Analyzing Building Failures: Tools and Methodologies

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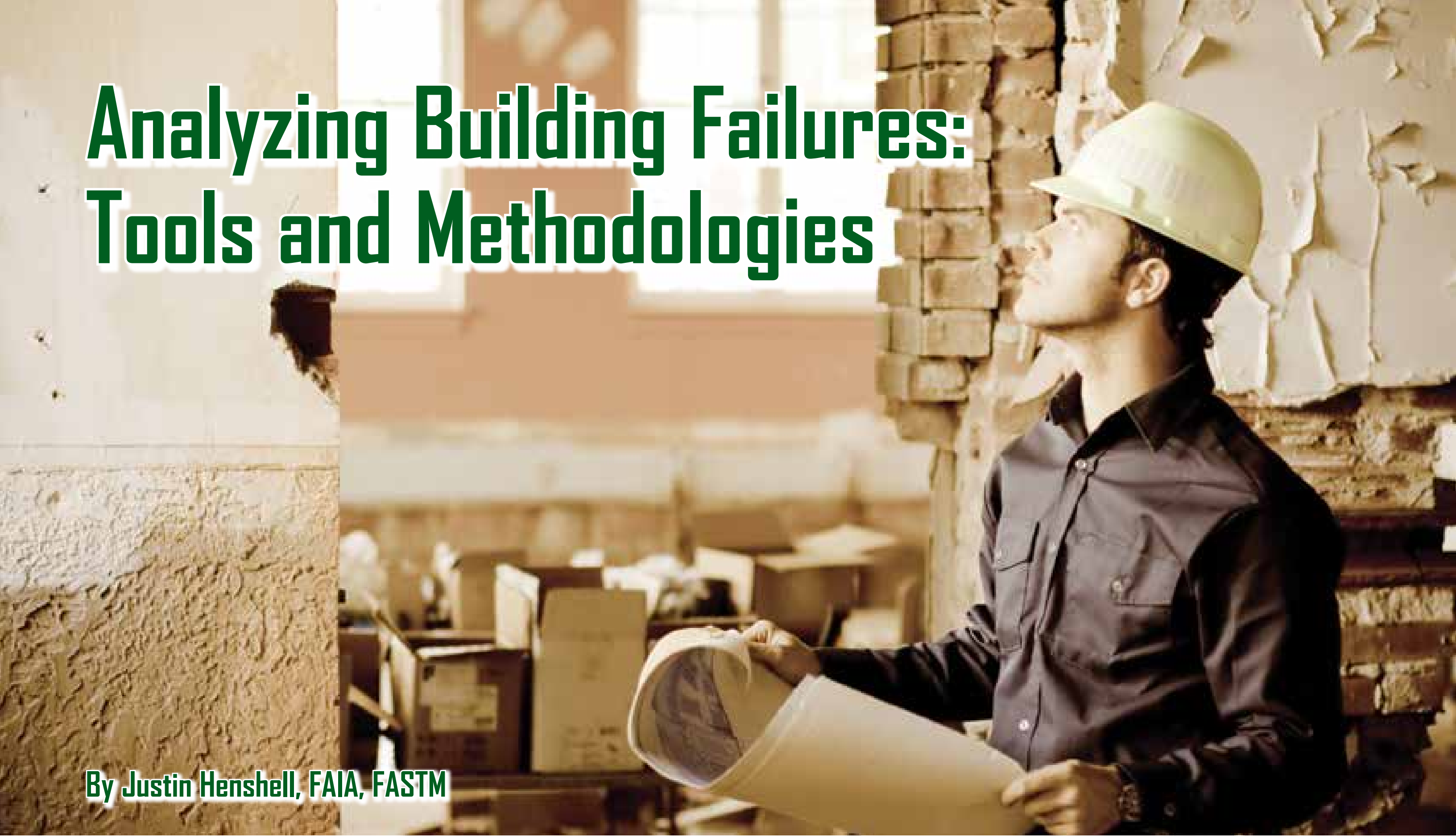


BACKGROUND

The science of analyzing building failures is often called building pathology. Pathology is defined as "any deviation from a healthy, normal, or efficient condition," and the science of building pathology is defined by CIB[1] Commission W86 as the "systematic treatment of building defects, its causes, its consequences, and its remedies."

Building pathology has been compared to a novel in which the building pathologist is a detective who solves the crime. The building is the victim; the defect is the crime; and the materials, details of construction, and environmental conditions are among a long list of suspects. In the conclusion, the detective solves the case by systematically acquiring the facts and data and identifying the most likely cause. The villain is exposed, and the detective gets the girl.

Today, the field of building pathology is creating new interest and opportunities in the United States, particularly among lawyers. Since attorneys have just about exhausted asbestos claims, they have been seeking new sources of income from distressed buildings. Water infiltration through the envelope and condensation are the most prevalent potential sources of substantial income for underachieving lawyers and their experts.

Building pathology was a little-known field of endeavor until it caught the fancy of several members of the British Building Research Establishment in the 1980s. Its objective was to help building professionals diagnose the causes of building failures and suggest ways to prevent them.

The commission began by deciding to determine the most important defect and

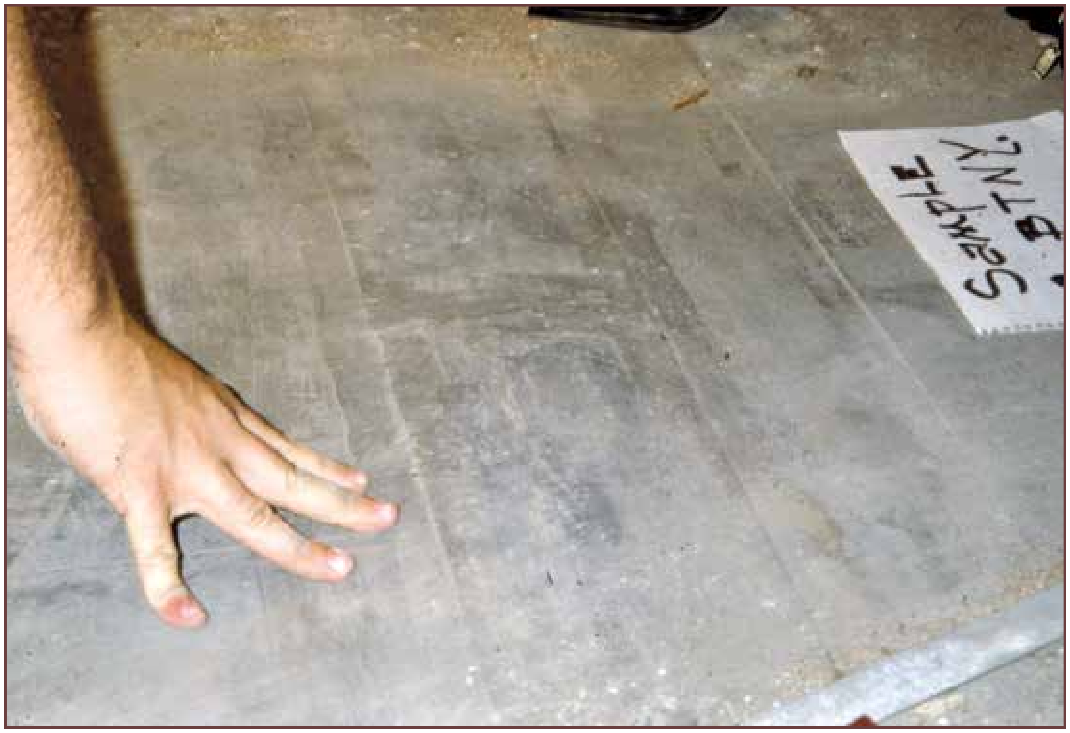


Figure 1 – Tactile testing for moisture.

Figure 2 – Measuring displacement.

then focusing its efforts on it. Members were polled and responses were obtained from about 15 different countries. The overwhelming majority of members said that water-related problems in the building envelope were by far their greatest concern.

To address these issues, the commission developed a structured scientific approach for investigating and reporting water-related issues in building failures. This paper discusses the methodologies and tools building pathologists use for this purpose.

Building pathologists would not exist if buildings didn't have problems. Therefore, the first steps are identifying a problem and then quantifying it. Building pathologists most commonly collect information by systematically inspecting the building. This is usually called a condition survey.

The investigator must make every effort to include all pertinent observations in reports to avoid an accusation of subjectivity. An investigator's background and area of expertise may skew his or her observations. For example, a ceramicist or brick expert may survey a problem building and conclude that the bricks are at fault because he concentrates on bricks to the exclusion of all else. The petrographer (a mortar expert) who performs the same survey concludes that the mortar is at fault because she is more knowledgeable about mortar than bricks. The professional association of the author of a report all too often reveals what will be identified as the cause of the problem.

Because of concerns with the objectivity of investigators, one aim of the commission was to devise an orderly and systematic scientific approach to data collection.

DATA ACCUMULATION

Depending only on the sense of sight is not always sufficient. We use our senses of sight, sound, smell, and touch, aided with instruments, to collect data. Diagnostic sheets and checklists can be helpful in this effort. We acquire information by looking for evidence of distress or deterioration, such as the presence of cracks, displacement, visible water, stains, rot, odors, and mold. Then we determine if the evidence is measurable and recordable (*Figure 1*).

Decay is often evident to our sense of smell.

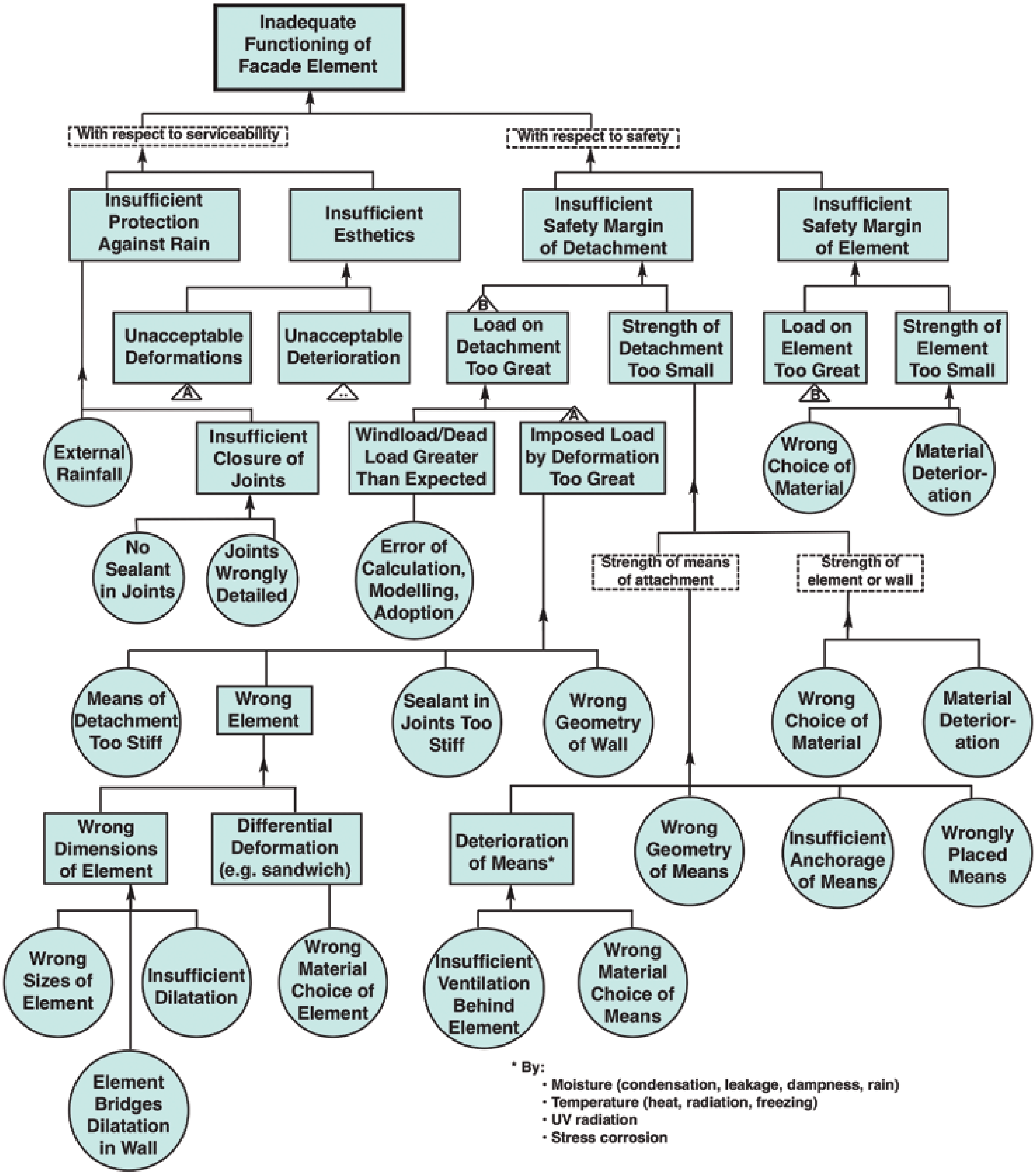
Salts are detectable by tasting them. A seasoned roof consultant will often use a taste test to determine the difference between asphalt and coal tar pitch.

Dampness can be discerned by touch, but often dampness and other properties are undetectable and not measurable. For example, laboratory studies have shown that most fibrous roofing materials do not feel wet to the touch until moisture is 45 to 50% of their weight (*Figure 2*).

To supplement our senses, we use tools that can be unsophisticated, such as pressing a facial tissue against a surface to detect dampness or poking with an awl to discover the presence of decay.

We supplement close-up viewing with binoculars, abseiling (industrial rope access), fiber optics (borescopes), videography, and robotics. Observations can be documented with photographs.

We can obtain information beyond the visible spectrum with thermography (infrared photography) by hand-held cameras and



* By:
- Moisture (condensation, leakage, dampness, rain)
- Temperature (heat, radiation, freezing)
- UV radiation
- Stress corrosion

Figure 3 – Condensed fault tree for façade failure.

flyovers, stereo photography, radar, x-rays, thermometers, and hygrometers. Other aids to sight include simple measuring, monitoring with gauges and remote monitoring, magnetic detection, pulse/echo, and nuclear testing.

To supplement our sense of taste, we use litmus paper to determine acidity.

To supplement our sense of touch to determine the presence of dampness, we use many nondestructive tests, including facial tissues and covering surfaces with plastic sheets.

Testing for moisture in concrete is specified in several ASTM Standards, including D4263, F1869, and F2170.[2] Among these tests are: calcium chloride cups, carbide meters for concrete, various moisture meters using galvanic, electrical capacitance, nuclear testers that detect hydrogen atoms, and infrared cameras. Nondestructive tests do require probes to establish a baseline for wetness. We conduct other tests, such as chemically analyzing water leaking into a cellar to detect the presence of coliform (if it is caused by a sewer leak) or chlorine (if it is a broken water main). We test air leakage by using blower doors, observing the flame from a match, or using a moistened finger.[3]

After raw data is accumulated, it must be analyzed and interpreted. The process is analogous to a doctor analyzing and interpreting an x-ray or—more pertinent to buildings—a technician interpreting an infrared scan of a roof.

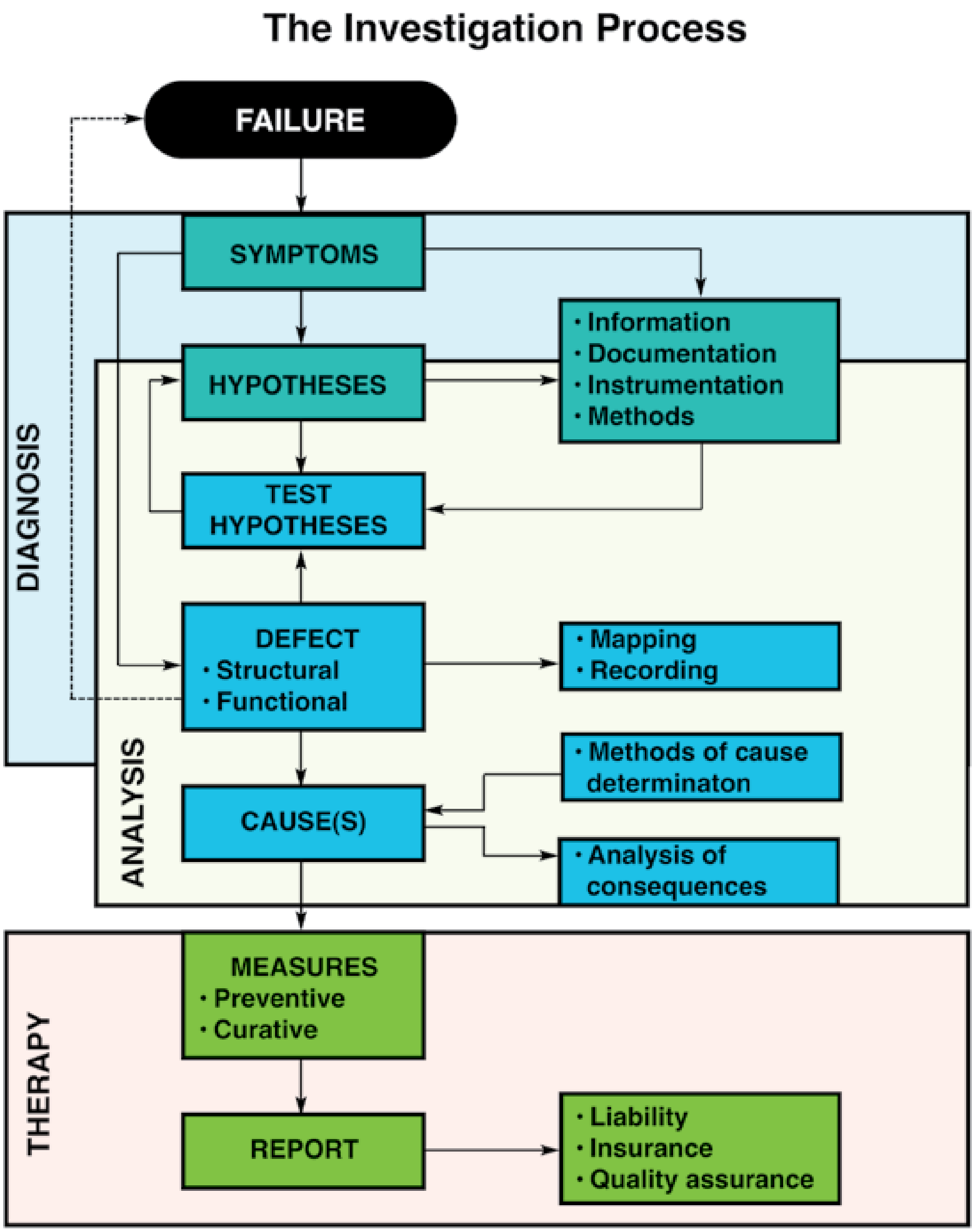


Figure 4 – The investigation process.

METHODOLOGIES

We have developed half a dozen diagnostic systems to aid in interpreting data accumulated by our senses and instruments to make the process as objective as possible.

Systems include diagnostic charts, data banks, fault trees, diagnostic trees, and artificial intelligence. Diagnostic or expert systems provide logical steps to diagnose building defects in a structured way.

The least sophisticated system is a diagnostic chart or table with a list of observable anomalies and a range of possible defects and causes associated with them. To be effective, these charts must be prepared for a specific defect, and they require the input of an expert in the particular building component under investigation.

Many technical organizations in the U.S. publish guidelines for condition surveys of specific building components, such as structures or walls. One is ASTM E2128 for evaluating leakage in building walls.

Fault trees are another type of diagnostic system in which possible errors affecting the performance of the building component are outlined. Fault trees are cause-oriented and use traditional logic for evaluating data to reach a conclusion. This chain of events leading from error to failure is called "forward chaining." A fault tree forces the investigator to consider all possible causes and thus counters the investigator's subjectivity (*Figure 3*).

While the fault tree is helpful in understanding relationships between an undesired event and possible causes, it does not always pinpoint the actual cause.

A diagnostic tree is the converse of a fault tree. It is a procedural guide leading from failure to error, also called "backward chaining." A diagnostic tree mimics the reasoning process an expert uses by backward chaining and attempting to ascertain the error that caused it. Thus, it relies more on the experience of the expert than the fault tree or diagnostic chart (*Figure 4*).

The primary advantage of the diagnostic tree is that it helps the expert be more efficient. It also helps the expert avoid the automatic and unconscious tendency to redefine any general problem to fit the Procrustean bed of his or her specialization.

Several other expert systems are worthy of mention. These include databases, data banks, and computer-based systems (often called artificial intelligence).

Databases are accumulations of case

Figure 5 – Poorly executed water testing.

studies. Their disadvantages are limitations of scope and magnitude, the cost of collecting and inputting data, and the effort to monitor the quality of the submitted data. Also, many databases are not maintained and, therefore, become dated. The French Sycodes is probably the only one that presently exists. One casualty was the Architectural and Engineering Performance Information Center (AEPC), which was established at the University of Maryland in 1982. It was not very successful for the very reasons stated above and only lasted about five years. Insurance companies maintain large databases, but consider them to be confidential business information. However, I've been advised that HAPM in the United Kingdom has made its data available.

With an artificial intelligence system, a pathologist examines a building while interrogating the software. The intelligence of these programs is limited by the quality of the information that has been entered into them. Artificial intelligence processes existing knowledge and produces a predefined choice from predefined information, but to do this it needs an expert's assistance and a knowledge base.

If you asked a computer, "What kind of an animal has four legs, a tail, and a long snout?" the answer might be "an elephant." However, the correct answer might also be "an anteater." The reason the elephant answer might be wrong is simply because "anteater" was never programmed into the database.

The major problem of each of these systems is that they rely on databases that are necessarily limited by the data in the data bank.

Some Eastern cultures use sticks, tea leaves, and coins to interpret problems. This contrasts with Western experts who claim that their methods are superior because they arrive at their conclusions by assembling and analyzing all the facts. Easterners contest this approach by asking: How do you know when you have all the facts?

Are expert systems going to replace building pathologists? Probably not. An expert system must be considered as a sup-

porting diagnostic tool for a human expert. After all, an expert system cannot produce any better information than the stored knowledge from experts. However, it produces information quickly, including information that might otherwise be overlooked.

TESTING

One of the most common and useful diagnostic tools to locate leak sources is the water test. While the presence of moisture on the interior face of an exterior building component subjected to water spray or ponding may be conclusive evidence that it leaks, ill-conceived and ill-executed water tests have many disadvantages. Given a hose with enough pressure, anyone can make any building leak (*Figure 5*).

The major disadvantage of water tests is the difficulty of simulating the actual environmental conditions that prevail when the building leaks. Water tests cannot simulate the effects of rain with complete accuracy. Although they are useful tools, at best they are approximations and require a host of assumptions that the building itself is not always willing to make.

As with visual observations, the objectivity of the investigator who devises the tests may be challenged. Consequently, making assumptions automatically introduces subjectivity, and this skews the results.

How representational is this test, and how close is it to reality? Testing attempts to replicate the conditions, but no test can include all the parameters or variables.

Before you initiate a test, consider these guidelines:

- Remember that some tests prove nothing, but they are repeatable and reproducible.
- Know beforehand at least half of what the results will yield.
- Develop a hypothesis of the problem. Use the test to verify or disprove your hypothesis.
- Know what you will do when you find a failure condition.

SUMMARY

This paper has discussed the methodologies, some of the tools, and the tests that help us examine a building problem in a systematic way, as well as some of the methodologies we use to avoid subjective observations. We have also stated our belief that testing must be based on realistic assumptions or the results will be flawed.

For more than 50 years, we have struggled to create and maintain data banks and seen them founder or at least constrict their scope. We still question the practicality of artificial intelligence and whether fault trees can be used over a wide enough spectrum of building problems.

Examining a building for defects is partly art and partly science. Methodologies and the tools we use emphasize the scientific aspect. However, most practitioners in the art of building pathology realize that there is no substitute for experience. Even after 40 years of opening buildings, I have yet to find exactly what I thought I would find.

One of the most important challenges faced by building pathologists is how to communicate. We must develop a method to transfer information from experienced building pathologists to lay people. Writing a diagnosis is not enough: it must be done in clear, understandable, jargon-free language.

Expert diagnosticians bring experience to problems, and most use the inferential method of backward chaining. As professionals increase their expertise, they become further removed from the ability to explain problems, methodologies, and solutions to people with no expertise.

We are blessed with many nondestructive tools to help us investigate buildings without invading the fabric of the building component. Even so, our methods to make failure-analysis a science have not advanced much in the last 75 years. In his book *Water in Buildings*, Bill Rose quotes Max Abramovitz, who, in 1949, bemoaned the fact that the science of building was going to disappear. With new methodologies, superfast computers, and the rapid dissemination of knowledge that we have today, we can develop new techniques and prevent this from happening.

CIB, publications produced by the old National Bureau of Standards, the *Canadian Building Digests*, the National Institute of Building Science, the Building Research Information Knowledgebase (BRIK), and some technical trade journals have made significant contributions toward advancing building science, but very little toward the art of failure analysis. Technology has been helpful, but we need more people looking at buildings and fewer staring at screens. As Albert Einstein said, "We don't know what we're looking for. That's why they call it research." Proponents of reducing an art to a science will continue to propose expert systems, but systems are likely to continue to be unable to replace the experience of a dispassionate and objective forensic investigator.

André Gide said, "Believe those who are seeking the truth. Doubt those who find it."

FOOTNOTES

1. International Council for Building Research Studies and Documentation (Conseil International du Batiment pour la Recherche L'Etude et la Documentation)
2. ASTM C1616, *Test for Determining the Moisture Content of Inorganic Insulation Materials by Weight*; ASTM D4442, *Test for Direct Moisture Content Measurement of Wood and Wood-Base Materials*; ASTM E2332, *Practice for Investigation and Analysis of Physical Component Failure*; ASTM F1869, *Test for Measuring Moisture Vapor Emission Rate of Concrete Subfloors Using Anhydrous Calcium Chloride*; ASTM F2170, *Test for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes*
3. According to Joseph Lstiburek of Building Science Corp., the minimum wind pressure that can be experienced with a wet finger is 1 Pascal; with a dry finger, 5 Pascals.

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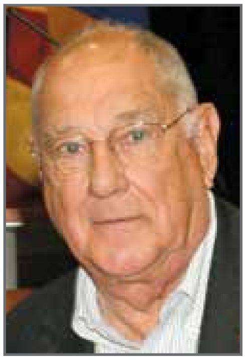

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Justin Henshell, FAIA, is a partner in Henshell & Buccellato, Consulting Architects, and has been a registered architect for over 60 years. He is a Fellow of ASTM, a member of CSI, and serves on the International Council for Building Research Studies & Documentation, Commission W086, Building Pathology. Henshell has authored more than 60 technical articles and papers and presented them in the U.S., Canada, and Europe on a variety of subjects related to construction materials, particularly roofing, waterproofing, flashing, and masonry. He is coauthor of an NCARB monograph on built-up roofing and the author of The Manual of Below-Grade Waterproofing Systems, *published by John Wiley & Sons.*