SUMMARY REPORT

PROJECT TERRA RESEARCH MEETING

May 14, 2000

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INTRODUCTION

In November 1997, following their collaboration on PAT96 (the first Pan-American Course on the Conservation and Management of Earthen Architectural and Archaeological Heritage), the International Centre for Earth Construction–School of Architecture of Grenoble (CRATerre-EAG), the Getty Conservation Institute (GCI), and the International Centre for the Study of the Preservation and the Restoration of Cultural Property (ICCROM) initiated discussions to establish a joint program in the study and conservation of earthen architecture. These organizations recognized—through their independent and collective activities in earthen architecture conservation—that the most successful means of leveraging resources and developing the field was through partnership. Having a long history of involvement in the field, these institutions created a new, cooperative framework to pursue this work : Project Terra.

The overall objective of Project Terra is to develop the conservation of earthen architectural heritage—as a science, a field of study, a professional practice, and a social endeavor—through institutional cooperation in the areas of education, research, planning and implementation, and advocacy.

An important focus in the past two years has been the education component of Project Terra. Through the development of PAT99 and the inauguration of the Terra Consortium and the Unesco Chair for Earthen Architecture at CRATerre-EAG, a strong foundation has been established for promoting the conservation of earthen architecture as a field of study.

The research component of Terra has also been developing over the past couple of years, building momentum for more concentrated effort in 2000 and beyond. In 1998, a Research Survey was undertaken as a follow-up to the Gaia Research Index of 1989. The Survey polled scientists and practitioners about perceived research needs in the field and endeavored to identify current research initiatives. In 1999, a review of the research literature began under the auspices of Terra, to determine through the literature the trends and gaps in earthen architecture conservation research in the past 15 to 20 years. Hubert Guillaud of CRATerre-EAG undertook an initial review, and in the next phase we will bring in additional colleagues from the field to elaborate the various themes and topics. This multi-phase effort will be compiled and synthesized, and the literature review is scheduled to be completed in 2001.

The Terra partners recognize the challenges posed by the rather limited research base for earthen architecture and its conservation, in particular research regarding the behavior of earthen materials, components, and structures. We believe that improved understanding of why and how earthen architecture deteriorates will enable the field to make better conservation decisions in the long-term and ultimately help to establish the conservation of earthen architecture as a "science." The Terra partners have therefore attempted to foster a dialogue amongst colleagues in the field about potential areas of investigation.

On May 14, 2000, the Terra Partners, in cooperation with English Heritage, hosted a meeting to discuss research needs in the field of earthen architecture conservation, as a post-conference activity of the Terra 2000 conference. The overall aim of the meeting was to formulate a set of research priorities in the field of earthen architecture conservation in order to:

- encourage individuals and institutions (both from within the field and in allied disciplines) to undertake needed research; and
- promote and facilitate cooperation amongst individuals and institutions in such research;
- explore possibilities for research collaboration amongst the Terra partners and colleagues in the field.

Eighteen colleagues from the field of earthen architecture conservation and allied fields, including scientists, architects, engineers, conservators, and other professionals, participated in the one-day meeting (see Appendix A). The meeting was preceded by a 6-week, on-line discussion with colleagues around the world, as well as by exchanges during the development of the PAT99 course in Trujillo, the 1998 Terra Research Survey, and the initial review of the literature. These efforts attempted to foster brainstorming about research needs before gathering a group together around a table. The questions raised during the on-line discussion and ancillary activities were clustered in themes; these themes then served as the basis for the meeting agenda (see Appendix B).

This report summarizes the discussions that occurred with regard to each of the research themes, as well as the priorities that were recommended by the participants at the end of the day's meeting. It is hoped that this report will prove useful in fostering continued discussion about research needs, as well as encourage individuals and institutions to take on some of these research issues.

RESEARCH ISSUES AND DISCUSSIONS

A 6-week on-line discussion in advance of the meeting served to generate research ideas and issues concerning earthen architecture conservation. The topics and queries that emerged from the discussion were summarized as a series of questions and grouped thematically, as follows:

Theme 1:	Classification, Binding, and Un-Binding
Theme 2:	Non-Structural Decay or Evolution
Theme 3:	Structural Decay
Theme 4:	Chemical Interventions
Theme 5:	Physical Interventions
Theme 6:	Continued Use

The meeting provided an opportunity to flesh out the themes and questions with a group of colleagues from a variety of fields. The themes provided a structure for the day's discussion, and the questions related to each theme were explored with an eye toward the following:

- Will understanding of the issue/question help to advance conservation practice?
- Is the knowledge available in other disciplines, such that it can be adapted and applied to the needs of earthen architecture conservation? And/or is new research required?
- What is the nature of the research? (where can information be accessed, who is working in this area, what tools would be required for the research, is desk and/or lab investigation required, etc.)

Of course, examination of the themes and questions from these perspectives generated many ideas and additional questions related to earthen architecture conservation. To capture the various ideas and exchanges that occurred during the day, a facilitation technique was employed whereby comments were noted on cards that were then pinned up on boards (see Figures 1 & 2). This served to record as well as focus the discussions, and also allowed the group to review their collective ideas at the end of the day and identify priority issues (see Figures 3 & 4).

Figure 1

Figure 2

Figure 3

Figure 4

The following provides a summary, in brief, of the discussions related to each theme, along with a listing of the initial questions.

Theme 1: Classification, Binding, Un-binding

Initial questions:

1.1 Could/should a new classification system for earthen materials be developed to suit the specificity of earthen architecture?

1.2 Could/should a new classification system for clay materials be developed to suit the specificity of earthen architecture.

1.3 What are the exact binding forces that keep earthen building materials and structures together?

1.4 On the molecular level, what are the effects of the electrochemical processes within and around the clay particles?

1.5 What is the nature of the binding forces at work between the "inert aggregates" of the earthen material and the "mortar"?

1.6 Around which particle diameter is the frontier between the "inert aggregates" part of an earthen building material and its "binding part" (the “mortar” that keeps the inert aggregates together) situated?

1.7 In the “mortar part,” at which particle diameter is the frontier between the finer inert aggregates and the specific "natural binder" part situated?

1.8 What is the exact nature of the binding forces at work at the interface between "inert aggregates" and "active natural binders"?

1.9 What is the nature of "natural stabilizing agents” (e.g. carbonates) present in the raw material and by what mechanisms do they contribute to stabilization?

1.10 To what extent do/might organic materials and bacteria act as binding agents?

1.11 What is the exact role of water - in whatever form - for what concerns the maintenance of the internal cohesion of the material?

1.12 Which factors influence and change the physical - chemical matrix, negatively or positively impacting existing binding forces?

1.13 Is it possible that loss of cohesion is a result of the dissolution of the finer active binding particles of the "mortar part" of the original material?

1.14 Is it possible that loss of cohesion is a result of the washing away over time of the finer active binding particles of the "mortar part"?

An initial review of the above questions resulted in two distinct conversations: one related to classification and the other to binding and un-binding.

With regard to classification, practitioners and researchers in earthen architecture conservation have traditionally drawn their analytical tools from a number of other disciplines involved with the subject of earth, including pedology, soil science, rock mechanics, mineralogy, agriculture, civil engineering, ceramics, etc. The classification methods of these disciplines have been devised for their specific use and objectives. Though the existing classification systems for clays are adequate for earthen architecture purposes, the existing soil classification systems are not sufficiently applicable to earth as a material in construction and conservation. For example, the AASHO[1] and USCS[2] soil classification systems, as well as the European systems, have groupings and subdivisions oriented toward the performance of earthen materials in engineering applications, such as earthworks, road beds, etc. In these classifications, the emphasis is on the gravely and sandy part of soil because, in roadwork or "horizontal structures," the most important element is the rigid skeleton. The performance required of earthen materials in architectural applications is quite different. Earthen architecture involves a more vertical application, and clay content is required for gravel and sand cohesion. For this reason, when the AASHO or USCS systems are used to characterize earthen construction materials, one finds that approximately 80% of the soils used for earthen architecture can be classified within one or two subdivisions. This lack of detail and distinction between building soils means that the current soil classification systems cannot yield the data needed to inform earthen construction and conservation decision-making.

A similar challenge is faced by those dealing with stone conservation. Many of the existing classification systems for stone are derived from geology and other disciplines, and often are not oriented toward building stones and their applications.

In order to advance the field, a classification system more appropriate to earthen architecture and its conservation is necessary. Through communication with other disciplines facing similar challenges, such as those dealing with stone conservation, as well as through collaboration with other disciplines associated with earth, such as soil scientists, pedologists, etc., this could be achieved. It is likely that the most efficient way to address this need would be to expand on existing systems by enlarging the necessary subdivisions rather than to elaborate a new system. Compatibility with the Eurocode would be an additional asset.

Because such an expanded classification would be for use in new earthen construction as well as conservation, the classification should be applicable to both fresh and aged materials. In the latter case, systematic efforts could be developed to classify different types of soils based on their condition or the weathering processes they have gone through.

With regard to binding and un-binding, a discussion of the initial questions resulted in some consolidation and elimination of questions. The two key questions were identified as 1.3 and 1.11, concerning the binding forces in earthen materials and structures and the role of water in that cohesive system, respectively. Several questions were seen as being derived from these (including 1.5, 1.7, 1.8, and 1.12), while others were eliminated as being secondary or not related (including 1.4, 1.6, 1.9, 1.10, 1.13, and 1.14).

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[1] Classification system of the American Association of State Highway Officials (AASHO).

[2] Unified Soil Classification System (USCS). This system was developed by the U.S. Army Corps of Engineers and adopted by the U.S. Department of Defense.

To understand the binding and un-binding mechanisms of earthen materials, knowledge from such fields as geo-technics and rock mechanics cannot be directly transposed. These applications usually imply the use of water-saturated earthen materials or of partially saturated soils (90% to 100% saturation), whereas for earthen architecture no more than 2% to 7 % of water is present in the building material. Most research has been project-specific, resulting in problem-solving for particular situations, but not yielding general, fundamental knowledge transferable to other disciplines. However, such fields should be investigated, in particular saturated soil mechanics as it may inform our understanding of what is going on during the manufacturing process of earthen products (wall, blocks, mortars, etc.).

Similarly, little research in clay mineralogy has addressed behavior of materials in “dense” milieus. The several binding forces at work and the resulting properties in emulsions and in dense milieus are, it seems, very different. It is clear that the exact binding mechanisms at work in the clay part of earthen building materials, which theoretically guarantee their cohesion, are not really identified. With regard to earthen materials in architectural applications, the relative parts of electromagnetic forces, ion exchange potential, friction, capillary forces, and microbiological effects, have not been definitively established, neither on the micron level (clay particle size fraction) nor at the millimeter scale between the binder part and the inert aggregates. Comparative studies between historic materials and new materials should be conducted and could yield enlightening results in this regard.

Ultimately, understanding how and why the constituents of earthen construction materials bind together is fundamental to advancing knowledge in the diagnosis and conservation of earthen architecture.

Theme 2: Non-Structural Decay or Evolution

Initial questions:

2.1 What is the influence of direct environmental (earthen) material on unexcavated structures over long burial periods?

2.2 What is the role of salts and what are the detailed mechanisms by which they act on earthen materials?

2.3 Is there a salt / flora relationship that could explain the absence of flora when salt is present in the structure?

2.4 Does organic material decay over time in earthen materials when the structures are protected from water infiltration?

2.5 What effect does the presence of micro organisms and bacteria have on the decay and evolution of materials?

2.6 How exactly (what are the mechanisms) is the cohesion of the material affected by a water surplus?

2.7 Is it possible that under special conditions the cohesion of the material is affected by a deficit of water molecules?

The issue of un-binding, raised in Theme 1, was fleshed out in greater detail as part of the discussions in Theme 2, particularly in relation to the role of water in the un-binding or decay process.

The macro-mechanisms of decay (structural decay) are relatively well known, but the micro0-mechanisms (non-structural decay) that trigger the failure of the physical-chemical matrix are still the subject of speculation. These mechanisms involve a range of external factors, including liquids, salts, wetting and drying cycles, etc. But they likely also involve micro and macro organisms that seem to use the substrate as part of food chains.

A highlighted factor that probably plays a significant role in non-structural decay is suction. It is observed that, up to a certain point, earthen materials can "recover," or regain cohesion, but the criteria that determine the exact point of irreversibility are unknown. Useful information on this subject might be gained from existing research conducted by the nuclear power industry on the subject of the interaction between disposed nuclear waste and the clays in burial sites, though such research generally deals with mostly pure clays. All the same, the bases of these experiments are also related to partially saturated soil mechanics.

Ultimately, water seems to play a critical, yet not well understood, role in the decay or un-binding of earthen materials. Historically, water has been regarded as a threat or negative force in the conservation of earthen architecture, through capillary (absorbed) water as well as hygroscopic (adsorbed) water from the atmosphere. However, water also contributes to the cohesion of the material, a positive effect that is largely overlooked, certainly from a quantitative point of view; and water may likewise be an origin of the suction phenomenon. The influence on both decay and cohesion of the presence or absence of water in different forms, such as relative humidity, vapor, snow and ice, is qualitatively acknowledged but quantitative data are largely lacking.

Though moisture transport is understood for well-bonded materials, the kinetics -- absorption, adsorption, and migration -- of moisture (and salt) transportation on the surface and in the bulk material, in relation to the pore structure of earthen building materials, are close to unknown. Likewise, the resulting cause/effect relationship vis-à-vis decay and/or reinforcement is neither modeled nor quantified, from either a static point of view or a cyclic point of view.

In addition, from the perspective of testing, the measuring of the exact water content at the very low levels present in earthen building materials is very problematic, as existing methods do not prove to be adequate/accurate, the main reason being that in "dry" structures, water content is not uniform.

The discussion of the role of water in un-binding/decay eventually led to a debate about the real role of salts. Though many studies have been done with regard to salts in stone conservation, it seems that the knowledge is not readily transferable.

What is clearly observed, however, is that the activities of salts are intimately linked to the presence or absence of water in earthen materials. Salts may act as a positive element, as there are indicators that salts may have a binding or at least an improved binding effect. To that extent, ion exchange could be very important. More information on this issue could possibly be drawn from agriculture. The influence of salts on the pH and the colloidal properties of soils have not been quantified. Salts could, it seems, also act as environmental buffers / inhibitors, and also prevent, though as well promote, the development of vegetal/plant growth. There seem also to be relationships between salts and micro organisms, which might in turn affect the decay of earthen architecture, as well as the health of human occupants in earthen buildings. On this subject, measurement of "total" suction (due to pure water and to salts) may be a good indicator.

The negative effects of salts are visually more obvious but certainly not better understood. Whether decay due to salts is only a surface problem or rather a mass problem is still uncertain. Questions also remain concerning the initial amounts of salts present in archeological materials, and their ensuing role in decay post-excavation.

In addition to salts, the role or organic material was closely tied to that of water. The negative role of the presence of organic material in earthen structures is understood up to a certain point. Many creatures (animals, insects, etc.) prefer wet soils, decaying roots become a food source (food chain issue) and create voids in the material, and many insects and organisms (such as lichens, bees, and termites) seem to "feel at home" on and in the material. But information /

knowledge is lacking for what concerns the positive role of organic material, such as its contribution to cohesion. Also the effects of certain conservation practices, like the use of pesticides and biocides, is not fully understood vis-à-vis the role of organic materials.

An issue that spanned both the non-structural and structural decay themes was that of earthen architecture in archaeological contexts. We do not seem to know enough about the effects of excavation on structures that have been buried for long periods of time. The consequences of mechanical interventions (e.g. digging, the scraping or brushing of surfaces, etc.), changes in environmental conditions (e.g. dramatic change in relative humidity, temperature, light, rain, wind, etc.), and changes in structural loading conditions (through the removal of fill) are not quantified. This lack of knowledge becomes even more problematic when it comes to reburial, as well as possible re-excavation for monitoring, conservation treatment, or presentation. Specific concerns include:

- the complexity of the system of strata/layers, which may result in ionic exchanges that are extremely difficult to control,
- the difficulty of *in situ* measurements and monitoring,
- the lack of indicators or quantitative data from previously excavated structure to help guide excavation and subsequent decision-making, and
- the difficulties in maintaining the sterility of reburial fill material and potential consequences.

It may be possible to learn more about survival conditions and post-excavation decay mechanisms from the analysis and monitoring of sites from the moment of excavation.

Theme 3: Structural Decay

Initial questions:

3.1 To what extent are earthen structures influenced by the creep behavior of earthen materials.

3.2 Are very ancient, multi-component structures (e.g. mudbrick masonry walls) subject to an evolutionary process whereby they may begin to behave like monolithic structures, especially those that have been buried for very long periods of time?

3.3 Do we need to know more about the behavior of earthen structures during or resulting from seismic activity?

3.4 Do we know enough about the relationship between water content and load-bearing capacity in structures?

3.5 What is the exact nature/mechanism of wall surface density relaxation and its influence on the further decay of the structure?

The extreme sensitivity and vulnerability of earthen materials are inherent characteristics specific to earthen architecture. In the case of earthen architecture, there seem to be relationships that exist between all levels of the structure: what is observed on the one micron scale has a direct relationship to what is observed on the ten meter scale. Though the exact relationships have still to be quantified, it can be surmised that the result is a combination of what is happening at the interfaces of each level of scale.

A variety of factors influencing earthen structures result in specific structural decay patterns. Some of the factors noted included the following:

Intrinsic factors:

- the variability of material properties,
- the low compressive and tensile strength characteristics of unamended earth,

- the very strong creep dependency (even over very long periods, as observed through the analysis of archaeological structures),
- the low elastic modulus,
- its extreme sensitivity to water content variations, and
- the resulting wall surface density relaxation.

Extrinsic factors

- architectural shapes (lack of structural continuity due to the use of corners, flat roof construction traditions, introduction of modern and stiff materials, etc.),
- use (live load conditions, change in use of the building, lack of maintenance, etc.)
- building traditions/constructive cultures (e.g. stiff foundations, high slenderness ratios, etc.), and
- environmental conditions such as earthquakes, flooding, extreme wind loads, etc.

In the majority of cases, cracks in earthen buildings can be regarded as normal, and part of the functioning system of the structure, as opposed to cracks in other building materials and systems that tend to signify failure. Structural engineers intervening on earthen structures should be educated to become familiar with the specific cracking patterns of earthen structures, to be able to discern threats from non-threats/normal behavior.

It is felt that earthen structures should be allowed to function in a "soft" mode. Stiffening of the structures can only lead to further disorders. But quantitative data are lacking for what concerns newly built walls as well as existing, historic walls. These data should also be related to the presence/role/control of ground water, the effectiveness/influence of regular maintenance, the composition of the material, and the parameters related to the interfaces with other materials (such as wood, renders, and retrofitting materials, especially given the low elastic modulus of earth compared to other materials).

Earthquake damage should be further researched. Shaking tables can be employed for new structures, but old structures require systematic surveys, preferably in conjunction with the intensive use of field instrumentation. It has been acknowledged that a great deal of testing data are available, but that there is a lack of analysis and synthesis, and that efforts should be developed to relate lab results to field observations.

For what concerns mitigation of earthquake effects and other structural damage, a number of points were noted:

- interventions should be based on thorough structural analysis and the design be done for the worst case scenario;
- remedial work should be evaluated by a third party;
- distinctions should be made between structural cracks and seismic cracks, which should be treated differently according to the "no stiffness" principle, requesting a partial re-education of concerned engineers and research on the use of new materials (new metal alloys, fibers, etc.) for stitching and strapping; and
- trigger levels should be developed for the rational use of information yielded by monitoring instrumentation (which in turn induces a need for empirical testing of trigger proposals).

Theme 4: Chemical Interventions

Initial questions:

4.1 How should the continued cross-linking of silicate networks – which potentially lead to embrittlement and eventually to structural collapse – be addressed? Given such concerns, what issues might be raised by the use of or re-treatment with silicates?

4.2 Are colloidal gels an option for treatment worth exploring/researching?

4.3 Is enough known about amended mixtures (e.g. mixtures amended with cement, microbiological, or other additives) and their efficacy as a treatment option?

A number of chemical consolidants have been under experimentation and employed over the last decades. Much of the testing has been empirical, without monitoring over the very long-term, and it was felt that more data are needed on the efficacy of existing treatments rather than continued experimentation with new consolidants. Specific questions that arise concern long-term stability, the breakdown of the consolidant, embrittlement of the treated material due to continued cross-linking, and re-treatment. Other questions concern the applicability of such treatments on large sites and the compatibility of treatments used for other materials, such as stone, for earthen applications.

Long-term and/or published evaluation of past treatments are very rare, and obviously there is a strong need for monitoring and reporting to the field at large. In the future monitoring should be related to clear treatment objectives, and to documentation at the time of treatment.

Amended mixtures have been the subject of some systematic research, especially as regards chemical and inorganic additives, but more investigation is required to understand better their properties and use.

The identification of inorganic/organic, natural/biological additives, in particular from regional, vernacular practices, and the study of their mechanisms related to the improvement of the cohesion of existing or new material is an urgent matter.

Future research might include:

- full evaluation of previous consolidant trials,
- investigation of the effects/potential of re-treatment with consolidants,
- study of the amendment of mixes with organic and acrylic components,
- study of the amendment of mixes with hydraulic lime or lime with hydraulic additives, and
- systematic collection and testing of vernacular practices -- not only to investigate their efficacy, but also to ensure that traditional practices are not lost altogether.

Theme 5: Physical Interventions

Initial questions:

5.1 What happens at the interface between original surfaces and sacrificial renders?

5.2 Is enough known about reburial, in particular the effects of burial materials and external environmental conditions on original material?

5.3 Is enough known about the long-term efficacy of existing crack repair methods? Are there other options/methods worth exploring/researching?

Some of these questions were addressed in other themes. Reburial was more directly discussed in Theme 3. Crack repairs were also explored, to an extent, in Theme 3. Continued discussion in this session focused on a variety of issues related to crack repair, including:

- the treatment of cracks in historic buildings vs. archaeological structures,

- the treatment of structural cracks vs. seismic cracks, and
- the bonding of old and new materials in crack repairs.

Some discussion focused on the issue of interfaces between original surfaces and sacrificial renders, questioning compatibility of materials (e.g. earth on earth vs. lime on earth) and the potential problem of salts at the interface.

Protective shelters were a significant topic of discussion in this theme. Shelters are traditionally understood to be "protective," but they can also induce changes in the microclimate, which in turn affect the pathology of the fabric of the sheltered structures, both in the short-term and in the long-term. Methodological approaches to shelter decision-making, the development of design criteria, and evaluation are urgently needed. The monitoring of the microclimatic changes and their effects on the fabric in existing sites could help to establish specifications for shelter development in the future.

On the whole, it was proposed that the practice of physical interventions needs to be based on thorough structural analysis, that interventions should take into account future changes in use and form, and that interventions should be designed for worst case scenarios. It was also suggested that remedial work should be evaluated by a third party.

Theme 6: Continued Use

Initial questions:

6.1 What additional understanding of the thermal performances of earthen building materials and earthen buildings might inform conservation work and promote continued use of earth as a building material?

6.2 How might it be possible to explore correlations between earthen building materials and human health, especially the potential health benefits of living in earthen structures?

The knowledge of the hydro-thermal behavior of earthen building components and buildings are of prime importance for the continuity and development of earthen architecture, as well as for the conservation of ancient structures. Extensive research on the subject has been done by a number of laboratories, but there is a need to analyze and synthesize the existing data. Such an analysis/synthesis would serve to establish a "state of the art" on the subject, and might cover all hydro-thermal related subjects such as: insulation, heat transfer, thermal mass, diffusivity, effusivity, properties change in function of the water content, static and dynamic behavior, etc.

Additional research on hydro-thermal issues might be necessary for what concerns cold climates, as much of the existing research has focused on warmer climates.

Eventually the data could be fed into existing software for modeling time-dependent hydro-thermal behavior of real buildings.

RESEARCH PRIORITIES

As noted previously, the last of the day's discussions was devoted to establishing research priorities from among the ideas explored throughout the meeting. Many of the priorities were derived directly from the questions and topics of the research themes, but the group as well looked to establish *strategic* priorities. That is to say, in addition to prioritizing potential research topics, the group also prioritized some of the conditions and efforts necessary to encourage, facilitate, and undertake such research.

It should be noted that the following priorities are not listed in any order of importance or urgency, but simply recounted from the discussions and recording.

Strategic Priorities

Three fundamental points were made with regard to fostering research in a strategic way:

- The research should be realized through activities and cooperation amongst a variety of levels – from high level labs to technologically appropriate on-site testing. This will ensure that research is responsive to the needs of the field and that it involves the range of people dealing with the issues;
- The research should be driven by a philosophy of maximum understanding, minimum intervention;
- The results of the research should be made broadly accessible, especially through the development of appropriate diagnostic methods and analytical tools.

The more specific strategic priorities are outlined below:

SYNTHESIS

- Obviously, information specific to the field of the conservation of earthen architecture is lacking in a number of areas. Nevertheless, a great deal of information exists in grey literature that is not readily accessible nor reported on. Additional information exists in other disciplines, such as clay mineralogy, geotechnics, soil mechanics, microbiology, pedology, seismic engineering, thermal engineering, etc., but has not been informatively adapted and applied to earthen architecture.
- For each specific research subject, it will be necessary to do a preliminary cross-disciplinary desk assessment and synthesis, in order to put as many parts of the puzzle together. Identified missing pieces will have to be adopted/adapted from other disciplines or generated specifically as a result from a specific research effort. This involves not only engaging researchers and professionals from other disciplines, but also allowing researchers within the earthen architecture conservation field to devote time to exploring these ancillary areas of study, in order to foster the necessary links and transfers.

ACCESS TO AND DISSEMINATION OF INFORMATION

- The access to existing data in the field of earthen architecture and its conservation is severely limited due to the lack of centralized databases, online catalogs meeting international library standards, and the like. Increased access is key to fostering research that is responsive to needs in the field.
- This does not only concern publications and grey literature but also expertise and facilities; access to data should be dramatically enhanced.
- Access should be accompanied by a language initiative, including abstracting in several languages and the development of a multilingual technical glossary (scientific dictionary of earthen architecture).

- An effort should also be developed to publish new material in peer review publications and to generate incentives for research write-up and publication.

INFORMATION SHARING AND MENTORING

- Research efforts could be fostered by the establishment of a network of multidisciplinary research partners. At least in the beginning, enthusiastic individuals might share expertise, taking advantage of joint sabbaticals or "discussion week-ends", which could be combined with video conferences, and accompanied by a set of annual local conferences.
- The involvement of students working on masters or Ph.D. theses is absolutely mandatory. Researchers should be encouraging students to tackle some of these issues.

EDUCATION

- Research activities should be combined with the education of scientists and practitioners, especially conservators, architects, and engineers.
- Additional education efforts should be developed to increase awareness among funding agencies.
- Training efforts need also to be developed on the basic level, in order to involve local people, and especially young people, in regular maintenance and to encourage a sense of ownership.

SUPPORT

- An absolute must is the politicization of the field of conservation of earthen architecture in order to obtain major funding. To this end, new activities and strategies have to be initiated yielding leverage for political lobbying.
- There is a need to provide incentives and opportunities for research to be written-up and published.

MONITORING

- A strong case has been made to install an in-situ monitoring culture, using existing and/or adapted instruments.
- Monitoring systems/methodologies with trigger levels should be developed for identification of conditions and decision-making about interventions.

TESTING METHODS

- A need has been perceived to develop reliable testing methods as quite often the very act of observing a mechanism disturbs the mechanism or the observation method misses the essential mechanism at work, for example because of scale difference.
- The testing methods should also be standardized so as to allow the discipline to communicate and exchange data and information in equivalent terms.
- Testing methods adaptable to a range of contexts and utilizing appropriate technology should be developed for field situations.
- There is a desire to design field testing methods that yield results that are directly related to the results yielded by lab testing methods, and that testing methods allow for a connection of results yielded on different scales. The concept of these testing methods should be clearly developed – through collaboration of those working in the lab and those in the field -- so that processes of approach can be unified to the extent possible.

EVALUATION OF TREATMENTS

- The evaluation of existing treatments was seen as critical to making any real advancement in the field, especially with regard to new treatments.

Research Topic Priorities

The priority research topics/issues, discussed in the previous section, are summarized in brief below. Again, it should be noted that the order of the topics relates to the flow of discussions and recording rather than to their relative importance.

CLASSIFICATION SYSTEM

- A classification system for soils is needed that is specific to earthen architecture and its conservation.
- Such a system should be applicable to both fresh (new construction) and aged materials (conservation).
- This could be achieved through the expansion of existing systems, facilitated by collaboration with other disciplines.
- Compatibility of the system with the Eurocode would be an additional asset.

BINDING

- There is a need to identify the exact binding mechanisms at work in the clay part of earthen building materials. The relative parts of electromagnetic forces, ion exchange potential, friction, capillary forces, and microbiological effects have not been established, neither on the micron level (clay particle size fraction) nor on the millimeter/centimeter scale between the binder part and the inert aggregates. Comparative studies between historic materials and new materials should be conducted and could yield enlightening results to that end.

UN-BINDING

- The macro-mechanisms of decay (structural decay) are relatively well known, but the micro-mechanisms (non structural decay) that trigger the failure of the physical-chemical matrix are still the subject of speculation. Specific questions relate to the role of suction.

WATER

- The influence on both decay and cohesion of the presence or absence of water in different forms (such as relative humidity, vapor, snow and ice) is qualitatively acknowledged but quantitative data are close to completely lacking.
- The kinetics - absorption, adsorption and migration - of moisture (and salt) transportation on the surface and in the bulk material, in relation to the pore structure of earthen building materials, is close to unknown and the resulting cause/effect relationship concerning their decay or reinforcement not understood.
- More should be understood about the relationship between the strength of earthen materials and small variations in water content when the material is already dry, i.e. when water content is already close to 0.5% to 1.5%.

SALTS

- The real role of salts still seems to be unclear. What is clear is that the activities of salts are intimately linked to the presence or the absence of water.

- More information could possibly be drawn from agriculture and other disciplines.
- The influence of salts on the pH and the colloidal properties of soils has not been quantified.

ORGANIC MATERIAL

- The negative role of the presence of organic material in earthen structures is understood up to a certain degree. However, information / knowledge is lacking for what concerns the positive role of organic material, such as its contribution to cohesion.

EXCAVATION / REBURIAL

- We do not seem to know enough about the effects of excavation on earthen structures in archaeological contexts.
- This lack of information impacts the ability to take decisions about reburial as well.
- Much can probably be learned concerning survival conditions and mechanisms from the analysis of the condition of newly excavated sites.

STRUCTURAL BEHAVIOR

- Structural engineers intervening on earthen structures should be educated to become familiar with the specific cracking patterns of earthen structures, to be able to discern threats from non-threats/normal behavior.
- It is felt that earthen structures should be allowed to function in a "soft" mode. Stiffening of the structures can only lead to further disorders. But quantitative data are lacking, for what concerns newly build walls as well as existing, historic walls.
- More needs to be learned about the influence of capillary absorbed water on the strength and structural properties of earthen buildings.
- Earthquake damage should be further researched. Shaking tables can be employed for new structures, but old structures require systematic surveys, preferably in conjunction with the intensive use of field instrumentation.

CONSOLIDANTS AND AMENDED MIXTURES

- A number of chemical consolidants have been experimented with and used over the last decades. Much of the testing has been empirical, without monitoring over the very long-term. More data are needed on the efficacy of existing treatments rather than continued experimentation with new consolidants. Specific questions that arise concern long-term stability, the breakdown of the consolidant, embrittlement of the treated material due to continued cross-linking, and re-treatment. Other questions concern the applicability of such treatments on large sites and the compatibility of treatments used for other materials, such as stone, for earthen applications.
- Amended mixtures have been the subject of some systematic research, especially as regards chemical and inorganic additives, but more investigation is required to understand better their properties and use.
- Future research might to include:
    - full evaluation of previous consolidant trials,
    - investigation of the effects/potential of re-treatment with consolidants,
    - study of the amendment of mixes with organic and acrylic components,
    - study of the amendment of mixes with hydraulic lime or lime with hydraulic additives, and
    - systematic collection and testing of vernacular practices.

SHELTERS

- Methodological approaches to shelter decision-making, the development of design criteria, and evaluation are urgently needed. The monitoring of the microclimatic changes and their effects on the fabric in existing sites could help to establish specifications for shelter development in the future.

THERMAL CHARACTERISTICS

- Extensive research on the subject has been done by a number of laboratories, but there is a need to analyze and synthesize the existing data. Such an analysis/synthesis would serve to establish a "state of the art" on the subject, and might cover all hydro-thermal related subjects such as: insulation, heat transfer, thermal mass, diffusivity, effusivity, properties change in function of the water content, static and dynamic behavior, etc.
- Additional research on hydro-thermal issues might be necessary for what concerns cold climates, as much of the existing research has focused on warmer climates.

NEXT STEPS

The priorities and recommendations that came out of this Terra Research Meeting are indicative of a process of hypothesizing about observations in the field. In many cases, these observations involve issues that lie at the edge of the existing context for earthen architecture conservation. For this reason, it is understood that there is a need for continued, interdisciplinary dialogue in order to define better the needs and opportunities for research, as well as to refine the specific research questions.

The Project Terra partners – CRATerre-EAG, ICCROM, and GCI – are committed to fostering the ongoing dialogue and to facilitating research collaboration. Though the Terra partners cannot address all of the research priorities, we intend to explore some of the research topics to the extent our institutional mandates and resources allow. Focus will, however, be on communicating with and convening colleagues so as to encourage cooperation amongst existing research projects, as well as on stimulating new, collaborative initiatives. (n.b. Projects may or may not involve the Terra partners directly).

The Terra partners have made some initial steps in this direction:

- As mentioned in the Introduction section of this report, the Terra partners are coordinating a critical review of research literature related to earthen architecture conservation. The review is expected to be completed in 2001.
- CRATerre-EAG, in collaboration with ICCROM and the GCI, is initiating a dialogue on the development/expansion of a soil classification system that meets the needs of earthen architecture conservation.
- CRATerre-EAG, in collaboration with ICCROM and the GCI, is fostering a continued dialogue and potential research collaboration on the issue of binding as it relates to earthen architecture conservation. To initiate this effort, a preliminary meeting is being held at CRATerre-EAG in early December 2000.
- Pursuant to the outcomes of the above mentioned initiative on binding, the GCI, in collaboration with CRATerre-EAG and ICCROM, aims to foster an ancillary dialogue and possible research collaboration on the issue of un-binding.
- The GCI and New Mexico State Monuments are currently undertaking an evaluation of amended mixtures and conservation treatments tested during research efforts at the site of Ft. Selden, New Mexico.
- The GCI, in collaboration with the US/ICOMOS Earthen Architecture Committee, the U.S. National Park Service, and New Mexico State Monuments, is organizing a colloquium on "Protective Shelters for Archaeological Sites in the Southwest," at Tumacacori, Arizona, USA, from January 9 to 12, 2001.

For those individuals and institutions who are interested in or would like more information about the above initiatives, please contact one of the Project Terra representatives below.

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APPENDIX A: LIST OF MEETING PARTICIPANTS

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APPENDIX B: MEETING AGENDA

8:30 – 9:00	Welcome, Meeting Background, Introductions, and Questions *Presenter/Moderator : Alejandro Alva*
9:00 – 10:30	Theme 1: Classification, Binding, Un-Binding *Presenter/Moderator : Hugo Houben*
10:30 – 11:00	Coffee Break
11:00 – 12:30	Theme 2: Non-Structural Decay or Evolution *Presenter/Moderator : Jeanne Marie Teutonico*
12:30 – 1:30	Lunch
1:30 – 2:30	Theme 3: Structural Decay *Presenter : Richard Hughes* *Moderator : Hugo Houben*
2:30 – 3:30	Theme 4: Chemical Interventions *Presenter: Jeanne Marie Teutonico* Theme 5: Physical Interventions *Presenter: Richard Hughes* Theme 6: Continued Use *Presenter: Hugo Houben* *Moderator: Jeanne Marie Teutonico*
3:30 – 4:00	Coffee Break
4:00 – 5:30	Priorities and Recommendations *Moderator : John Fidler*
5:30 – 5:45	Conclusions

Meeting facilitators/recorders: Hugo Houben & Erica Avrami