BUILDING PERFORMANCE (Mechanical, Electrical, and Other Building Systems)

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The ability to fairly assess the performance of existing building systems is a critical component in the process of determining the future (restoration, re-use, renovation) of an existing building. Overly positive evaluations increase the incidents of cost over-runs, giving preservation a black eye, and overly negative evaluations either doom buildings, or make them subject to excessive interventions that needlessly destroy historic fabric.

For purposes of this colloquium, and because no other session appears to address building systems, this discussion will attempt to discuss building performance in general terms as applicable to all building systems and will attempt to outline the competencies that all of the engineering disciplines commonly need. As I am a structural engineer, however, the point of departure for many of my comments will be from that discipline.

Engineers almost inevitably are involved with the systems of an historic building in one or more of the following ways:

- Evaluation of existing performance.
- Establishing the desired performance level for building systems, existing or new.
- Designing modifications to existing building systems, or designing new ones to replace the existing.

Evaluation of Existing Performance

Evaluation of existing performance is a critical first step and provides the basis for the two subsequent tasks listed above. Sometimes this can go very wrong.

In advance of a proposed major renovation of the most significant building at a college campus, the structural evaluation of a mid-19^{th} century masonry bearing wall building by an otherwise competent licensed engineer deemed the foundations inadequate because they lacked spread footings. This notwithstanding the fact that the walls were nearly three feet thick, there were no indications of distress in any of the five stories of masonry construction above, and the proposed use of the building, therefore the loading conditions, was not going to change. The resulting recommendation that the entire building would require underpinning nearly doomed the project and the building.

A similar evaluation of a one-hundred-year-old Pennsylvania bank barn could have yielded disastrous results. It suggested that the service load capacities of the timber framing were less than 30 PSF when only weeks before the hay mow had been filled with hay to height of over 15 feet.

What is the source of this disconnect between analysis and reality? Lack of knowledge regarding archaic systems, and inexperience in observing the evidence the artifact itself presents.

My own engineering education may not be a reliable benchmark vis-à-vis current curricula, but nowhere in my undergraduate courses were we introduced to archaic structural systems. The emphasis was modern materials (mostly steel and concrete) and new construction. Even then, wood framing and masonry construction were severely short-changed. Although we were introduced to materials and how they fail, it was done in a laboratory setting and nobody thought to teach us how those failures manifest themselves in real buildings.

To be able to assess the performance of an existing building system one must have knowledge of the original basis of design and be able to compare it with the current performance expectation and bases of design. This requires knowledge of the design practices, code requirements, and properties of the system components available at the time of the original construction. If the building has been modified in the intervening years, one needs the same compendium of knowledge for the period of the alterations. Again, at no time in my undergraduate education can I remember courses on building codes and standards, much less discourses on the history and development of those codes and standards.

When a performance analysis is based solely on current practices and codes it ignores several questions:

- What was the intent of the original design?
- Was the system properly designed to meet that design intent and applicable codes of the time of its construction or installation?
- Were the components of the system properly sized and fabricated to meet the design intent?
- Does the system's performance bear out the correctness of the original design?

Engineers need to learn to research historic documents and study original design documents to understand the design intent. A remarkable amount of information is contained in original documents.

To put the design intent in context and to evaluate whether the design met both intent and applicable codes and standards, one needs to study the design methods of the period and understand the underlying theories supporting those methods.

Much of the existing stock of buildings was constructed with systems and materials that are no longer in standard use. The unknowledgeable assumption is that those systems and materials are in some way defective or inferior. In fact, as much obsolescence may be the result of economics as performance deficits. Due diligence requires the engineer to know as much as possible about the obsolete systems and materials to be able to properly evaluate their performance, or capacity.

One also needs to be able to evaluate the condition of the installed/built systems and learn to recognize the symptoms of failure, or inadequacy. This requires understanding the original design. All systems over time reveal their flaws and anything designed by humans has flaws, but most in a surviving building are not yet fatal.

Once those questions are addressed, then the next set of questions needs to be:

- Is the current design intent significantly different from the original?
- Have the original design codes and standards under which it was designed been rendered obsolete, determined to be flawed, or been repudiated in any manner?
- Can the original design be considered comparable, albeit different, from a current design to accomplish the proposed design intent?

This type of assessment would have avoided the absurd recommendation to underpin the structure described above. It would have introduced the consideration of past and existing performance into the evaluation process. Although we neither design nor build buildings the same way we used to (we don’t even do it the same way it was done twenty years ago), it is unreasonably harsh to hold older buildings to current standards and not at least acknowledge proven performance over a wide range of conditions.

Ultimately one cannot rely totally on past performance as a prelude to future performance, nor can we ignore the potential for hidden flaws that will adversely affect future performance, but there are methods available to provide that added insight and which are the subject of another session at this colloquium.

Establishing Desired Performance Levels

Too often the determination of desired performance levels for building systems is out of the engineers' hands, whether dictated by the client, the prime professional, or code mandates. On the other hand, the engineer should be relied upon to understand the limits of existing performance and be able to design a complementary way to achieve what the new program requires. The engineer also needs to know when attempts to achieve new performance levels will damage, or endanger, the existing historic fabric. It is in this latter task that egregious mistakes have been made, particularly in the design of climate control systems in historic buildings.

For generations of engineers the design methods we were taught were acknowledged approximations of reality. In an era of hand calculations, simplified analytic methods based on simplifying assumptions regarding performance, and heavily dosed with safety factors, were standard practice. It seems to be second nature for engineers to gravitate to designing for the "norm", or the statistically-based bell curve of anticipated conditions, materials properties, and systems performance. This is a practical approach to satisfying both the responsibility to public safety and the limits of the project's budget.

Unfortunately, such broad-brush, standard design approaches tend to ignore both the inherent qualities, both positive and negative, of existing archaic building systems. Furthermore, it violates a fundamental tenet of preservation that each building is a unique object, not an average example. Again, a deeper knowledge of what was considered the standard, or norm, of the era of original construction would inform the current engineer as to the potential idiosyncrasies of the original design.

Today, with the increasing sophistication of computer modeling and analysis, we have the capacity to liberate ourselves from the simplifying assumptions used in the past. We can monitor and model existing conditions and performance and use that information to customize our designs to the conditions at hand. This is a rapidly developing technology (again covered in another session of this colloquium) that needs to be included in the education of preservation engineers of all stripes.

Designing New Systems or Modifications to Existing Systems

The tendency of engineers when unfamiliar with, or unsure of, an existing system has been to remove it, or bypass it, and install a completely new system in its stead. This often leads to unanticipated consequences and excessive loss of historic fabric.

Renovations, alterations, and replacements to mechanical, electrical, and plumbing systems are particularly egregious sources of damage to historic fabric. In large part this is because these systems have such short life cycles that they are redone many times within the life of a building, providing additional opportunities for causing damage. This short-cycling is a function of both changing technology and manufacturing rendering existing systems obsolete, or un-maintainable, and changing public attitudes toward creature comforts.

Among the design parameters we were taught to place a high priority on satisfying were code-compliance, cost-effectiveness, efficiency; collateral damage to building fabric and interaction with other building systems were not on that list. We designed with tunnel vision and without regard to these other parameters so integral to the preservation ethic. The design considerations demanded by preservation ethics need to become design parameters that rise higher on the preservation engineer's priority list.

Such a reorientation, or expansion, of design priorities comes with a need for enhanced design expertise. There is a need to learn how to achieve conventional results by unconventional means; a need to provide more detailed documentation than normally expected in a conventional installation; a need to understand and mitigate the adverse affects of new building systems on existing building systems; and a need to explore the potential to keep and possibly supplement the existing systems instead of wiping out the old and replacing it with new.

Education / Curriculum/ Research Needs

In broad terms, the discussion above describes the shortcomings of the "general practitioner" engineer with regards to the competencies one would expect the preservation engineer to possess. How would one describe the salient differences between the two?

First and foremost is knowledge of history, not necessarily cultural history, or architectural history, but history of his, or her, respective engineering discipline. This should include:

- People of note
- Evolution, characteristics, and properties of building systems and materials
- Notable technological developments
- Evolution of design theory and key analytical advances

Second, the preservation engineer needs to develop enhanced powers of observation to be able to recognize the physical evidence of system performance failures.

Third, the preservation engineer needs to learn how to research and interpret existing documentation, including specifications and drawings.

Fourth, the preservation engineer needs to look beyond his, or her, particular discipline to learn about the interaction between systems, especially between new and pre-existing systems.

Fifth, the preservation engineer needs to become familiar with methods of monitoring and testing the performance of existing systems, not only with respect to current standards, but with respect to original design intent.

Sixth, the preservation engineer needs to develop an understanding of not only the letter and intent of current building and design codes, but an understanding of the history and reasons for the way the current codes evolved with comparative analysis of the affect of key code changes.

Clearly, within this general framework the specific content of these six competencies will be different for each engineering discipline, but I am not aware of any existing curriculum covering this information for any discipline. A scattering of articles have appeared in journals such as the APT *Bulletin* which present research on some aspects of these topics, but they are few and none are exhaustive, or comprehensive. I am not aware of any bibliographies on these subjects. Therefore, there appears to be a need for the development, writing or amassing, of course reference materials for each discipline. I am unaware of how such an effort would be funded.

Nevertheless, even in the abstract, it is worth considering when, where, and how these competencies might be introduced into the engineering curriculum.

It is acknowledged that the undergraduate curriculum in most engineering programs allows little room for additional courses within a four-year program. Core courses required by accrediting institutions and mandatory courses required by the institution leave few opportunities for electives and most schools are loathe to adding more required courses at the expense of electives. It would seem doable and appropriate, however, to provide an *Introduction to the History and Theory of [insert your specific discipline]* at the undergraduate level.

Likewise, improved powers of observation, especially recognition of defects in actual installations or systems, could be developed in “hands-on” laboratory sessions at the undergraduate level. This could be accompanied by instruction on how to document fields observations, how to research existing documentation, and how to interpret or understand existing documents – such as specifications and drawings. Admittedly, mechanical drawing and drafting have fallen out of the standard curriculum, but some introduction to those skills would be beneficial.

There is a substantial need for both historical research and primary research to support the development of preservation engineering expertise. This may be an opportunity for postgraduate work if financial support can be found. There are probably more topics than I can imagine, but some research topics that come to mind are: history and development of codes, history and development of design theory, history and developments in the manufacture of products and systems (of particular interest to me has been the evolution of the manufacture of iron products and the inter-relationship between the evolving product and the changing of design methods in response). Eventually, one can imagine that this research would become the basis of text books.

In terms of primary research, again, the topics are numerous, but could include: design and application of methods to monitor and test performance of existing and archaic systems and materials, development of methods to model performance of existing and archaic systems materials, develop refinements to modern analytic techniques that permit their ready application to archaic systems and materials using the results of the previous research results.

These are modest proposals, but the intent is to encourage the development of a framework for an engineering discipline that, with respect to existing and archaic systems, has knowledge of historical precedents, a respect for what was previously produced, and an ability to understand what they still can offer.