first wetted.

The solution, thus, was found in the use of a mixed technique: silicate and polyvinylic acetate.

Finally, we drained the Temple of the Arco Iris (Rainbow) using PVC tubes 4" in diameter. This pipe system was connected to the fourteen enclosed deposits which surround the central structure; at the centre of each enclosed area a reservoir was built. Two other reservoirs were placed in the lower part of the inside corridor, to collect the rainwater and drain it to two other reservoirs, with a capacity of 12 m^3 each, placed 10 metres away from the perimetric wall. The rains, however, surpassed the capacity of the reservoirs. These measures prevented flooding in the reliefs and structures; this is extremely important, for this monument, we must remember, lacks foundations.

We have examined, in this paper, the more important aspects of the conservation of adobe in Chan Chan. This work has been carried out by a team of restorers and archaeologists since 1974. Our thanks to Carlos Castañeda, Carlos del Mar, Héctor Suárez, Ana María Hoyle and to the Director of the Restoration Centre, Cristóbal Campana.

Conclusions

1. It is urgent to take measures to protect the base and lower part of the wall in order to avoid inclined planes which carry the rainwater towards them.
2. Drainage is the immediate and necessary solution for Chan Chan and similar monuments.
3. Protection for the top of the walls should be done using capping whose structure does not differ from the walls they protect. These cappings require permanent maintenance.
4. Consolidation tests clearly show the advantages of using ethyl silicate 40 over all other plastic materials.
5. It is necessary to set up an Emergency Project, where priority actions be established according to the types of natural disasters.

Suggestions

1. To set up a Regional Project for the Peruvian North Coast, where norms would be established and carried out for the protection of archaeological adobe monuments during rainy seasons against flooding and other natural disasters.
2. To seek the participation of international organizations, such as the OAS, UNDP and others, as well as the Peruvian Government, to establish the aforementioned Regional Project for the Protection of the Adobe Archaeological Heritage.
3. To establish in Chan Chan a Research Project for its conservation.

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A Survey of the Painted Mud Viharas of Sri Lanka

Ashley De Vos

The Island of Sri Lanka, an Independent Republic located South of the Indian Land mass, is predominantly Buddhist. It has a well documented and written history of over 2200 years and a civilization extending much further into time. Sri Lanka is not affected by earthquakes or cyclones but is subjected to four months of annual rain and an 80% humidity. It is, therefore, a country possessing an aggressive vegetation and tropical climate.

Life in a typical Sri Lankan village revolved around the temple, its focal point. The temple was the school, the community centre, the council and refuge. Sri Lanka can still boast of about 2500 such temples of different shapes and sizes scattered around the country in varying conditions of construction, maintenance or decay.

The construction technology of the buildings in a typical temple complex consisting of the temple (vihara, pilimage) bo-tree and platform (bodhi maluwa), the dome-shaped monument enshrining sacred relics (dagoba, stupa) preaching hall (bana maduwa) and the residences of the monks (pansala) leaned heavily on that of the simple village dwelling for methodology and style.

The dwellings in the villages were basic and built of material extracted from the immediate environment. Mud being readily available in a variety of compositions and qualities dominated this technology. Six basic construction techniques were used, namely,

a. Wattle and Daub (Varichchi)
b. Cob (Undi)

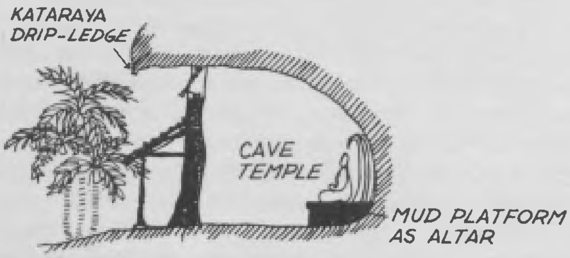
c. Adobe (Mordegal)
d. Rammed Earth (Thappa Bammi)
e. Stone walling in Mud (Sakka Bammi)
f. Laterite block (Cabook)
(along the western coast line)

The vertical surfaces of the buildings were protected from rain erosion by constructing roofs with wide eaves.

The viharas are of two basic types, the cave temples (gal viharas) and temples built on pillars or platforms, the structural temples.

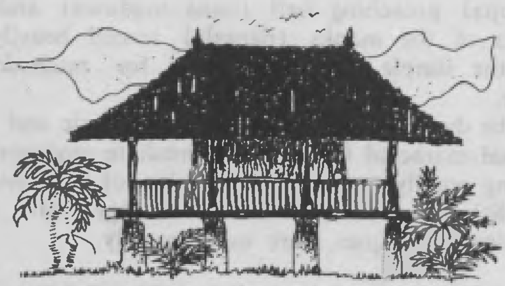
a. The cave temples, consist of natural caves, specially prepared with a drip ledge (kataraya) cut around the mouth of the cave. This ledge protected the interior of the cave from rain water runoff flowing down the external face of the rock. The donor's name was at times carved on the face of this ledge. Immediately below this ledge, a timber framed, terra-cotta tiled, lean-to roof supported on carved wooden pillars or stone columns (kuluna) with wooden brackets (pekada) formed a protected walkway or verandah (pilla). A thick wall with one or more doors and windows separated this verandah from the inner caves in which the image or images were placed.

This wall was made of mud carefully smoothed, plastered and covered with paintings of the Jatakas (stories on the lives of the Buddha) or other significant events. The ceiling of the cave was levelled and sized by covering it with a layer of finely ground sand and clay mixed with rice water. This surface was further prepared before painting.

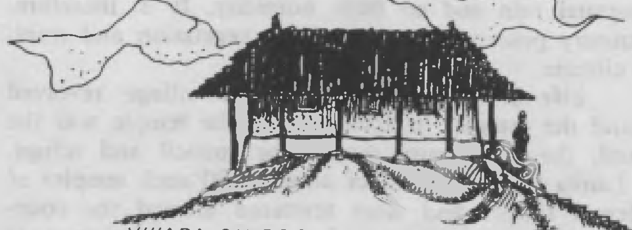


MUD WALL AS PROTECTION. DOOR AND WINDOW IN TIMBER. TIMBER ROOF AND COLONNADE IN FRONT.

TAMPITA VIHARA - ON STONE BOULDERS MUD STRUCTURE ENCLOSING TIMBER FRAME TILE ROOF.



TAMPITA VIHARA - ON STONE PILLARS. TIMBER FRAMED. MUD WALLED SHRINE IN CENTRE. TILE ROOF.

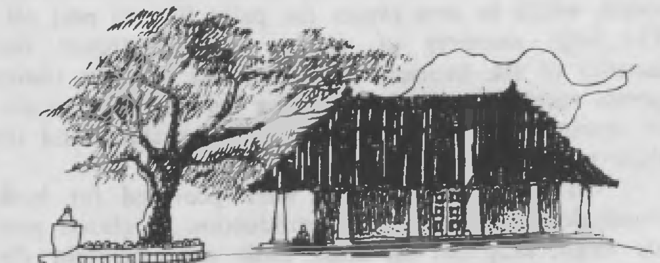


VIHARA ON ROCK OUTCROP, TIMBER FRAMED STRUCTURE INDEPENDENT OF WALLS. SHRINE IN MUD. TILE ROOF.

b. The structural viharas, like the village dwellings are raised higher than the surrounding ground. They are either built on:

1. Short stone columns
2. On boulders
3. On high plinth; or
4. On bare rock outcrops

The viharas on short stone columns (Tampita Viharas) or on boulders are reminiscent of the mud granaries (bihi) or paddy storage bins in the village that are raised in a similar fashion as a protection against termites (white ants) or rising damp. These temples consist of a single rectangular or square image house, covered by a timber framed, double slopped terra cotta tiled roof. The outer part of the roof shelters the open verandah, that encircles the image house. The



VIHARA - EXTERNAL CORRIDOR EITHER TIMBER COLUMNS OR MASONARY, MUD WALLS ENCLOSING MAIN SHRINE.

VIHARA - TWO STORIES. IMAGE HOUSE ON UPPER FLOOR PREACHING HALL (Bana Madura) ON GROUND FLOOR.

inner wall, made of mud, plastered smooth and painted is afforded protection from the elements by the verandah and wide eaves that encircles it.

In the hill country, the viharas are often built on top of rock outcrops. These temples stand out in the environment and form focal points in the landscape. The walls are often made of stone set in mud, plastered and painted. In other areas high terraces of stone and mud are constructed on which the viharas are placed. These viharas are at times two-storeyed. They are capped with timber framed, terra-cotta tiled roofs with wide eaves to protect the mud walls below. The upper floors are made of timber boards supported on timber sub-frames.

Location of Painted Surfaces

Most walls of the viharas are covered with paintings of the Jataka Stories, in long, narrow, continuous panels. This visual narration is at times interspaced with an explanatory note. In the majority of the temples, the paintings are limited to the inner face of the shrines. However, examples of viharas with the external faces painted do exist. The decision to paint a particular wall is not governed by a convention but rather by a decision dictated by time and place.

In addition mouldings, pilasters and ceilings were also painted. The areas inbetween were filled up with designs to create a continuity of painted surface. The statues of the various deities were first framed in timber, moulded in mud, plastered, painted and placed in their order of importance at the entrances to the shrines. The statues in the inner chamber of the shrine had a core of stone, brick or timber, completely moulded in mud and were carefully plastered and painted.

Methodology

The wall surface was carefully prepared by first plastering the mud wall with a layer of finely ground clay and sand. Clay from termite mounds was ideally suited for the purpose. It was then covered with a thin layer of kaolin (kirimati) made very smooth and compact by rubbing with a metal or stone tool. This was finally covered with a coat of magnesite (makulu).

The outline of the painting was then executed on this pure white surface using a fine brush made of teli tana grass (*aristida adscensions*) and black paint.

Brushes made of squirrel's hair for fine work, and those made out of the root of the Pandanus (vetakeyiya) were used for filling up the spaces between the figures. This back ground was executed in a technique using layers of two to three coats of pink and red pigment, until the final intensity of the required red background was reached.

The materials used in the manufacture of the various colours were first gathered and carefully ground into a fine powder using a stone mortar. This powder was mixed with gum (divul latu) from the elephant apple tree (feronia elephantum) and water to form a paste. The paintings were executed using a tempera technique. The paintings in exposed situations were done using the oil from the Dorana Tree (Dipterocapus Glandulosus).

The painters painted traditional themes in a traditional style, drawing inspiration from scenes and objects in their particular contemporary environments. These paintings today are a window into the History of the times. Their visual narration make them more accurate than any history book. The scenario unveils exactly how the people lived at the particular period the paintings were executed. The architecture, fashions and designs, the transport systems, the food, the furniture, the foreign influences, the fauna and flora, etc., were all vividly portrayed on the walls.

Deterioration Factors

This patrimony is subjected to a number of deterioration factors both natural and caused by man. That which is mancaused, namely neglect or lack of maintenance, is invariably the most serious.

In the past these temples were patronised and maintained by the village. The temples were repaired and repainted on a regular basis by the temple societies (Dayake Sabhas) using traditional techniques and methods. Today, with education and the chase for material wealth, the traditional protection devices have disintegrated. The population has less time, the material schedules have changed, in that concrete is used to repair mud. Cheap, glossy oil paints have replaced the traditional paint pigments, all culminating in destruction rather than preservation of the temples.

The temples, traditionally lighted with oil lamps, are today fitted with electric lamps in an effort to exhibit the paintings to 'tourists'. The crude fixings of the light fittings with wires trailing across the painted surfaces are a common sight.

The temples of the East are objects of a living religion as opposed to the Museum attitudes in the West. The dark, limitless spaces are used for meditation, but today the electric lights add a theatrical quality to these simple spaces. Suddenly the boundaries are visible. The lights have displayed paintings hitherto unseen, but the exposure to excessive light has started a new type of decay from exposure to radiation, leading to the fading of the colours. These lighted temples attract more visitors, thereby increasing the humidity levels, which in turn causes the paint film to peel off. The large numbers of visitors have destroyed the sanctity of the interiors of the shrines. Guides tramp across sacred boundaries dragging behind them gaggles of tourists, like geese trouping across pasture land on their way to the water.

Traditionally, windows were provided for both ventilation and light. The introduction of glazed panels might keep out the bats, birds and maintain the natural light levels, but destroys the effect of natural air movement through the structures, which is essential, for drying of the wall surfaces in the humid tropics.

Conservation and Conclusions

The causes of destruction are universal and so is the theory of conservation. Each country should evolve a theory best suited for its aspirations, within the guidelines set out in the International Conventions. We should not forget that all cultural property belongs to the Heritage of Man. It is our duty to preserve it for those who come after us. Our choice of methodology should be responsible and devoid of excessive experimentation. Traditional methodologies, which included careful and regular maintenance has preserved much of this patrimony from the ravages of time.

This presupposes a need to re-acquire some of this lost knowledge. The conscious study and the systematic documentation of traditional technologies is of prime importance. The most humble village is an unlimited fountain of knowledge. Many of the solutions to our problems are available at grass-root levels. We must be humble enough to acquire them. We cannot always pray to the Gods (UNESCO) to constantly send us experts to solve our problems. We need to develop skills within our own countries; we need to communicate with each other. It is only then that the real meaning of the Heritage of Man will emerge.

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Conservation and Consolidation

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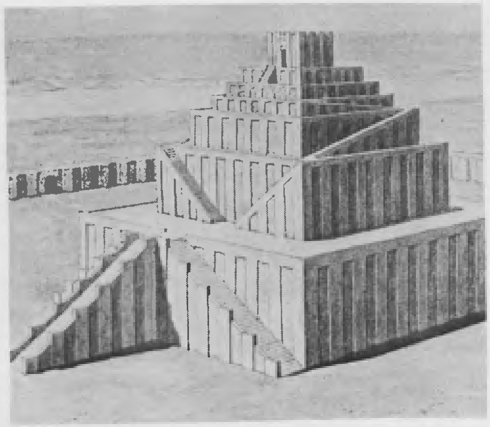
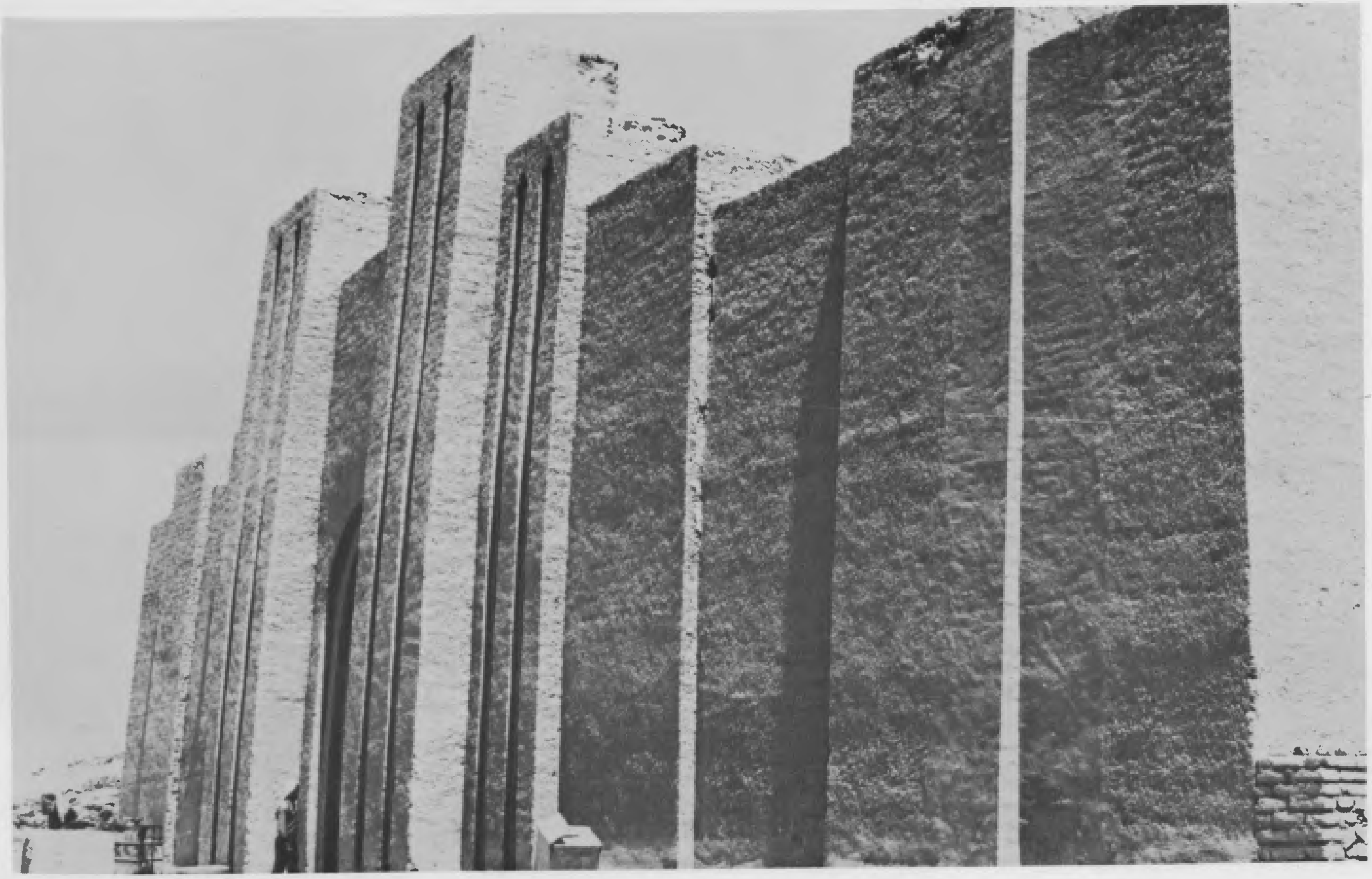
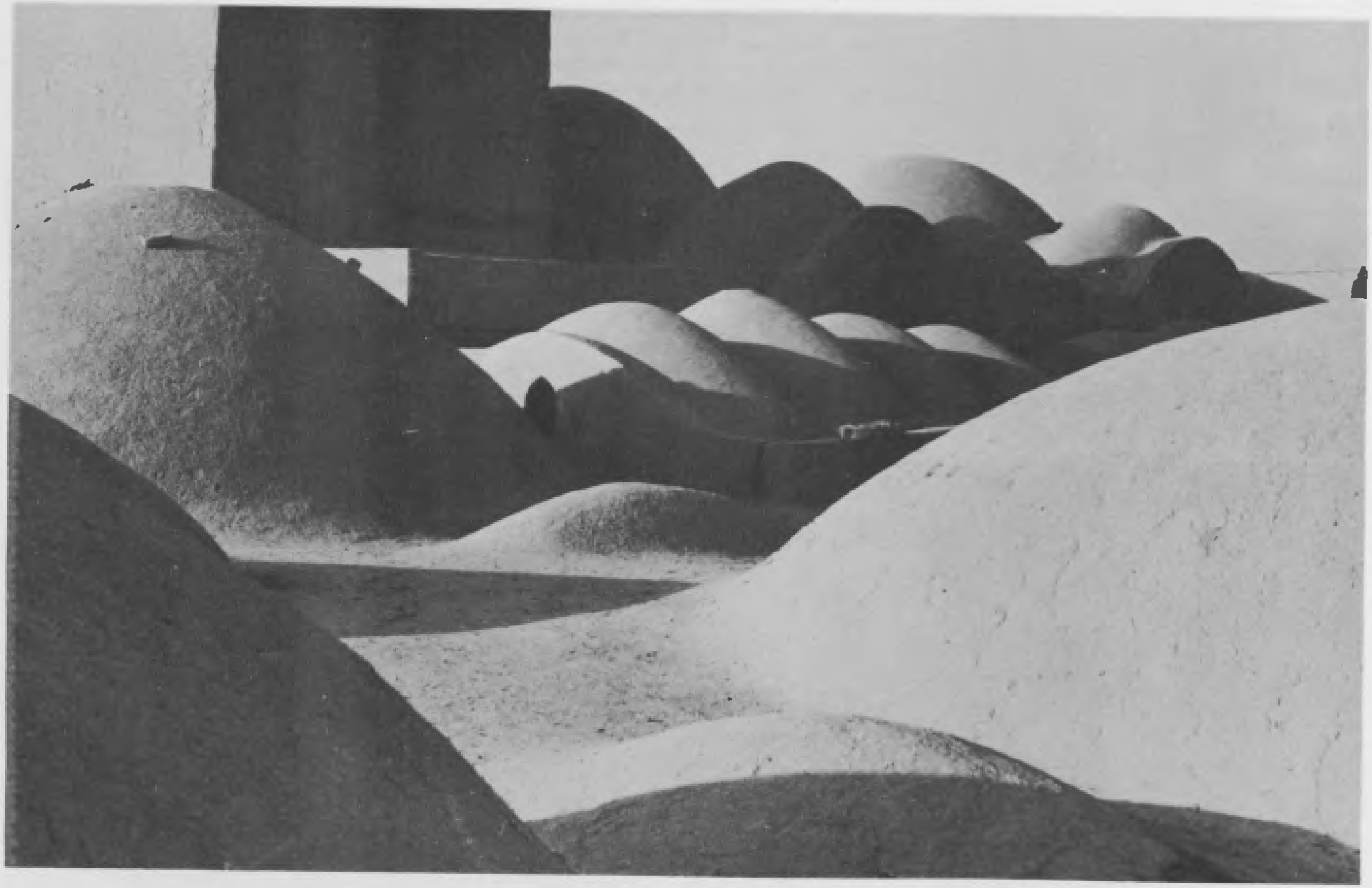
A reconstitution of the tower of Babel in Babylon. It is most probable that the huge tower dedicated to the god Marduk was the tower mentioned in the Bible.



Temple of Emah, Babylon, Iraq. Reconstruction.





Iran. Yazd. Domes on the roof of the bazaar.

Adobe building, Punjab, Pakistan.

Ecuador. Rural adobe arquitecture.

Previous page:
Adobe buildings, Mali.

Adobe and mud architecture. Mali.

The Mission Church at Tumacacori, New Mexico, USA after restoration. It is a National Monument today.

Using precise levelling equipment to detect foundation settlement at Tumacacori National Monument.

The Masmak in Riyadh, Saudi Arabia. Around it the city loses its character and has become "westernized".

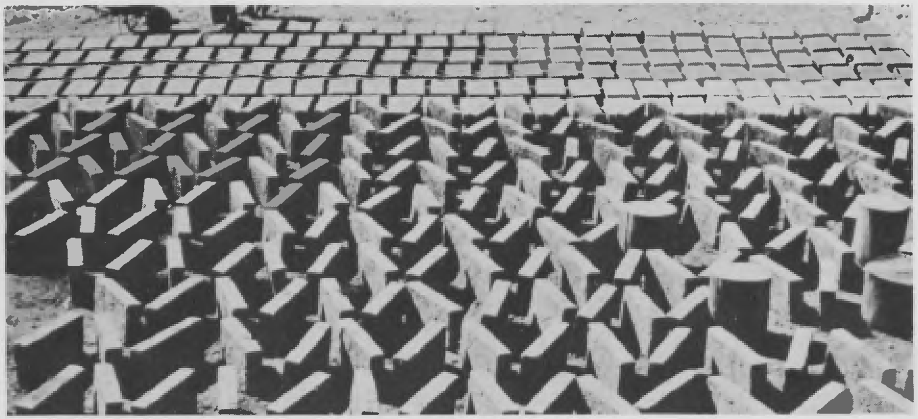
Tower inside the Masmak in Riyadh, Saudi Arabia before and after reconstruction in 1982.

Ruins of Chan-Chan, Trujillo, Peru: a view of the archaeological site after the heavy rains of March, 1982. Drainage is crucial to solve this problem.

Huaca del Dragon, Trujillo, Peru. Initial consolidation of the relief by injecting plastic substances.

Making adobes in Usak, Turkey.

Drying adobes in Iraq



Drying adobes in the Andean region.

Conical adobes are shaped by hand in Africa.

The mud is mixed with straw to strengthen the block. Making adobes in the Andean region.

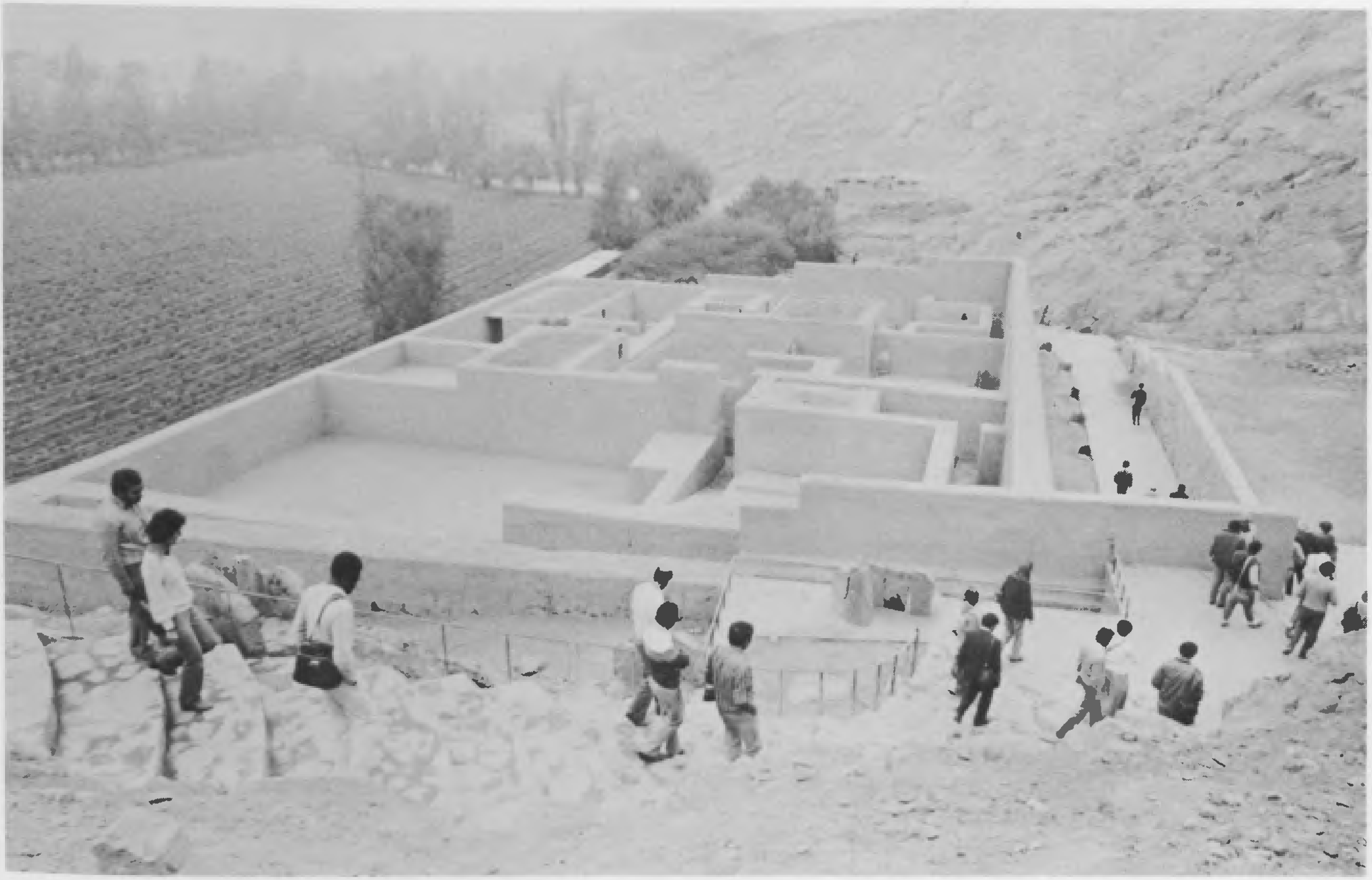
Gers, France. Adobe and wood architecture. Notice in the lower part of the house the different techniques used for plastering.

Dr. Erder and Mr. Sylvio Mutal, Regional Coordinator of the UNDP/UNESCO Regional Project on Cultural Heritage and Development chat with the former President of Peru, Architect Fernando Belaunde Terry during the visit to the Government Palace.

Dr. Cevat Erder, Director of ICCROM, and Ülku Izmirligil from Turkey in Machu Picchu.

Two views of the work sessions during the Symposium.

The participants visit Puruchuco, a pre-Columbian adobe monument outside of Lima.



Giacomo Chiari (ICCROM, Seymour Z. Lewin (USA) and Paul Schwartzbaum (ICCROM).

A group of participants in the Symposium during the visit to the National Museum of Anthropology and Archaeology, Lima.

Right:
French Basque region. Earthen construction on the right-hand side of the street.

Legislative Palace, Tlaxcala, Mexico.

Convent of Tepeyanco, state of Tlaxcala, Mexico.

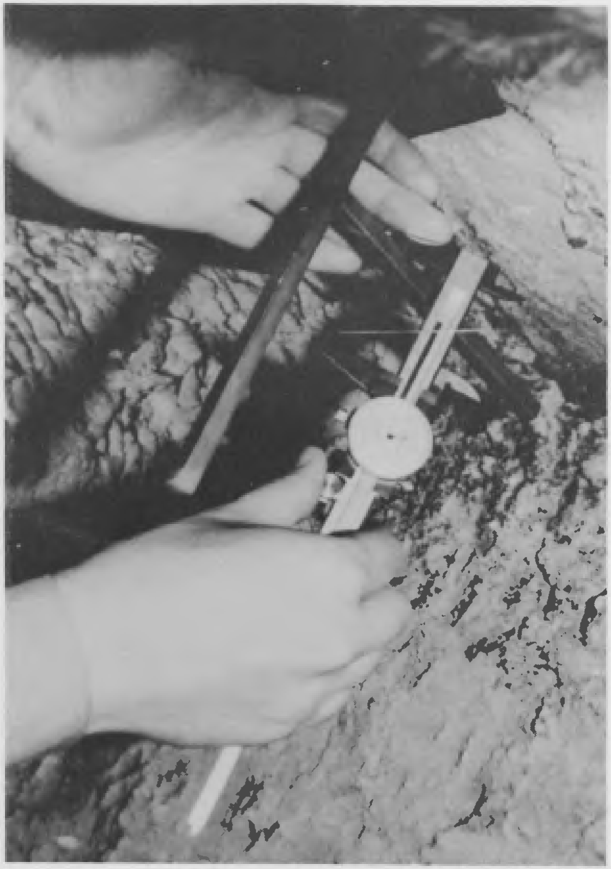
Below: Interior of the open chapel at Tizatlan, Tlaxcala.

Left:
A typical 18th century house near Cusco. It is still used today as such, but lacks plumbing and other services.

Casa Vivanco, Ayacucho, Peru, restored by the Banco Industrial and now its headquarters in that city.

Hacienda-house, Buena Vista, Cusco.

Below: Determining changes in wall tilt by periodically measuring the distance between a plumb bob string and a permanent reference bracket.



Ancient College of San Bernardo, Cusco, restored with support from Unesco. Today it is the seat of the National Institute of Culture in that city.

Left:
Old convent of San Francisco, Santiago de Chile. Once restored, it houses a Museum.

Tower of the former Hacienda Mendoza in Rengo, Chile. Today it is the seat of a Benedictine Monastery for Women.

Below: Tower of the Church of La Merced, Rancagua, after restoration.

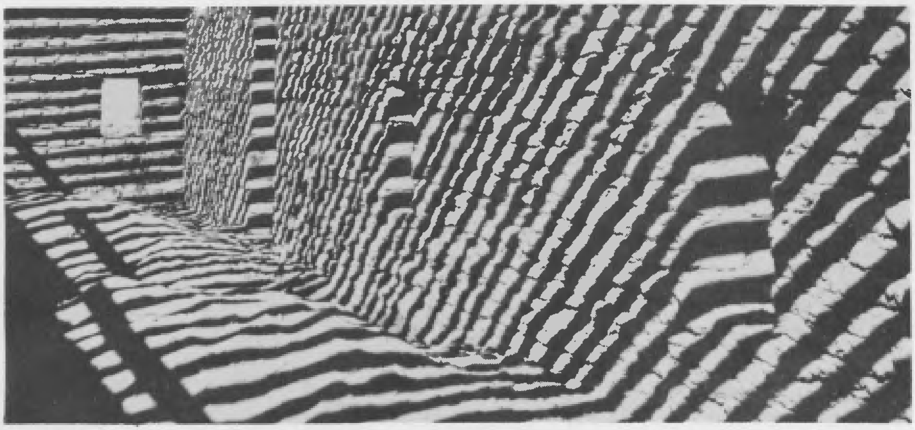
Bamba, Senegal. Plastering with mud over adobe.

Malatya, Turkey. Contemporary adobe houses.

Experiments carried out at the Catholic University of Peru to achieve seismic-resistant adobe houses.

Fortress of Van, 12th century A.D. Adobe towers, Turkey.

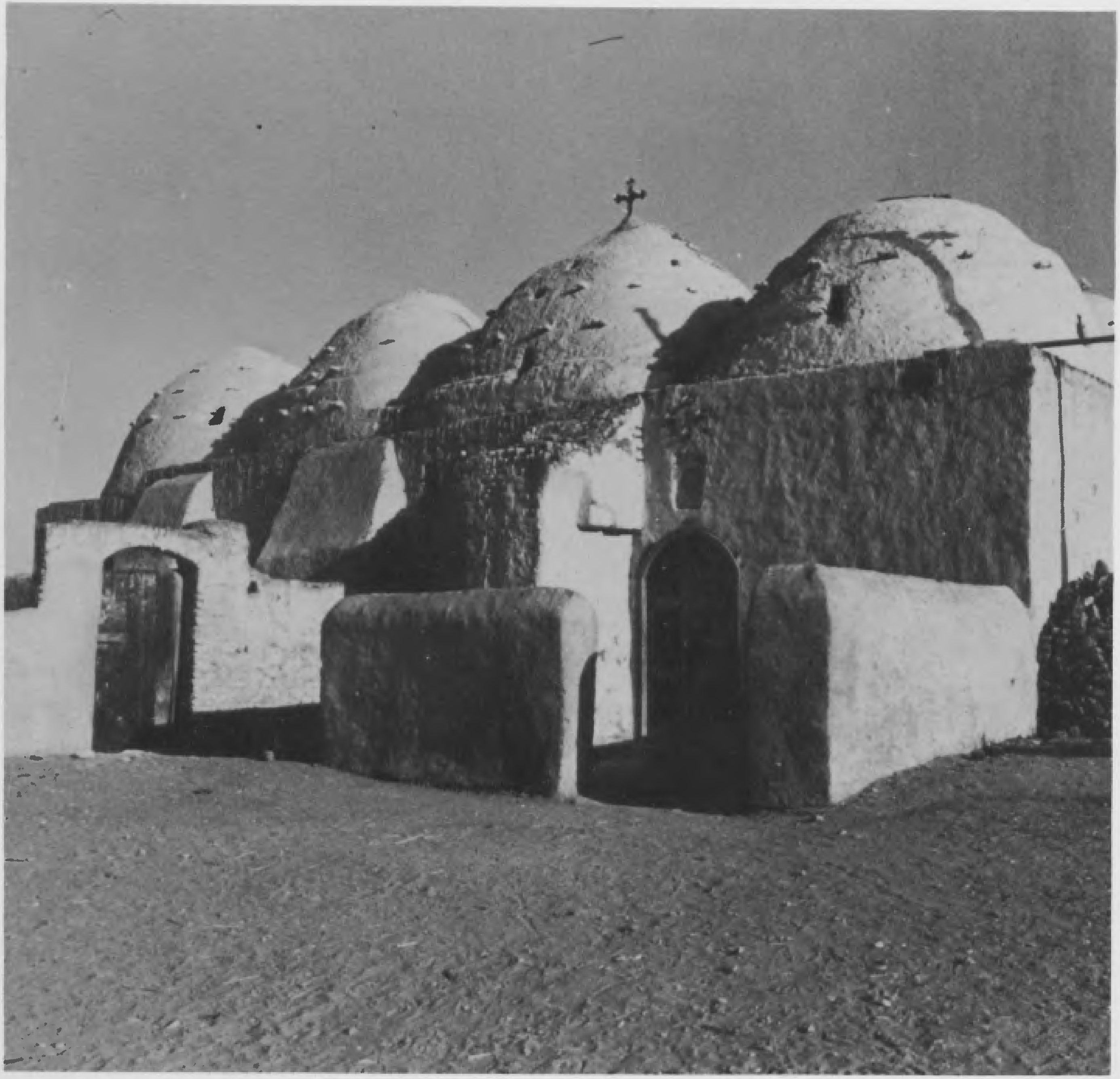
China. Turfan oasis. Central Yar Steppe.



Siria. Inside of a house under construction.

Mud frieze, Chan-Chan, Trujillo, Peru.

Next page: Convent in Tod, Egypt.



Raw Earth Techniques ('Banco') Used in Mali

Nianti Bouaré

I. Introduction

Mali is located in the heart of West Africa. It occupies an area of 1.240.710 square kilometres and extends between 10º and 25º latitude north. The Greenwich meridian crosses Gao. The country is land-locked and surrounded by Algeria to the north; Niger to the east; Upper Volta, the Ivory Coast and Guinea to the south and Senegal and Mauritania to the west. Bamako, the capital, is 1.272 km. from Dakar by railroad, and 1.086 km. from the seaport of Abidjan by road.

The country is located in the northern tropical zone. Two seasons exist: the rainy season, going from June to September, and the dry one, extending from October to May.

The average annual temperature varies according to the latitude; towards the north, it is quite high.

The country is subject to the influence of two predominant winds:

—a dry wind (northern trade wind or harmattan), which blows from northeast to southwest during the dry season.

—a humid, warm wind (the monsoon) which blows from the southeast to the northwest and which brings rain.

Different climatic zones exist; going from north to south these are:

—a tropical and humid zone, with a Sudanese climate, which extends south of a line passing through Kayes and Bandiagara. Annual rainfall varies between 1.350 mm. to the south and 800 mm. to the north.

—a tropical arid zone, with a Sahelian climate, extending between this line and the parallel of Timbuktu, with an annual rainfall of between 600 and 250 mm.

The Saharian zone, extending north of the parallel of Timbuktu, whose annual rainfall is under 300 mm.

According to the 1976 census, the country has a population of 6.750.000. The district of Bamako and its satellites (Kati, Kulikoro) has a population of 600.000. There are 43 cities with over 5.000 inhabitants.

About 90% of the population works in the primary sector (agriculture, fishing, cattle raising).

Historians agree that —as far back as one may go in the history of humanity— the first civilization appeared on the banks of the Nile.

From this Egyptian civilization come the Proto-Wangara, that is, the civilization of the soninkés situated in the border area between Senegal and Mali.

The Sarakolés in Senegal and the Marakas in Mali have inherited a knowledge thousands of years old, and have transmitted it from generation to generation. (Cf.: *Africa, Cradle of Civilizations* and *Black Civilization or Barbarism,* by Cheich Anta Diop).

This explains why the Sudanese — Sahelian style is found throughout this area in north and northeast West Africa.

The trade between Black Africa and White Africa gave rise to cities in the crossroads of the caravan routes. We will mention here only the oldest cities: Timbuktu, Djenne, Mopti and Gao were born of this traffic and their layout, often radioconcentric, has a flexible texture.

The building material used was always earth; often, the houses were two —and three— storeys high and the thickness of the walls lessened as they grew higher. This gave the buildings a truncated-pyramid look.

The majority of these edificies are well conserved, thanks to the constant maintenance given to the important buildings, such as the mosques and the large "bourgeois" homes. A large part of them, however, has been destroyed by *razzias,* wars or other conflicts.

The use of earth as a building material is deeply rooted in the soul of the Sudanese-Sahelian population, closely linked to the nourishing earth.

Construction of a building gives rise to a series of ceremonies. The cult of the *Gabibi* is celebrated; (that is, of the being possessing spiritual powers that confer grace) and a festive atmosphere exists as a result of the help given by all the community to the person building his home.

The building techniques and the material have remained almost invariable through the years. It would be desirable, however, that the necessary measures be taken for the good conservation of the old cities —among them, Timbuktu. Teams of archaeologists should continue to excavate the historical buried sites and consecrate themselves to the protection of those sites which have already been dug-up as well.

II. Building Materials

Mali has an enormous potential insofar as traditional building materials are concerned.

Throughout the country, clay, lime, sand, laterite, etc. are found. In certain regions, also slate, schists and marble exist.

1. Banco

Banco is the most traditional building material and the one most commonly used in Mali. The use of this material makes Malian architecture extremely original and very well-known, both in Africa and world-wide.
Banco pits are found all over the country; however, the chemical composition, as well as the physical and mechanical qualities differ from one region to the next. The rural habitat (over 90% of the total population lives in rural areas) is made of raw *banco;* the same is true of the historical monuments which are the pride of Mali.

2. Some Traditional Methods Used in the Conservation of Raw 'Banco'

The rural populations, concerned with preserving their homes against the inclemency of the weather, have developed certain methods for the conservation of *banco.* Among them are the following:

—Stabilization using straw

This technique consists in mixing a certain proportion of straw with *banco* (this is known as "reinforced *banco*"). This stabilization method is used both in the making of the bricks and in plasterings.

—Stabilization using oil

In the south of the country there is a tree, called Karité, whose nuts produce oil. The inhabitants of this region mix this oil with the *banco* to obtain a material resistant to rain. Generally, the plasterings are stabilized either with the oil or the residue of *Karité* nuts.

—Stabilization using animal excrements

In many areas, earth is mixed with animal excrements to obtain a more resistant material against weathering.

—Stabilization by firing

In the regions of Mopti, Goundam and Diré, small fired bricks are made. These bricks are used to line the flat terrace-roofs. This method is unknown in regions with abundant rainfall.

3. Actions Taken to Revalue the Use of Local Materials

Bamako, the capital of Mali is 1.000 km. away from a maritime port, as we have seen.
Since 1973, as a consequence of the energy crisis, the price of cement augmented noticeably. The Government of Mali at this time established a policy with a view to revalue the use of local materials and to improve traditional building techniques.
The National Centre for Research and Experimentation in Construction and Public Works (CNREX-BTP) was asked to do a study on the different *banco* pits found in the diverse regions of Mali; this work was sollicited by the Department of Urban Planning.
The results of this study are to be found in a publication entitled: *Studies on Stabilized Earth in Some Regions of Mali.*
The most important research project in the field of *Banco* is the one of the Centre for Adapted Technology (CTA), whose objective is to improve the living conditions of the poorer sectors of the population by improving their traditional habitat. In order to achieve this, it is necessary to find a cheap basic binder.
This project, now in its third year, has established an inventory of the existent typology of buildings in Mali. It has indicated the location of the different sources of lime in the country, as well.
This project will make it possible to obtain cheap basic binders, by installing small artisanal lime ovens near the rural centres.
In keeping with the concern to use *banco* as a fit building material, Mali has initiated the construction of some public buildings, such as the Health Centres. These buildings, financed by the African Development Bank (BAD) will be built by the ADAUA (Association for the Development of an African Architecture and Urban Planning).
All these efforts undertaken by Mali, one of the countries most severely touched by the drought, risk being in vain if a solution is not found for the conservation of raw *banco*. In effect, because of the already exorbitant cost of imported cement (1.100 French francs; about US$ 137 per ton) stabilization using cement, even in percentages of 5%, is no longer economical.

III. Research Structure

In almost all of the countries of West Africa, research organizations have been set up. Among them we may mention the following:

—in Senegal: the School of Architecture and Urban Planning; the Research Centre for Habitat, Urban Planning and Architecture (CRHUA).
—in Mali: the National Centre for Research and Experimentation for Construction and Public Works (CNREX-BTP); the Project of the Centre for Adapted Technology (CTA), which is funded by UNDP.
—in Togo: the Centre for Construction and Housing at Cacavelli, near Lomé (CCL).
—in the Ivory Coast: the Centre for Research, Architecture and Urban Planning.

An essay in sub-regionalization has been undertaken by the Centre for Construction and Housing in Togo. On a sub-regional level, mention should be made of ADAUA in Ouagadougou, Upper Volta and the ENDA in Dakar, Senegal.

One of the problems that limits the use of *banco* is that of roofing. There are some ongoing research projects to try to solve this problem. ADAUA has built, in Rosso, Mauritania, homes with a dome as a roof. In Mali, as well, the Agency for Cooperation and Equipment (ACA, France) has experimented with straw roofs with intercalated polyethylene sheets. Although one should be careful in predicting the durability of these straw roofs, all these experiments should be fostered and supported.

It would be desirable that the international organizations establish a set of specific norms for each region, so that buildings made of *banco* might have the same access to bank loans as those built in concrete or cement mortars.

Much has been done to the present, but unfortunately information concerning *banco* has not been centralized. UNESCO, ICCROM or ICOMOS could take up this task of centralizing and divulging all existing information regarding *banco*.

The Protection and Conservation of the City of Tlaxcala, México

Gilberto Reyes Zepeda

During the Conquest, and as a result of the alliance of the Spaniards and the Tlaxcaltec Culture, were built, among other buildings, several open chapels, which are characteristic of the first phase of the Conquest; as well as Franciscan monasteries in the XVIth century and churches during the XVIIth, XVIIIth and XIXth centuries.

From the point of view of urban design, several cities, such as Huamantla, Calpulalpán and the capital Tlaxcala, are characterized because they have maintained practically the same urban image during the last 400 years. Specific measures for their preservation, and restoration plans for several buildings, both public and private, have been taken with the basic objective of preserving the cities, their buildings and the existing and future urban image as a cultural heritage for the inhabitants.

The city of Tlaxcala, the State capital, has 20,000 inhabitants and in its surroundings at least 80,000 more, in villages and cities comprising five municipalities.

Following the urban development plans and in accordance with the decision taken both by the State Government and the National Institute of Anthropology and History to define an area — urban center, norms have been established to maintain the 400 year-old image of the city.

In the streets and urban locations, the solution has been to provide sidewalks suitable for the circulation of pedestrians with a row of trees and low bushes, as well as to maintain a harmony in the colour of the facades within the same range of shades, varying from ochre to oxide red.

This same criterion has been applied in small towns and cities where common spaces like the Civic

Squares and meeting places have also been treated.

Special attention has been given to the recovery and restoration of public buildings, of a historical and cultural value. These buildings have a special characteristic: all were built in adobe and a soft stone called *xalnene,* which combined with adobe provided them with an adequate resistance.

One of the sites which has been preserved is the Monastery of San Francisco, a XIth century complex which has survived the centuries and consists of a cathedral, monastery, walls and surrounding streets with buildings made of adobe and *xalnene*, including the bullring.

Another building is the State Art Gallery, originally a private home. It was adapted respecting all the spaces and recovering others already deteriorated, to serve as exhibition hall and paintings deposit. The straw loft was transformed into a small auditorium.

The Legislative Palace, located downtown, was built at the end of the XVIth century and originally an annex of the church, presently known as Parroquia de San José. During the last 30 years, this building operated as a hotel. The building was completely deteriorated, outside as well as inside, having lost its original characteristics. Attempts were made, when restoring this building, to preserve the oldest walls; inside, two arcades which are the most valuable elements were found during this restoration.

What originally was a school, built at the beginning of this century, was adapted to serve as the State General Archives. The original spaces were respected, creating at the same time a luminous atmosphere with an inner garden.

The open chapel of Tizatlán was an interesting restoration example; it was close to collapse and, while recovering the monument, two XVIth century frescoes were also discovered.

The convent of San Francisco in Tepeyanco, is also a XVIth century building, monumental in its construction and comprising an open chapel with five big arcades with a double aisle, now under restoration.

Another convent of the XVIth century, one more of the twelve existing in the State, is the Franciscan convent of Atlihuetzia. This complex is spectacular also for its monumentality. The principal nave and the convent in itself have lost the roof, but its main inner arcades, in the choir area, have been conserved. Its walls are still standing, creating a space both pleasant and impressive.

What we have showed in this Symposium is part of a State's effort, within a country like Mexico, where both the inhabitants and government officials are trying to maintain, among other things, the historical and cultural patrimony inherited from our ancestors. It is also their concern to leave to future generations witnesses of a country's cultural development. We hope you will have the opportunity to visit us and enjoy these buildings in their original location and, above all, see them functioning, given that the basic criterion for their restoration and recovery has been daily use, which also supposes timely and preventive maintainance.

Tumacacori National Monument

Paul McHenry, Jr.

History

The Tumacacori Mission, located approximately 50 miles South of Tucson, AZ, the northern outpost of a mission chain constructed by Franciscan Priests in the later 1700's. Its present form was completed and in use about 1823. The principal structure is a church, built mainly of adobe bricks with 6 ft. thick lower walls. The church building incorporated a single bell tower, a dome over the sanctuary, and a barrel vaulted sacristy. Many ornamental features were done in low fired (burned) adobes.

Most of the wall surfaces were plastered with a lime/sand plaster, with the lime kiln being located on the monument grounds.

Other features of the monument include partial remains of a granary, funeral chapel, service buildings and a camposanto wall. The camposanto wall plaster was decorated with red brick chips, original portions of which still remain. Plastering techniques used made use of locally available materials without the newer portland cements and products used today.

Until its designation as a National Monument in 1908, the structure had been vandalized and looted for usable building materials. Since its acquisition, repeated efforts had been made at various times for restoration and stabilization. Many of these well meant efforts incorporated new types of building materials, i.e. asphalt stabilized adobe bricks colored cement stucco, plastic vapor barriers, various types of chemical waterproof coatings and sealants. Some of these repairs created unwanted side effects, concentrating moisture and accelerating deterioration. Moisture infiltration from unknown sources in the massive nave walls was of prime concern.

Design Criteria

The criteria established by the National Park Service was to stabilize and preserve the cultural resource rather than full restoration. First priority for the project was to determine causes, stabilize the structure to prevent further deterioration, and to take no steps that might have unforeseen consequences. The first rule of preservation technology was to be followed, do nothing that would be irreversible.

Stabilization methods and materials used in the past were to be examined and evaluated. Fragile plaster wall decoration, rapidly deteriorating from moisture was to be stabilized and preserved. A futher purpose was to make the project serve as a testing site with field conditions for the determination of appropriate, practical procedures for restoration of adobe structures.

Implementation

The primary problem to be addressed was moisture infiltration into the massive walls, from an undetermined source. A superficial surface investigation did not offer any obvious clues for the source of the water. Major wall cuts, often a practical approach for many earth buildings, were not adviseable because of the historic nature of the resource. Crack monitors were installed to check and measure wall movement and settling. Moisture sensors were placed in the walls at regular intervals and at different heights and depths so that a profile of the moisture levels could be determined. Monitoring of these sensors for several years indicated that the probable moisture source was from capillary action from the base of the wall.

These profiles apparently had some seasonal variation. Cement stuccoed walls, preventing the evaporation of wall moisture, and the insertion of stabilized adobe bricks had caused moisture transference to other locations not previously affected. The major task of the stabilization effort was to determine original materials and techniques used, duplicate them, and evaluate the results compared with more modern materials and methods. The methods evaluated would provide new information and guidelines for the maintainance of other earth monuments for which the National Park Service is responsible.

Adobe test walls were built on the Monument grounds and subjected to various conditions and treatments. Extensive testing was perfomed by NPS laboratories on soils used in existing historical walls and plaster, as well as repair materials proposed for use. Adobe bricks were manufactured, using idealized soil mixtures, as well as locally available soils. By laboratory standards, the local soils seemed unsuitable, having a high percentage of expansive clays, but it was discovered that they worked well for both bricks and plaster. Traditional historic materials and techniques were employed for repairs, supplemented in some cases by modern tools and equipment. Ongoing maintainance costs were evaluated. Wall voids were repaired with adobe bricks or mud plaster, depending on the depth of the damage. Satisfactory mix proportions were determined by trial and error, duplicating the original surface coating, and were applied to test walls. The stark white color this produced, which was a visual intrusion on the monument, was tempered by the addition of a clay soil wash, which enhanced the overall appearance.

Lengthy testing and careful maintainance cost projections indicated that the use of original materials and labor intensive methods would not be more costly than modern materials.

A repair crew was formed of NPS maintainance personnel, from the monument and regional staff, supplemented by local unskilled labor, including University of Arizona students and faculty. Training sessions were held and various team assignments were made, matching natural aptitudes with the tasks to be performed. Work commenced and was completed in a timely manner. On completion of repairs, the monument presented a pleasing appearance, integrating old and new surfaces neatly, obviously of the same basic materials, but delineating old from new in a subtle manner.

The visitor center was built in the 30's by the Works Progress Administration during the great depression. It was designed in the architectural style of the original mission buildings, and built of adobe bricks, using many hand labor techniques. It contains artifacts, models and exhibits of significant features. One outstanding exhibit is a small diorama of the interior of the church during its peak period. The monument is intact for visitor enjoyment in the actual spaces used, and the diorama offers the fully restored space appearance at a minimum cost, as opposed to full total restoration of the monument itself.

Adapting Adobe Buildings and Monuments to New Use

Roberto Samanez Argumedo

Preliminary Remarks

As opposed to other artistic expressions, such as music or literature, which can be copied or conserved by oral tradition, architectural creations are linked to the materials which form them. When these materials disappear or suffer decay, the architectural work dies as well. In this inevitable natural cycle, the need arises to preserve the works that remain, while human history goes by.

Materials, however, are only one of the components of the architectural works inherited from past generations. The historical character, the testimonial condition and aesthetic expression of these works are factors linked to them; this is why it is so important —and at the same time difficult— to preserve this heritage from the past in an authentic manner.

Architecture, on the other hand, is always linked to the aesthetics of a given period, as well as to the function for which it was destined. This explains the fact that some buildings which remain standing today have been admired by contemporaries and forgotten later.

Thus we see it is not the monument that changes, but the mentality of the people, who change their way of feeling about historical monuments and their way of valuing them.

Our century is characterized by the importance given to history; consciously or unconsciously, we all perceive it — even if we are mere observers of changes and events. Carlo Ceschi, the late master in restoration, used to say that, to see how immersed we are in history, it suffices to observe how even moderately-educated people can identify the historical period of the monuments of their city.

In this context, it is easy to see how theories have been established, as well as ethical principles, seeking an authentic conservation of the past and how a technology of restoration (related mostly to the older and more abundant experiences, that is, the European ones) has emerged. In these brick or stone edifices, experience accumulated during half a century of sound restoration work has been applied. We should, however, point out that when dealing with earth as a building material, we confront different experiences and technologies.

Without discarding universally valid theoretical principles, the context where adobe historic buildings are located (usually underdeveloped countries) makes it impossible to apply the aforementioned technology.

As an alternative, a technological adaptation is proposed, applying the technology which is more appropriate to the financial possibilities of underdeveloped countries and which implies a return to the traditional building methods and artisanal techniques used in the past.

Experiments in adobe restoration are quite recent, compared to those of stone, masonry or wood. As we have stated, in all monuments one must conserve not only the form but the material of the building itself, which embodies its personality and aesthetic expression. In the case of adobe, this is truly a challenge: one must restore these buildings, not make them into copies or variations of the monument existing before intervention.

Criteria for Adaptation

Twenty years ago, during the International Restoration Conference held in Venice which gave rise to the Venice Charter, Piero Gazzola brought some important corrections to the final recommendations. It had been proposed that: "when adapting edifices considered as 'living monuments' to new use, they should be destined to functions or uses not too different from their original end, so as not to alter —when adapting them— the essential parts of the building".

Gazzola considered that, although the intention to avoid adapting a building to a practical use in order to avoid negative results on the integrity of the building was valid, this intention had been stated erroneously. Firstly, because a new use, quite different from the original one, can have more respect for the integrity of the building than to continue using the building in its original function. He gave as an example the conversion of a Renaissance palace into a modern home. This can only be done with changes which affect it more or less seriously, and which are inevitable requirements of modern life; adapting it to a Museum or cultural center, on the other hand, can be done with less sacrifice.

He also considered that the distinction between "living" monuments and "dead" monuments should be debated, for these concepts are based on an empirical approach to the problem. If one wanted to refer to a monument as "living", because it could be used, one should remember that many ruins are more alive and "usable" than many complete monuments. He proposed the statement to read thus: "That the monuments that conserve their internal spaces intact be destined to functions which will not go against the formal configuration of those spaces".

This last definition is very precise and contains the ideas that can be a starting point and orient us when we consider adapting an old adobe edifice to contemporary use.

The precautions and recommendations are not to be taken dogmatically or rigidly, because the scope of possible adaptations of a building to new use is immense and each case is a specific problem. Oftentimes, it is hard to obtain funds for the conservation of historical monuments and the possibility of giving them a practical use —in many cases— justifies an investment which would not be considered otherwise. If the fact that an old building can be adapted to contemporary use with all the necessary modern confort were understood, we could avoid the idea (held by many public officials and experts) that substituting new for old is always best.

When dealing with the conservation of historic centres, it has been confirmed that it is not only necessary to have legislation for the protection of these areas; it is also necessary to establish urban renewal plans, studying the typology of the buildings so as to propose a new function for them and introduce modern comforts without altering the traditional structures or moving the inhabitants from one neighbourhood to another.

Every day, more and more adobe, *tapia* and *quincha* buildings are lost in the historic centres of Latin America. Thus, it is urgent to establish pilot projects showing that one can, at the same time, preserve the historic past and solve the acute housing problem, present in all these countries.

Unfortunately, there is no awareness of the fact that what is happening to our monuments and historic complexes is similar to what happened in other parts of the world, where economic pressures and real-estate speculation changed the use of buildings: these became shops and later, collective dwellings which were literally hovels. When the process of social change was accelerated because productive activities became concentrated in few hands, the buildings in the central zones were demolished and substituted by new ones. This produced congestion and deteriorated the quality of urban life in these areas, once more there was a migration towards the peripheral areas. Modern centres sprung up, centred around business activities. This process takes place, with some variants, in most cities: improvisation, tolerance, the acceptance of initiatives that are merely commercial ventures, have had a sad result for the cultural and archaeological heritage. If we want to learn this lesson and avoid its repetion, we must urgently renovate old buildings for use as homes, as well as other public buildings which have become obsolete, assigning new functions to them, but always in keeping with the needs of the community.

Adapting Historic Buildings

It is interesting to analyze a precedent; that is, the contemporary use of industrial buildings of the XVIIIth and XIXth centuries. Most of these interventions were carried out in England, Germany, Italy and other countries in Europe; this was also done in the United States. In all cases, it has been very important to determine the social or cultural significance of the activity to which the building was to be adapted.

The well-known US publication, *Architectural Review* devoted one of its issues to old buildings and their adaptation to contemporary use, emphasizing the importance of this not only because of the intrinsic value of the buildings, but because their adaptation to new use can teach contemporary architects. It is true that adapting buildings of the beginning of the industrial age is easier than converting an important historic monument which, by its very nature, requires the intervention of a specialist, and limits the choice of possible new uses.

When intervening in these buildings, one must strive to maintain and respect them. This contemporary position is not new: the adaptation of buildings to new use has been done in the past. During the Renaissance, Michaelangelo adapted a great Roman edifice, the Baths of Diocletian, and converted it into the Church of Santa Maria degli Angeli. We have some examples of this in our midst: the first convent of Santa Clara, built in Cusco in 1558 was transformed in 1649 into the House of Don Jerónimo Luis de Cabrera y La Cerda, Mayor and Chief Justice of the city. This was done using the walls of the church as the façade.

In Germany and England many churches which are not used for religious services have been transformed, with the approval of the ecclesiastical hierarchy. The Anglican church studied the functions it considered appropriate for buildings not used for religious services any more; it proposed they should be used as concert-halls, libraries, social centres, exhibit halls and museums.

In Urbino, Italy, the well-known architect, Giancarlo de Carlo adapted an Agustinian convent of the XVth century which had been used as army barracks to a university facility having a library, auditorium and classrooms. The possibilities of the building were exploited to the hilt; the appearance and character of the edifice were preserved. The library, reading room and book deposit which needed large spaces were built underground, under a garden and the cloister. This solution, which required complex work, is an example of adaptation to new use, while maintaining the character and original style of the convent.

We do not want to continue using European examples. To conclude, we will cite the case of England, where rural buildings such as barns, have been adapted to music, dance and theatre centres. Thanks to the support of private British Foundations, such as the National Trust, these modest rural edificies have been saved and stand as testimonies of another age in an industrialized society.

Adaptation of Adobe Buildings to New Use

In Brazil, the National Institute for the Safeguard of the Artistic and Historic Heritage, with the support of the Programme for Historic Cities of the Planning Secretariat has established an interesting programme for the preservation of the artistic and historic heritage. Many of the monuments included are built in rammed earth and the interventions performed on them constitute interesting examples of restoration of this material.

The house of Antonio Díaz in Ouro Preto, the Intendencia in Sabará, which was transformed into the Gold Museum, and many others have been salvaged and converted into Museums. These buildings have become special tourist attractions in the circuits established in the historic cities.

In Chile, interesting restoration work has been carried out in the "haciendas" of the central valley; these constitute important examples of adobe architecture and include the plantation houses, warehouses and annexes. The Hacienda at Calera de Tango, which was owned by the Jesuits is a vast complex of horizontal buildings having a façade more than 200 metres long, as well as 10 patios. Although it had suffered modifications, today it has been restored thanks to the initiative of a philantropist. Other cases include the house at Lo Fontecilla, near Santiago, restored by a historian, and the Hacienda Lo Contador, an XVIIIth century building which houses the School of Architecture of the Pontifical Catholic University of Chile.

We could continue with other Latin American examples of adaptation of adobe buildings to new use, yet we believe it would be illustrative to comment on the buildings which the participants in the Symposium has a chance to visit, that is, the Peruvian examples.

One of the richest and most attractive homes in the Colonial architecture of Latin America was, without a doubt, the Palace of the Marquis of Torre Tagle, built in Lima at the start of the XVIIIth century. This stately home, with its Sevillian tiles, tall galleries supported by superimposed corbels, and Mudéjar arches, has been restored and serves today as the seat of the Ministry of Foreign Affairs. Another interesting example, the Casa de Oquendo, of the end of the XVIIIth century, with its five balconies and a portal as high as the house itself is presently being restored to be used by various cultural associations linked to the Instituto de Cooperación Iberoamericana.

In the city of Ayacucho, on the occasion of the 150th anniversary of the Battle of Ayacucho which put an end to Spanish colonial dominion in America, an interesting initiative was taken by the public and private banks: each one of the commercial banks acquired an ancient house. These adobe and stone houses were restored, and used as headquarters for these banks, as well as for the College of Architects.

Finally, in Cusco, a great number of Colonial adobe buildings have been adapted to contemporary use. The first intervention was the restoration of the home of the writer Inca Garcilaso de la Vega, son of a Spaniard and an Indian. The house initially was transformed into an Art Museum; today it houses the Historical Archives of Cusco.

In the framework of the Technical Assistance Programme of UNESCO and the COPESCO Plan, between 1975 and 1979 the following monuments, among others, were restored: the Jesuit College of San Bernardo, built in 1620 and probably one of the Cusco buildings which has been used successively for more functions —many of them inadequate. It was a school, the seat of the Departmental Junta in 1828; it housed the Post Office, it then became seat of the Court of Justice, and, at the turn of the century, was transformed into the seat of the Provincial Council, until the 1950 earthquake. Twenty-eight years after the quake it was restored and the old College became the headquarters of the National Institute of Culture.

Another monument restored within this same programme was the Casa del Almirante, the best example of civil architecture in the city, outstanding because of its mullioned windows and a façade crowned with two coats of arms, as well as for its coffered ceilings and a patio with arches on two levels. After restoration, part of the house was transformed into the Regional Historical Museum, while another part houses a section of the University of Cusco.

The Banco Hipotecario sponsored the restoration of the House of Fernando de Vera y Zúñiga (XVIIIth century) which, during the last century was the home of the writer Clorinda Matto. This building has valuable murals and today is the headquarters of the Bank. The Community House of Las Nazarenas, also an old adobe building, has been adapted to serve as administrative headquarters for the COPESCO Plan, while the House of the Marquis of Valleumbroso is being restored to house the Regional School of Fine Arts.

A larger adobe building, the Seminary of San Antonio Abad, is being restored to serve as hotel; this is probably the first example in the city where a building destined to this end is transformed with respect for the original edifice.

We should emphasize that many adobe buildings in the city were repaired and adapted to become hostals or small hotels. However, this was done in a very unsatisfactory manner. There are still numerous buildings of historic value in Cusco which have not been restored and have been adapted inadequately. Such is the case of the three buildings which house the Guardia Civil (Police Force); the seats of different political parties; or the many ones which, adapted in a makeshift way, are used as stores.

In the last years, inadequate adaptation of some buildings has meant irreparable loss of the cultural heritage. The House of the Marquis de Valleumbroso was occupied by a political organism, until a throng of university students set fire to it. Recently, another fire demolished a business concern, located in a large portion of a XVIIth century building.

The examples analyzed and the comments expounded have allowed us to gather information on the adaptation of adobe and rammed-earth buildings. Valid conclusions may be reached and applied to the different contexts where adaptation of old buildings to new use is sought.

Adaptation of Adobe Constructions to New Use

[illegible] historic heritage. [illegible] built in rammed earth and the interventions performed on them constitute interesting examples of [illegible] [illegible] and others which have been [illegible] converted into Museums. These buildings have become special tourist attractions in the circuits established in the historic cities.

In Chile, interesting restoration work has been carried out in the "haciendas" of the central valley; these constitute important examples of adobe architecture and include the plantation houses, warehouses and annexes. The Hacienda at Calera de Tango, which was owned by the Jesuits is a vast complex of horizontal buildings having a façade more than 200 metres long, as well as 10 patios. Although it had suffered modifications, today it has been restored thanks to the initiative of a philanthropist. Other cases include the house at [illegible], near Santiago, restored by a historian, and the Hacienda Lo Contador, an XVIIIth century building which houses the School of Architecture of the Pontifical Catholic University of Chile.

We could continue with other Latin American examples of adaptation of adobe buildings to new use, yet we believe it would be illustrative to comment on the buildings which the participants in the Symposium has a chance to visit, that is, the Peruvian examples.

One of the richest and most attractive homes in the Colonial architecture of Latin America was, without a doubt, the Palace of the Marquis of Torre Tagle, built [illegible]

[illegible] these banks, as well as for the [illegible] [illegible] home of the writer Inca Garcilaso de la Vega, son of a Spaniard and an Indian. The house initially was transformed into an Art Museum; today it houses the Historical Archives of Cusco.

In the framework of the "Technical Assistance Programme" of UNESCO and the COPESCO Plan, between 1975 and 1979 the following monuments, among others, were restored: the Jesuit College of San Bernardo, built in [illegible] and probably one of the Cusco buildings which has been used successively for more functions —many of them inadequate. It was a school, the seat of the Departmental Junta in 1828; it housed the Post Office; it later became seat of the Court of Justice, and, at the [illegible] of the century, was transformed into the seat of the Provincial Council, until the 1950 earthquake. [illegible] years after the quake it was restored and the old College became the headquarters of the National Institute of Culture.

Another monument restored within this same programme was the Casa del Almirante, the best example of civil architecture in the city, outstanding because of its mullioned windows and a façade crowned with two coats of arms, as well as for its coffered ceilings and a patio with arches on two levels. After resto-

Protection and Conservation of Adobe Historic Complexes

Jacques Verité

1. Historic Complexes and Building Materials

In order to identify the place of earth as a building material in historic complexes, the different architectures, technologies and the material itself must be considered.

These differences depend:

—*for the architectural styles*: on environmental factors, such as climate, topography, nature of the terrain, materials available; on the degree of technical development reached by a society; on social and cultural factors — but, above all "without falling into a linear evolutionism. . . one must consider the habitat in relation to the development of the productive forces of a given society and to the growing complexity of its organization" (1).

—*for the building technology*: on the various existing possibilities. There are houses covered with earth or excavated in it. Trogloditic houses; "quincha" (wattle and daub); layers of plastic mud (*barroca* in Brazil); *champas* (Argentina); mud shells (*tijuco* in Brazil); layers of mud placed on rush-matting; hand-made adobes, moulded adobes, rammed blocks and compressed earth (*tapia, adobón*) are also used.

—*for the material itself*: on the nature of the soil used and its transformations (added materials and clay stabilizers).

This general level, however, is not sufficient to explain the variety existing whenever earth is used in historic complexes. Following the methods applied by linguists in the study of the vernacular tongues and dialects, we will try to determine specific rules. It is essential, in order to do this, to emphasize the rupture between the vernacular and the modern (2).

Vernacular Architectures

Vernacular architectures are defined as "habitats conceived and produced in and for specific place and culture" (3). At a given moment, these have a unity within a geographic space: they constitute an area.

a. *Areas*

The regional variations, differences and specific forms define the architectural areas. In Peru, we can define architectural areas following two axes: along the coast, variations can be observed from valley to valley; within one valley, perpendicular to the coast, variations are also visible.

b. *Limits and Transition Zones*

Actually, these areas are crossed over by different architectures, technologies and building materials, so that their limits become relative. This leads us to define transition zones.

—the different areas may be crossed over by similarities linked to the geography and the possibility of contacts. But the similarity depends on the criteria used when identifying the different forms of Pre-Hispanic adobes found in Peru, we find a common element in the technology employed: they are all hand-made (4).
—In an area, similar architectures are built with different materials and differing technologies: throughout 6000 years of history, the unity of the Chilca valley cannot be identified either by the manner of building or by the changes in materials (5).
—The evolutions or regressions, due to the intervention of specialists or to a type of building of a particular status, lead to unclassifiable variations. In the Southeast of France, for example, in a zone 5 km. around the town of Viozan, there is a style of building where adobe and small stones are used in a chessboard pattern; it is unique in its kind.
—Finally, even in societies where writing is unknown, the cultural exchanges produce a unity in diversity: the Tiahuanaco or Inca horizons have a unitarian influence, identifiable in the regional variants with which they coexist or on which they are superimposed.

The Strata: "Culture" Architecture and Vernacular Architecture

"Culture" architecture is defined as the architecture transmitted and taught by written documents.

a. *The role of "culture" architecture*

"Culture" architecture is applied to monuments in the first place; it intervenes in the modification of the architecture, the technology and the nature of the building materials. The research undertaken by architects against earthquakes in Latin America is an example of this: "Soon after the earthquakes of 1606 and 1609, a council of architects decided to change the roof of the Lima cathedral, which was originally a barrel vault with arris domes substituting it by ojival-style vaults. In 1639, Vasconcellos adopted... a system of vaults... made of *quincha* or bahareque. Quincha is an ingenious system, using wood and straw with mud, which was employed to build the arches. It is a very lightweight ensemble and acts very flexibly in the vibrations produced by earthquakes" (6).

b. *The knowledge of "culture" architecture*

"Culture" architecture can be transmitted and superimposed on vernacular techniques. Thus, for *quincha:* "this innovative system became popular in the 17th century in the Peruvian coast and the south of Ecuador. We can state that few houses or buildings of the Colonial period or the 19th century remain today in the coastal region which did not use this system" (6).

But the propagation of "culture" architectures is also subject to variations:

—if the process is slow, the technical advances or local practices create particular types.
—the different social groups integrate innovations differently. Vernacular architecture can coexist with "culture" architecture.

These phenomena were described by Tschudi when he visited Lima in 1839 and 1842: "the manner of building the houses... may be considered typical, although there are variations. The walls of the large buildings are either adobe or brick; those of the small houses are merely cane, covered with mud and then painted (7).

c. *The feed-back effects*

Feed-back effects take place between vernacular architecture and "culture" architecture. The example of Latin America is characteristic, for here "the ideas, forms, models and even artists transplanted had to adapt themselves to the conditions of the "new world" (6). It is for this reason, for instance, that —during Colonial times— there were differences in the size of the adobes: "In the highlands, blocks 41 to 61 cm. long and 19 to 30 cm. high are used; on the coast smaller dimensions are used" (4).

Conclusion: Architectures of the Past

The architectural complexes of the part are characterized in this analysis by:

—Areas with imprecise limits, crossed over by elements of unity and variations.
—A stratification of architectures, techniques and materials, some of wich still survive today.

Modernism and Remnants

a. *The change in the XIXth century*

We will not discuss the changes brought about by the industrial revolution, but will only examine three aspects:

—*The transportation of materials*: this brought about a modification in the act of building, caused by technical progress. A characteristic example is the action taken by Haussmann in Paris: he was the first to have available the technical means to destroy the wood and mud city which was Paris at the beginning of the XIXth century.
—*Contemporary binders*: artificial hydraulic lime and cement are also a result of technical progress. Contrary to the older binders, these have a positive capacity to resist traction.
—*Technologies and architectures*: changed slowly until the end of the Second World War, when concrete and cement blocks began to be widely used. During this transitional phase, earth as a building material disappeared but some of its technology survived: in France, we find compressed blocks made of slag and lime, as well as concrete made of lime and cement, using the system of moulded earth.

b. *Today: earth in the historic complexes*

The contemporary position of earth as a building material is defined by two extreme situations:

—buildings made of earth have been destroyed.
—the practice (techniques) of building with earth still survive. In this case, this produces a new vernacular stratification whose variations are the following:

- the composition of the material is modified, because the old stabilizers and additives are not used. (The material is thus deficient, if compared to the older one). Sometimes, the old additives and stabilizers are substituted by modern binders (laterite/lime or soil/cement).
- the techniques are modified because of economic reasons (the required time for mixing or drying is not observed).
- the architecture and the organization space are modified: an effect of feed-back has taken place with the prevalent architectural and urban styles. They reflect a new social organization.

—Between these two extremes, the position of earth as a building material is very variable. There are historic complexes where earth continues to be predominant. But, often, these are only remnants (let us bear in mind that these are stratifications).
This earthen heritage is in danger of being destroyed, but we must equally stress that any interventions in the constructed space in the historic complexes has both negative and positive consequences:
- the actions leading to modification and repair of the habitats contribute to the destruction of the remnants, but the new constructions, built over old earthen houses,

or the use of new plasters are ways of conserving earth.
- the actions taken by the specialists in restoration who work in the monuments included in the historic complexes participate of certain new fashion or styles, whose effects can be either positive or negative for the conservation of the stratitifations of the material earth. (For example: the restorations of the Alhambra in Granada).

Conclusion

Within an architectural area, earth is identifiable across the variations in the material, the techniques used, the architecture and the organization of space.

It is only within a stratification that there is unity and we have found the following:

—pre-industrial types:

- dominant vernacular
- "culture" models (sometimes superimposed)
- "culture" vernacular (which integrates into the vernacular elements of the "culture" models)
- "culture" model/vernacular (which integrates into the "culture" models elements of the vernacular)
- dominant popular (with some traces of the "culture" models)
- popular/vernacular (found in the edges of the urban sites)

—modern types:

- one or several vernacular modern types, identifiable depending on the social groups and the proportion of modern materials used.

2. The Problems of Conservation

We must act not only on a material, but on the superimposed or mixed imprints of different cultures.

Technical Difficulties

a. *The basic problem: the characteristics of earth as a building material*

—The transformation of soil into a building material is difficult, due to the characteristics of the soil components and to the nature of the binder, clay: earth is a material with a weak resistance to traction.

—building with earth is expensive.

—its thermophysical characteristics are nothing special.

b. *Actions on stratifications and remnants*

Stratifications and residues are sometimes hard to identify, and are often justifiably destroyed during restoration operations undertaken in "buildings" with no historic or architectural value" (UNESCO recommendation).

c. *Scientific conservation*

The conservation of historic complexes is not a scientific act; this is stated in the same UNESCO recommendation which says: "Restoration works *should* be founded on scientific bases... More attention should be given to the harmony and aesthetic emotion which arise from... the different elements present in the complexes..." (the use of the conditional is a confession: harmony and aesthetic emotion are social values, essentially variable).

Ideological Difficulties

a. *The importance of modernism*

The products and the incidences of a dominant modernism (real-estate speculation, hygiene, materials market, loss of technical know-how) are all partly the cause of the disappearance of the earthen heritage, be it directly (by destruction) or indirectly (by disdain).

b. *The dangers of nostalgia*

The opposite attitude is also very dangerous. By idealizing the past, generally limited to one of its cultural stratifications, nostalgia can destroy as much as modernism (for example, the reconstruction of Cusco after the 1950 earthquake). The remnants (remains) become folklore, because appearance is preferred to substance.

c. *The attitude of the restorer*

The restorer, whether he wishes it or not, is influenced by these ideologies for his action is not scientific. A. Stevens, for example, uses erroneous judgement when writing on the condition of the roofs of the Palaces at Abomey (Benin):

1. "The old roof, made of aluminum sheets. . .
Integration: colour, when oxidized, is similar to that of the ground; . . . a foreign material.
2. The new roof made of aluminum sheets.
Integration: none" (8).

Are metal sheets in Africa —and elsewhere— foreign or vernacular? Must a roof be "integrated?".

3. Possible Solutions for the Protection and Conservation of Earth

Earth in Rural Architectures

In the "Seminar on the Conservation of the African Heritage" held in 1982, the working group on conservation of the rural architectures arrived at these conclusions:

". . . what must not be done:

—transportation of whole houses to the city. . .
—conservation aimed at tourism, without regard for the opinion and real interests of the population. . .

It would be more reasonable to foresee different practices in regard conservation — and especially:

—to preserve *in situ* whenever possible, which implies a policy of adapting these complexes or centres to a new use.
—to substitute using documents . . . this will allow conservation . . . at least in memory.
—in some exceptional cases, especially for structures which are obsolete, one might consider a more classical *in situ* conservation of some specimens, eventually changing their function" (9).

The limits in these propositions show that earth in the rural architecture stands between disappearance or the museum.

Earth in the Urban World

a. *Monuments*

The solution for protection and conservation, and, in particular the use of appropriate tenhnologies have been considered in this Symposium.

b. *Speculation in the urban context*

Because nostalgia revalues ancient things, people with the necessary financial means try appropriate parts of the historical complexes.

Protection should be carried out:

—by legal action.
—by example. This example should come from the specialists and should be transmitted, above all, to the actors (architects, enterprises, administration). We will cite as an example action taken by architect C. Sánchez Gómez in Granada and we will emphasize the role that private enterprises or associations can play.

c. *The degraded urban context*

Two examples, two solutions:
—In Tunis, small teams of workers financed by the Town Council and directed by architects-restorers are responsible for maintaining the visible parts of the habitats. Owners and tenants are also urged to revalue their homes.
—In the Abaicín in Granada, urban planners and municipal architects, together with representatives of neighbourhood organization have acted together. A strong and responsible community can act effectively in protecting and conserving its heritage — even if the risk of creating a new stratification (vernacular/modern/restored) exists.

4. Conclusion

Earth disappers more rapidly in the historic complexes than the rest of the cultural heritage, which we all know slowly disappears day by day. We will be aware of the importance of its conservation if we try to imagine its future — which will possibly be very similar to that of the French vernacular habitat (a large part of which is built with earth): "Probably, in the year 2000, the number of persons who will enter into ancient residences will be one percent (of the French population). It is not only a technical or financial problem, nor is it related to building permits: it is a problem of society". (10).

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Conclusions

— This Symposium dealt with the topic of adobe conservation; monetheless, it also considered, in a global manner, all architecture made of earth, be it archaeological, historical or contemporary, partially or totally built with this material.

— Inasmuch as adobe is a material that has been continuously used throughout time, different cultures have been able to perfect their techniques, giving rise to specific building methods which constitute a living testimony of the history of different nations.

Architecture made of earth, supported by the use of local materials, lead to the definition of direct and unmistakable forms based fundamentally on functional demands and lifestyles implicating, oftentimes, traditional, social and religious aspects of shared life and beliefs.

— There are towns and cities which, due to their geographic location, economic and technological development and availability of labor and regional materials, have no other alternative but to use unbaked earth in the construction of their buildings and dwellings.

The use of this material identifies and characterizes the urban landscape man and his city — creating a harmony with the surrounding environment, be it natural or built by the hand of man.

It is necessary, therefore, before any intervention, to know the cultural characteristics of the different peoples, in order to avoid confrontation with the preexisting culture.

Historical monuments and, in a general way, adobe buildings have suffered severe damage due to the rigors of weather, natural disasters and man himself. The disadvantages associated with this behaviour are being overcome, thanks to the research developed in recent years.

Recommendations

— Upon analysis of the use and techniques of unbaked earth in construction in the Latin American area, specifically, it was the general consensus of the participants in this Symposium that the concepts which transpired are applicable generally throughout the world and especially in developing nations.

— It was not the task of this Symposium to call into question the Venice Charter or any other document drawn up by governmental or non-governmental conventions whose principles have been internationally accepted, but to enrich them with a particular chapter devoted to earthen architecture.

Hence, it is necessary to perform complementary studies on the topic of adobe and its conservation under the sponsorship of UNESCO, ICCROM, ICOMOS and other specialized bodies.

— These studies/documents should compile data, among others, on the uses, techniques and typology of existing edifices and cities built in mudbrick, according to the historical, social, cultural and economic reality of each area.

With a view to establishing these studies, the organization of regional and sub-regional networks of specialists should be considered. These experts should set up an interdisciplinary, geographically well-represented team. It was suggested that ICCROM, UNESCO and UNDP, through pertinent channels, make the necessary arrangements in order to carry out this work.

The output of these studies should be compiled within two years at ICCROM and would become part of the existing data bank.

These studies shall prove extremely useful, especially in training courses given at ICCROM or at other national, regional or international institutions which deal with the conservation of adobe and other materials made of mud and unbaked earth.

— In the case of intervention in architectural works made of earth, the architectonical language *must* be taken into account, including the original structure, the nature of materials, techniques employed and the historical period of construction. The original architectonic intention must be maintained and respected with simplicity and sensibility.

— Because historic centres built in adobe are the product of a society, they should be valued and protected as the patrimonial legacy of the human group which created them. They are the cultural heritage of the inhabitants and should be considered as living urban organisms, whose significance remains in force in contemporary life.

— Knowledge of the values of the cultural tradition will guarantee the harmonious development of the cities and their inhabitants.

In keeping with the rapid development of present times, urban dynamics and local technologies must be taken into account when planning and designing the development of historic cities built of mudbrick.

— The problem of slums in historic centres should be viewed not only as a problem of design, but as a social problem as well. The solution of economic and maintenance problems is critical in order to erradicate it. Hence, in the case of protection of cities, experiments are proposed, which will encourage self-help in construction, with international technical assistance. Special attention should be given to maintenance; this should be done using preferably the same techniques employed in the original construction and homegeneous materials.

— With regard to archaeological sites built with earth, it is recommended that a detailed inventory be established in collaboration with agencies such as UNESCO, so that governments and specialists may program their research, restoration and maintenance activities.

— In relation to the preservation, conservation and restoration of the historical sites, it is recommended that a group of experts establish the criteria to be adopted, taking into account the interests and the knowledge of the community itself, since the community is heir to the original tradition.

This should be reflected, as well, in accompanying architecture, which must take into account the popular know-how of the region.

Likewise, the use of traditional techniques, where they are still known, is recommended for completion or repair of ancient edifices, thus ensuring the survival of expertise in the use of analogous techniques and materials.

Governments should give special emphasis and interest to the preservation of historical evidences made of mud in order to ensure their survival as the cultural heritage of future generations. This should be done with support from regional and local legislation which will guarantee its application. Special tax exemptions and economic incentives should be given to those who maintain these buildings.

— Historic centres should reflect and genuinely express the life of the society which inhabits them, and not be merely "scenery for tourists".

— It is recommended that international credit organizations, as well as national, state and private ones, allot special funds for the restoration, conservation and preservation of cities, buildings and dwellings made of mudbrick.

— One must bear in mind that adobe buildings, owing to their specific construction quality, are not adaptable to any new use. Hence, careful study should be given to any foreseen changes, taking into consideration suitable structural and functional adaptation.

— Knowing that the installations will become obsolete long before the structure itself, the Symposium recommends that in projects designed to give a new use to mudbrick buildings, the mechanical fittings and installations be incorporated in a totally reversible manner.

— It is specially recommended to study the adaptation of mudbrick buildings for housing, thus ensuring their survival and, consequently, that of the historic centre.

— Taking into account the acute housing shortage felt throughout the world, it is recommended to promote earth architecture, given its proven economic and climatic advantages, incorporating technical advances only when necessary. To this effect, it is recommended to carry out studies on the functional characteristics of adobe housing, taking into account technical, economic and social aspects.

— Bearing in mind the need to eliminate prejudice linked to the use of this material, the Symposium recommends a massive dissemination of the qualities that can be attained, so that mud architecture continues to be used not only by lower-income groups but by all sectors of society.

— Adobe structures used in monuments and historic sites should be studied with the purpose of safeguarding them against earthquakes and other natural disasters, taking advantage of the latest technology and research developed in this area.

— Studies on the construction and restoration of presently-damaged monuments located in seismic regions should include a complete seismic analysis of the edifices, leading to the interpretation of causes of faults and potential damage. This, in turn, should encourage repair projects which will avoid such damage in the future.

Competent agencies should channel all preventive actions in order to ensure that specialists will be in charge of rescue and restoration operations in the case of disasters.

Due note was taken of the work being carried out in areas affected by natural disasters, such as Popayan, Colombia (earthquake) and the north of Peru (floods).

The Symposium recommended taking into account the conclusions and recommendations of the Seminar on the Protection of Historic Monuments in Seismic Areas organized by UNESCO/UNDP, UNDRO, ICOMOS and the OAS in La Antigua, Guatemala and published by the UNDP/UNESCO Regional Project on Cultural Heritage, as well as the establishement and publication of studies on the protection of adobe monuments, historic centres and buildings located in seismic areas.

— When intervening in the structural reinforcement of monuments all possibilities of using the same materials and/or traditional techniques should be exhausted before employing other materials, foreign to adobe.

— Bearing in mind the specific problems of painted surfaces on adobe wall's and the need to improve preservation techniques, it is recommended that a pilot project be established for study, experiment and training of personnel specialized in the conservation of these paintings in a country possessing a rich heritage of said paintings and especially trained personnel. For the purpose of continuing work initiated in this field in Peru, it is recommended that this project of studies and training be established in Peru with the support of UNESCO and ICCROM.

— An international study-group shall assess, within two or three years, the results of this program and arrive at relevant conclusions.

— Universities and higher-learning centres should place particular emphasis on training and both experimental and *in situ* research, seeking to improve the qualities of the material. Special efforts should first be made to reinstate traditional techniques, and then to study the possibility of incorporating recent technical developments, in keeping with economic, social and cultural characteristics.

— It is recommended that intensive courses on adobe conservation be given at existing training centres (such as universities) and that this topic be included in national, regional and international courses on restoration and conservation of monuments and historic sites.

— Training relative to the technology of the material should also include middle-level professionals and, primarily, the social groups who build their own buildings using traditional know-how.

— These studies should be published and made available to professionals in order that they be applied both in conservation and in the construction of new edifices. For this reason, the Symposium recommends to continue holding periodical specialized meetings.

It is recommended that the working papers presented at the Symposium, enhanced by the lecturers and discussions, be included in a special publication to be distributed worldwide by the organizers of this meeting, i.e. UNDP, UNESCO and ICCROM. It is also recommended that UNESCO publish didactic material (in the form of booklets, exhibits and audiovisual aids) on the history and conservation of adobe. For this purpose, private and public, national and international financial support should be sought.

— The conclusions and recommendations herein stated engage the participants in this Symposium to follow them henceforward, and to enrich and divulge them in their respective countries, so that earth architecture may occupy the place it deserves in the context of the Cultural Heritage of Mankind.

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