NONDESTRUCTIVE DIAGNOSIS OF BUILDING CONDITION

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I. INTRODUCTION

The conservation of a monument can be compared to the treatment of a sick patient by a physician. The initial step is the correct diagnosis of the illness by noting the symptoms and performing appropriate tests[1]. A knowledge of the pathology of the identified illness then leads to a prescription of a treatment. Thus there are three major steps: diagnosis, pathology and treatment. In the field of architectural conservation, research has focused primarily on treatments, with a lesser emphasis on pathology, i.e. understanding the chemistry and physics of the deterioration. However, very little effort has gone into improving the state of the art of diagnosis, which is the essential first step.

Building diagnostics is now beginning to be recognized as a separate field[2]. However, this field has a very broad scope. Not only does it include understanding the deterioration of the structure itself, but also the performance of subsystems within the building such as heating and cooling, and even to the influence of the design on the well-being and productivity of the occupants. For the purposes of this paper we would like to confine the discussion to the first item, the physical deterioration of the building itself.

II. IDENTIFYING SYMPTOMS OF DETERIORATION

There are several general classes of deterioration problems. These include defective building materials, loss of protective surface layers, accelerated weathering due to air pollution, attack by soluble salts, and interactions between materials, especially the corrosion and expansion of iron reinforcements[3].

A variety of methods have been used to study deterioration. These fall into two classes: visual inspection on site and instrumental analysis in the laboratory on samples taken from the building[4]. Neither of these two classes are the complete answer. Visual inspection requires trained observers who make subjective judgements about building condition such as degree of paint peeling. These observations are difficult to relate to quantifiable physical or chemical factors that affect the deterioration process. Moreover, the observer is not capable of determining important quantities such as moisture content or chemical composition of materials. On the other hand, observers can also easily see characteristic patterns of decay such as the traces of rainwater flow over a surface, that are impossible to recognize using instrumental measurements alone.

The other class, instrumental measurements, gives quantita- results. However, because they involve the taking of samples, they are destructive which limits their usefulness in the case of monuments. In any event, they do not yield information about the condition at depth within the walls, unless the even more destructive procedure of drilling cores is used.

What is needed are non-destructive methods that can be applied in the field and that provide information about building condition, both at the surface and at depth within walls or other parts of the structure.

III. NON-DESTRUCTIVE EVALUATION

There have been several reviews of the possible non-destructive methods that could be applied to building diagnostics[5,6,7]. The most promising are given in Table 1 along with the damage characteristic each measures. It can be seen from this table that there is no one method that does everything. Hence the building diagnostician must choose the most appropriate method or methods for each case of deterioration. These methods are :

A. Infra-red Thermography - The infra-red radiation given off a by a building is recorded by a device like a television camera. The resulting image shows warm and dark parts of the walls. These areas can be related to such things as variations in building material composition or the presence of moisture. However, this technique cannot effectively penetrate below the surface.

B. X-ray Fluorescence- This is also a technique limited to the surface. It beams x-rays from a portable source on to the surface and measures the energy of the emitted x-rays. This gives information on building materials, paint pigments, and contaminants like salt.

C. Neutron Probe - Unlike the previous two methods, this one uses a portable neutron source to measure the distribution of elements within a wall. It can identify material composition, the presence of contaminants such as salt or moisture, and the occurrence of voids or reinforcements within the structure.

D. Radar - Portable radar sets can be used to identify metal structural elements or moisture within walls.

E. Magnetic Surveys - Proton magnitometers are portable instruments that are very sensitive to changes in magnetic fields and thus can be used to detect iron reinforcements.

F. Neutron Radiography - Neutrons from a portable source could be used to make images of the interiors of structures in a process like taking x-ray images. The advantage of neutrons over other types of radiation like gamma or x-rays is

TABLE 1: POSSIBLE IN-SITU NON-DESTRUCTIVE METHODS FOR ARCHITECTURAL CONSERVATION

	Materials Composition	Salt	Moisture	Voids	Reinforce-ments	Surface Roughness	Cracks
1. Infra -red Thermography	no	no	Yes, surface only	no	no	no	no
2. X-ray Fluoresc.	yes, surface only	yes, surface only	no	no	no	no	no
3. Neutron Probe	yes	yes	yes	yes	yes	no	no
4. Radar	no	no	yes	no	yes	no	no
5. Magneto-meter	no	no	no	no	yes, ferrous only	no	no
6. Neutron Radiography	no	no	no	yes	yes	no	yes
7. Acoustic Emission	no	no	no	no	no	no	yes
8. Piezo - Hammer	no	no	no	no	no	no	yes
9. Pneumatic Gauge	no	no	no	no	no	yes	no
10. Acetate Peel	no	no	no	no	no	yes	no

that they are much more sensitive to variations within building materials.

F. Acoustic Emission - The infinitesimal movements of building materials as a result of wind loads or thermal expansion and contraction will emit sound at points of stress or micro-cracking. These acoustic emissions can be picked up by arrays of microphones and used to locate areas of structural problems within walls.

G. Piezoelectric Hammer - A specially instrumented hammer is used to generate sound pulses a point on the stucture. The pulse is then picked up by microphones at other points on the structure. The changes in the wave form of the pulse between the hammer and the pickup can be used to identify structural problems.

H. Pneumatic Gauge - The roughness of a surface can be determined non-destructively by measuring the resistance to air flow across the surface. The increase in surface roughness over time is an indication of material weathering.

I. Acetate Peels - A very simple way to measure surface rough- and cohesion of building material surfaces is to take an impression of the surface using a sheet of plastic acetate. The roughness of this surface replica can then be measured in the laboratory.

IV. RESEARCH AND DEVELOPMENT NEEDS

All of the equipment listed in Table 1 is available in some commercial form. However, they may not be specialized for the purpose of architectural conservation. Thus, some additional research and development may be required to produce instruments that are most suitable. This research would cover several categories including: calibration for materials composition, precision, accuracy and minimum level of detection. Some equipment redesign for better portability or weather proofing may also be necessary.

There are several approaches to conducting this kind of research. One consists of simulating the performance of the instrument using mathematical models, usually operating on computers. This approach has the advantage of being relatively inexpensive and quick, and permits one to investigate the effect of a wide range of conditions. However, it may be that the phenomena involved are too complicated to model realistically.

A second approach would be experiments in the laboratory under controlled conditions. This makes it possible to establish precision and accuracy, but the test conditions may not be representative of the real world.

Finally, the equipment may be tested in the field on real buildings. Although this is clearly the most realistic kind of test, it may not yield a clear understanding of the performance of the equipment unless the measurements can be confirmed by independent methods.

Ideally, the research and development should be carried using an optimum combination of the three approaches. Many countries have organizations for such testing and standardization. Some examples are the American Society for Testing of Materials and the Deutsches Institut fur Normalen. These organizations cooperate at the international level in the International Standards Organization. It may be useful for ICOMOS to bring to the attention of these organizations the specific research needs for architectural conservation.

In addition to research on the instruments themselves, work is also needed to understand the data that will be produced. This kind of research concerns the relationship between the measured variable and the actual process of deterioration. For instance, given that we can measure the concentration of salt in a porous material like brick, we still need to know how much salt can be tolerated before the brick will begin to fail. This threshold may be different for different brick compositions.

Moreover, these instruments may generate so much data that some attention must be given as to how this information will be interpreted and presented. Consider the difficulty in comprehending data on eight to ten elemental concentrations measured at 10 to 100 points along a single wall and then relating this to measurements of acoustic emissions. The solution may lie in the application of computer assisted design techniques used by architects. Ultimately, it may be worthwhile to use advanced computer methods like expert systems to help recognize significant patterns in the data.

V. TRAINING AND QUALIFICATION

It is not enough to provide the equipment for non-destructive evaluation. Consideration must be given to the training of the persons that may use it. At one of the spectrum are the engineers and scientist who develop the instruments. While these are most familiar with the operation and limitations of such equipment, they may not be aware of the special problems of architectural conservation. At the other end of the spectrum are the conservators who are trained in the techniques for conserving buildings but may not be have the necessary scientific background to operate the non-destructive testing equipment. In between presumably lie the building diagnosticians, who understand both architectural conservation and non-destructive evaluation. Even here there are gradations. There are specialists in particular types of diagnostic techniques. There are also generalists in building diagnostics who may call upon specialists in a given situation.

This division of labor is efficient. Given the significant capital cost of many types of non-destructive instruments it not worth the expense for the architectural conservator to acquire this capability simply to examine a single building. A significant investment in time may also be involved in order to learn how to operate such equipment. Finally, many types of instruments need continuing attention to insure proper operation and calibration.

Nevertheless, it is important that the architectural conservator have some understanding of the equipment in order to judge when it would useful or appropriate. Conversely, the specialist needs to understand the particular needs of the conservator. This suggests a variety of training courses at different levels of professional interest and specialization. For comparison, the American Society for Non-destructive Testing, which deals primarily with industrial applications, conducts a range of short-term training courses in a variety of techniques. Graduates are given certificates of qualification. The subject of training and qualification in non-destructive testing could be another matter for consideration by ICOMOS.

VI. VENICE AS A CENTER FOR STUDY IN BUILDING DIAGNOSTICS

It would be desirable to bring together research, training and application of non-destructive testing for architectural conservation. One possible location for this effort could be Venice. This city is the site of many architectural monuments which have been built with a wide range of building materials from brick to marble. The interiors display a variety of wall coverings from mosaics to fescoes. Unfortunately, Venice is also the victim of almost all known factors of deterioration, ranging from air pollution through salt damage to flooding and subsidence. Thus there are plenty of opportunities for field testing of diagnostic methods. Recently, the Italian Nuclear Energy Agency has been testing the neutron probe on a number of buildings in Venice including the Basilica of St. Marks.

Also in Venice are a number of research and training facilities. These include the Stone Conservation Laboratory of the Soperintendenza di Beni Artistici and the National Research Council's Laboratory for the Study of Dynamics of Large Systems, which has applied remote sensing techniques to study the problem of flood control in the Lagoon. The University of Padua conducts research in the physical processes of building deterioration. Finally, UNESCO holds an international training course in stone conservation in Venice every other year.

VII. CONCLUSIONS

The diagnosis of building condition is an essential part of architectural conservation. It is preferable to use non-destructive methods that can be applied in situ. The equipment for several non-destructive methods is available, but may not be optimized for architectural conservation. Thus some research and development is needed to realize the full benefits of these techniques. The standardization societies at the national and international levels may be a very useful resource for such research and development. Training and qualification in the use of these instruments is also necessary. ICOMOS could play a important role in such a training program. Finally, consideration should be given to Venice as a central location for conducting research and training.

VIII. REFERENCES

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The diagnosis of building condition is an essential part of architectural conservation. It is preferable to use non-destructive methods that can be applied *in situ*. Important factors that need to measured include: materials composition, presence of salt or moisture, metal reinforcements, voids, surface layers and cracking.

Several non-destructive techniques have been considered for application to architectural conservation. These include: infrared thermography, X-ray fluorescence, neutron probe, radar, magnetic surveys, neutron radiography, acoustic emission, piezoelectric hammer, pneumatic gauges,and acetate peels. The equipment for several non-destructive methods is available, but may not be optimized for architectural conservation. Thus some research and development is needed to realize the full benefits of these techniques. The standardization societies at the national and international levels may be a very useful resource for such research and development. Training and qualification in the use of these instruments is also necessary. ICOMOS could play a important role in such a training program. Finally, consideration should be given to Venice as a central location for conducting research and training.