DIAGNOSTIC METHODS FOR EVALUATING CONDITIONS AND MANAGING CHANGE IN HISTORIC STRUCTURES

Hugh C. Miller, FAIA, Chief Historical Architect,
National Park Service, Washington, D.C. 20013

DIAGNOSTICS AS AN IDEA

The evaluation of historic building performance is not unlike the practice of medicine and the science of pathology. It follows all the steps of the medical process -- the diagnosis is based on the analysis of symptoms, the prognosis is based on testing and monitoring, and the prescription of a remedy is undertaken with controlled observations of the treatment. However, the understanding of a building is currently more of an art than a science. One can see how the building condition surveyors use diagnosis as a valuable tool. But unlike medicine, they have not spent centuries gathering and organizing information about building response to maladies. This knowledge is essential to diagnostics and, like medicine, should include the history of diseases, that is, how building problems are expected to behave.

Good diagnosis is based on good models of the condition studies. Normal states must be defined so that abnormal states can be recognized. The diagnostic evidence is separated into "symptoms" and "signs." Symptoms are reported by the building user. Signs are objective physical evidences of abnormal conditions and include measurements made with instruments. Effective diagnosis is based on the ability to organize data into coherent relationships that might be called pattern recognition. In the near future we could expect that computer programmed "expert systems" or artificial intelligence systems could be developed for building diagnostics and treatments similar to those now used for medicine. For now, the building diagnostician must have such a diagnostic model in his memory. He must know the normal state or condition of a specific situation and he must be able to analyze abnormal conditions and their probable causes.

Diagnosis is not an end in itself but is linked to the prediction of future events. Time is an important dimension of building disease histories. The building surveyor must anticipate the series of events and form a prognosis based on his knowledge of the building disease measured in time. The quality, precision and application of this knowledge will determine the outcome of events for the building. The prognosis may be "good" or "poor," or more likely "meets expectations," "doesn't meet expectations" or "exceeds expectations," as for example, a column that can support additional loading. Prognosis is not an end in itself any more than diagnosis. The decision must be made -- "is the future it predicts acceptable?" or "is it desirable to intervene?" This intervention is termed a "treatment."

When doctors initiate treatment or therapy, they anticipate that, with the passage of time, the patient who might have arrived at an undesirable state, will instead be rejuvenated if therapy is successful. At this point the analogy with the building ills and treatment of human disease is less direct since building ills have no internal rejuvenation to deflect the building diseases from their natural course.

But, as in medicine, treatment of building ills is not always undertaken. In some cases it is not available and in others the building's problem can be allowed to run its course unimpeded because it's self-limiting or very slow in progressing. If the disease and its risk are well known, the dangers of the intervention can be intelligently weighed. A high probability of a dangerous result of untreated disease may justify a treatment that carries a high risk of adverse reactions. In some cases the treatment is more serious than the disease. Architectural conservators have learned that in treating some building ills "less is more" and sometimes doing nothing but watching the problem is the best solution.

BUILDING DIAGNOSTICS AS A PRACTICE

In England and many European countries the diagnostic process is much more advanced than in the United States since material and building sciences are taught to architects and engineers and are supported by government research. Also, the work of chartered surveyors is well understood since their evaluation of the condition of an existing building is the basic part of the leasing process. (Long term leases -- up to 99 years -- is a common practice.) The development of building diagnostics in the United States is just evolving from the lessons learned in managing historic structures, from the application of the home inspectors' service at the time houses are purchased or for condominium management, and a growing awareness of maintenance as a preventive practice rather than a "fix-it-when-it-happens" event.

Building diagnostics are traditionally used for "trouble shooting" but may be performed for a variety of purposes. If a historic building is going to be restored to an earlier appearance the detective work to differentiate between original parts and later accretions is a sophisticated form of diagnosis. If the building is going to be restored or rehabilitated, there is an interest in the performance of the existing structure, envelope interior, infrastructure, landscape and site to determine if these elements are acceptable and will continue to function or if they need to be modified to meet the requirements of the new use. If the structure is going to be preserved "as is," building diagnostics are an essential part of the initial repair and preventive maintenance program. Continual observations and monitoring for change and rates of change in materials and systems are important. For preservation or maintenance treatments there are opportunities to learn how the building really behaves since the diagnostic work is not distress oriented and monitoring can occur over time.

THE OLD HOUSE DOCTOR APPROACH TO DIAGNOSTICS

The process of building diagnosis is sensual. All six senses, with tools or instruments that are extensions of these facilities, are used. Sight is most important since the symptoms and process of decay are often evident even in casual observation. Smelling is useful...musty odors indicate that moisture levels may be at or approaching dangerous levels. Feeling is important. The texture of surfaces can indicate gross distortions. The feel of frass can indicate something about the species of termites or wood-boring beetles. Hearing can be useful. Sound can indicate the solidness of a member; with a stethoscope one can hear carpenter ants or carpenter bees chewing on a timber. Taste can also be useful in determining the presence of salts; however, considering that many toxic substances also can form crystals on the surface, one should not be tasting. These five senses are then combined with the sixth sense of "intuition." This knowledge is the feature that makes building diagnostics more of an art than a science. The classification of symptoms into pre-existing signs with or without instrumented measurements is important to the art of diagnosis.

Understanding the forces of deterioration is essential to determining the real cause of the problem. These can be broken broadly into two categories -- intrinsic factors and extrinsic forces. The intrinsic factors include environmental conservation such as location, geology, soils, and climate. They also include given structural conditions such as materials, design and workmanship. The extrinsic or external forces include natural processes -- biological, chemical and physical as well as human forces. Human forces include direct actions such as wear and tear, inappropriate maintenance or lack of maintenance and physical changes. Indirect human actions include riots, war, and adjacent construction or remote public works that affect the building.

TESTING, MONITORING AND THE NEED FOR MORE DATA

In many cases the disease entity of building deterioration is well defined and the problem is obvious although the repair or the solution may not be simple or inexpensive. In other cases, the symptoms and signs are complex and it is necessary to select additional procedures to determine the actual cause of the problems.

The use of instruments is important to the diagnostic process. They extend the senses to places that are hard to see or to indicate movement or environmental conditions that are hard to preserve or measure with human faculties. The desire to know what is inside a pipe or wall cavity or where they are or learn about their condition has motivated the application of available technology to non-destructive testing. The use of magnets has long been a practice to locate studs or pipes in a wall. This technology has been expanded to the use of the magnetometer to locate ferrous reinforcement bars in concrete and other dense building parts and objects in the wall or ground.

The application of the portable X-ray system, used to look for bombs in police work, for building diagnostics grew out of the desire to be able to draw the exact size and location of wooden framing systems. Radiography including portable nuclear source equipment is now used to evaluate flaws in metal, like the Liberty Bell, to locate anchors in masonry or determine the extent of corrosion in hidden structural view. Other kinds of nuclear source equipment has been developed to locate wet areas of roof decks or to analyze the chemical elements of salts in masonry.

The recent interest in energy conservation has expanded the application of infra-red technology to portable thermography that can provide images to locate heat loss, wet insulation, overheating electrical motors and transformers and more. Such infra-red images have also been used to find wooden framing and steel lintels in masonry.

Current research is refining the use of sound and electrical currents to locate objects and determine flaws or density of materials. Eddy currents have long been used to locate flaws in metal and are now being studied for application to other materials. Ultrasonic analysis long used in concrete, ceramics and metal investigation, is being refined to obtain better information about hidden flaws in these materials and this method is being applied to understand the condition of masonry and wooden buildings. Radio-frequency detection and ground penetrating radar (microwave analysis) can be used to locate objects underground and define voids in massive masonry or adobe walls.

Moisture in materials can be measured by an electrical resistance or electrical capacitance meters that can accurately determine the moisture content of wood and will provide information on the relative wetness of other porous materials in direct read out portable instruments. Other portable electronic instruments can measure temperature and relative humidity with instant precision. Similar instruments will indicate if a surface condition is at or near dew point and if condensation has or can occur.

More traditional diagnostic methods involve intrusive testing or exploratory examination. The use of fiber optics devices inserted in a small hole to look inside a wall cavity or duct is a diagnostic possibility. Miniaturized remote control television cameras can record the inside of pipes or hard to reach spaces. The taking of small, or not so small, samples of paint, mortar, metal, concrete, wood, etc. for laboratory analysis of their composition is common place. However the analytical methods are becoming more sophisticated and can be expected to give more information about more complex materials. It is now even possible to do a surface scan chemical analysis of stone.

There are a whole range of tests and sampling methods that can be done on building equipment and the quality of indoor environments. The development of objective methods of learning how building environments work and how people react to them is an essential part of diagnosing the whole building performance. Much more work is needed to apply the building conservation ethos and credo that it is better to preserve than to reconstruct to these concerns.

Gross intrusion into the fabric of the building or the gutting of major elements along with load test or other destructive testing is contrary to good conservation practice. Usually these methods are very expensive, often the results are not more conclusive than other tests and the tests may not focus on the real problem. (There is the case of a late 19th century Court House that passed a load test but the floors failed three years after the test was approved.) There are however, always opportunities to learn from building failures and testing and analysis when a building is changed or demolished.

Monitoring conditions over a period of time with systematic recording of change is an important part of the diagnostic system. Many building owners are unwilling to take the additional time and expense to study a situation although in most cases the answers that result from a monitoring program saves money in the direct application of a solution. Structural monitoring can involve simple glass tell tales or plastic calibrated plates that break or slide as a crack opens (or closes). Plunger-type micrometers fixed across a crack can measure every movement of the building and also indicate a trend if the crack is getting larger. Survey techniques, using precision theodolite or laser systems or photogrammetric methods can be used to measure distortion or movement in a structural member of a system. In all cases the information must be plotted on a chart -- manually or automatically.

Monitoring of moisture in materials and measurement of indoor environment have been used to understand dampness problems and to provide a suitable environment for museum objects. The applications of the same technology as found in the portable instrumentation can record the information continuously on a chart or "data logger" for analysis of what is really happening in the interaction of water in the building and water in the air. For buildings, excessive moisture, humidity that can result in condensation or too dry air can be destructive over time.

The monitoring of change or loss of surface is important knowledge for long term conservation. New important developments of measuring surface loss of masonry or metals with transfer tapes for microsope study of the surface or laser micro measurement are being developed in the acid rain research now underway. Besides learning a lot about the behavior of building materials in a polluted environment, monitoring tools and monitoring systems are being developed and used in this research.

While better tools or techniques will make building diagnostics easier or more reliable, it is not technology that holds us back. The use of diagnostics for "trouble shooting" is an old art. It has been used to solve specific building problems for years. Many of the practices that appear as alchemy are in fact based on scientific principles--spoken or unspoken. An old roofer showed me how to look for frost spots on a flat roof to find wet insulation.

The lack of concerns for building performance or condition is the result of the way building professionals and building owners think about them. Materials and systems are not considered as a time-line of deterioration that can be mitigated. They are considered as problems.

Roof problems, foundation problems, energy problems are all typical conditions when building owners take action. This concern for economic loss has resulted in diagnostic services and the development of related instrumentation for non-destructive testing and monitoring of these problems. On the other hand, the transfer of available information about the performance of wall joints whether they be made of mortar or sealants is in the realm of mythology with lots of opportunities for the snake oil salesmen to recommend sure-fire cures. The whole arena of leaking masonry walls in general, and stone and brick spalling in particular, are building ills that are like the common cold...they have symptoms that are well defined and causes that are generally understood but for which there is no effective cure.

What I'm proposing is a comprehensive approach to building performance analysis that in terms of human health maintenance might be called a "well building physical." While building owners will buy a maintenance contract on typewriters or office copiers they generally will not talk about inspection or preventive maintenance programs on whole buildings. The current maintenance management program has made National Park Service managers realize that a comprehensive inspection of their building is cost-effective...making a small repair rather than correcting a costly failure. Such a report of the building's condition may also recommend doing nothing but watching a situation. This would be possible under work managed by a Maintenance Management System (MMS).

The other side of this chicken-egg situation is that aside from the home inspectors there are few professionals offering comprehensive inspection services. Here-in lies the opportunitiy for institutions and individuals who own historic property. There is an opportunity for them to use the available information and techniques to provide comprehensive information about the condition of their building...what's working, what's limiting, what's changing (and how fast), what went wrong and what's the repair. There is the opportunity to join with private sector architects, engineers and materials scientists in an international effort to adopt "space age" instruments for more effective measurements or non-destructive tests of building materials or systems. We now can talk, read together and learn how to keep buildings "living" as well as "create" better new buildings in the future. The historic structures of the Park Service along with others can be laboratories for this learning from old buildings.

June 1987

DIAGNOSTIC METHODS FOR EVALUATING CONDITIONS AND MANAGING CHANGE IN HISTORIC STRUCTURES

Hugh C. Miller, FAIA, Chief Historical Architect,
National Park Service, Washington, D.C. 20013

SUMMARY:

The economic and technical success of historic building conservation should be based on a comprehensive evaluation of the building's actual condition and its ability to continue to function or to meet the needs of a new program. Too often buildings are gutted, systems are abandoned, or architectural features are removed, without recognizing the inherent nature of the building to continue to perform. Too often unnecessary work is undertaken in the name of restoration or rehabilitation without understanding the economic, social, and cultural values of the existing architectural character and fabric.

The application of available knowledge and technology to systematically diagnose a building's condition or "diseases" and make a prognosis as well as prescribe treatment is the basis of an analytical approach that will promote a building's longevity. These techniques are appropriate as continuing or expanded services of architects or architectural conservators. These evaluative methods can be used for inspecting new work or recently made repairs, for post-occupancy surveys, for "trouble shooting" problems, for developing maintenance plans or for project planning of a whole-building rehabilitation.

There is a relationship between preservation decisions and the ultimate building performance that must be based on evaluative standards. The analysis of these standards, with data collected from field measurements or laboratory tests, can predict the performance of the whole-building and show the interaction of the building's elements - the envelope, the structure, the interior, the infrastructure (mechanical, electrical, lighting, etc.) and even landscape and site features. The experience learned from treating monuments and rehabilitating historic buildings has shown that all too often repairs were not effective because the symptom of the problem was treated rather than the cause, or, the retrofitting of a system has not considered the repercussions of the change on its other existing parts.

Although the use of diagnostic methods and monitoring systems has been slow in its application in the United States, there are a number of off-the-shelf instruments and state-of-the-art techniques available to analyze a building's condition and rates of change in a structural system or material. There now are good case histories to aid in the selection of appropriate non-destructive testing, intrusive sampling, exploratory investigation or destructive testing methods for the diagnosis and monitoring of a particular building or condition.

There are new opportunities for applied research to utilize existing technology from material sciences or other technical fields for the diagnosis and monitoring of conditions of building materials and systems. The importance of understanding the principles of existing building performance, the practical development of diagnostic skills and an understanding of the purpose, range and potential of building diagnostic techniques will be discussed in this paper.

Méthodes de Diagnostic pour l'Évaluation de la Conditon des Immeubles Existants

Hugh C. Miller, FAIA, Chief Historical Architect, National Park Service,
Washington, D.C. 20240

Résumé

On devrait baser la réussite économique et technique de la conservation d'immeubles sur l'évaluation d'ensemble de leur état actuel et leur capacité de continuer à fonctionner où à répondre aux besoins d'un nouvel usage. Trop souvent des immeubles sont dénaturés, des systèmes abandonnés où bien leurs particularités architecturales oblitérées sans prendre en considération la nature inhèrente de l'immeuble de continuer à fonctionner ou sans se soucier des valeurs culturelles, sociales et économiques qui font partie du caractère architectural et de son tissu.

C'est en se servant des données et de la technologie disponibles pour diagnostiquer l'état d'un immeuble et ses "maladies", faire des pronostic aussi bien que prèscrire un traitement qu'on arrivera à une méthode analytique qui prolongera la vie d'un immeuble. Ces systèmes techniques font partie des services élargis des architectes où des conservateurs architecturaux. On peût se servir de ces méthodes d'évaluation pour le contrôle de nouveaux traveaux où pour des réparations récentes, le constat des lieux suivant le départ d'un occupant, pour les problèmes de base, pour le développement des plans de maintien où la planification d'un projet de réhabilitation de tout un immeuble. Il y a un rapport entre les décisions de conservation et le rendement ultime de l'immeuble qui doit avoir comme base les standards d'évaluation. L'analyse des standards en question avec les données constituées des mesures sur le terrain où les analyses en laboratoire permettent de prevoir le fonctionnement de tout l'immeuble et de montrer l'interaction des éléments de l'immeuble, tel que l'exterieur, la structure, l'interieur, l'infrastructure (mecanique, les installations electriques, l'illumination etc.), les parterres et les particularités du terrain. Les données obtenue des restaurations des monuments historiques nous ont prouvé que les échecs étaient dus au fait de traiter les symptomes indépendemment de l'ensemble.

Malgré le fait que l'emploi des méthodes de diagnostic et des systemes d'enregistrement ont été mis en usage assez tard aux États-Unis, il y a bon nombre d'instruments courants et de techniques disponible pour analyser l'état d'un immeuble et la cadence de changement dans un systeme de strucure ou de materiel. Actuellement on a accès à une bonne quantité de références pour permettre le choix de méthodes afin d'analyser un immeuble et de diagnostiquer ses problèmes. À présent il y a de nouvelles possibilités pour permettre à la recherche appliquee d'utiliser la technologie courante dans le domaine de la science matérielle et des autres domaines scientifiques pour diagnostiquer et suivre les matériaux de construction et les systèmes.

Cette étude traitera, donc, de l'importance et de la comprehension des principes du mode de fonctionnement actuel des immeubles, du développement practique de l'art de diagnostic et de l'usage économique des instruments s'y rapportant ainsi que des systemes de monitorage.