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Preservation Engineering: Framing a New Curriculum

As significant, beginning steps for new academic programs in preservation engineering are being made at several universities in the United States, some reflection on how we got here and how we might approach this critically important undertaking is warranted. A model for preservation engineering education may be that of historic preservation itself, which grew out of architecture and architectural history. Like historic preservation programs, preservation engineering education will likely develop and evolve on multiple fronts, and the specific nature of this progress will inevitably depend upon the needs and means of particular localities and institutions. The study and practice of preservation engineering mediates a critical juncture between the architectural and cultural heritage essential to our humanistic society and the science and technology that has made much of it possible—seemingly disparate realms with distinct languages. With this challenge, a framework of core fluencies is proposed in this article as one possible guide for new curriculums. From this, the specialized tools and technologies that have become important components of current preservation practice can be studied, applied, and interpreted with greatest reward.

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Preservation engineering education is happening. Although this is nothing new, what is new is the groundswell of effort to bring this education from the world of practicing professionals into the academy. As significant, beginning steps for new programs are being made at several universities in the United States, some reflection on how we got here and how we might approach this critically important undertaking is warranted. This article explores a philosophy and core fluencies that can serve as a foundation and framework for future preservation engineering curriculums. Bridging the gaps among disciplines through translation between their specialized languages is essential in bringing this project to fruition. [1]

Today, much of new design and construction must interrelate with existing constructions that make up the physical setting of the project, particularly within an urban environment (Woodcock 1998).[2] Those approaching this task must be familiar with the building systems of the past, understand the mechanisms of decay and their visual manifestations, and translate this potential using current standards. However, the overly narrow focus on new construction in engineering education and related areas leaves students ill-prepared for entering the profession and perpetuates a mindset for building new and neglecting or disposing of the old; this fuels an unsustainable economic model.

Undergraduate engineers interested in historic structures confront the quandary of few options to further pursue their studies. Some enter historic preservation programs but effectively set aside their engineering studies until they complete a degree. Recapturing engineering concepts after a number of years often proves challenging, and the potential for good preservation engineers is lost. On the other hand, most undergraduate engineers do not have sufficient exposure to historic structures to begin to cultivate that interest.

A growing number of educators are now seeking answers to this problem by expanding university curriculums to include topics addressing engineering for the existing built environment. The answers, consistent with the diverse and rich history of building technology, are inherently multifaceted and contextually dependent. A model for preservation engineering education may indeed be that of historic preservation itself, which grew out of architecture and architectural history, with university coursework beginning as early as 1959 at the University of Virginia and expanding in the 1960s at both Cornell and Columbia universities (Tomlan 1994, 188). Diverse historic preservation programs emerged in many forms, with a number of distinct emphases. Likewise, preservation engineering education will likely develop and evolve on multiple fronts, and the specific nature of this progress will inevitably depend upon the needs and means of particular localities and institutions.

The study and practice of preservation engineering mediates a critical juncture between the architectural and cultural heritage essential to our humanistic society and the science and technology that has made much of it possible—seemingly disparate realms with distinct languages. With this challenge, a framework of core fluencies is proposed as one possible guide for new curriculums. From this, the specialized tools and technologies that have become important components of current preservation practice can be studied, applied, and interpreted with greatest reward.

MOMENTUM FOR CONSERVATION: RESISTING INERTIA

In North America, practicing preservation engineers have made substantial progress in recent years in defining the nature and philosophy of this work, particularly under the auspices of the Association for Preservation Technology (APT) and its Technical Committee for Preservation Engineering. Two issues of the *APT Bulletin* stand out defining the field and establishing standards of practice: a special issue on conservation engineering (1991, 23:1) with guest editor Stephen J. Kelley; and the special issue on preservation engineering (2005, 36:1) with guest editor Donald Friedman. The year following the first issue, the United States Congress passed the Historic Preservation Act Amendments of 1992, creating the National Center for Preservation Technology and Training (NCPTT), NCPTT's advisory board, and NCPTT's grants program. As part of the training mission, the architecture and engineering branch of NCPTT offered programs on engineering for historic buildings as early as 2000. [3]

In June 2009, NCPTT and the University of Vermont sponsored a colloquium, developed by Doug Porter and other UVM civil engineering and historic preservation faculty, on developing a curriculum for preservation engineering. The colloquium brought together leaders in the practice and education of preservation engineering and related areas, who advocated for infusing the ethics of preservation engineering into the undergraduate curriculum where possible while developing a master's program for advanced study.[4]

Internationally, organizations such as the Construction History Society have published on a diverse range of topics since 1985, including engineering and mechanics for historic constructions. Starting in 1998, a series of conferences on the Structural Analysis of Historical Constructions (SAHC) have taken place every two years and bring a strong academic focus to the challenge of quantifying and assessing the physical behavior of historic monuments and structures. In 2003, a document produced by the International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH) entitled "Recommendations for the Analysis, Conservation and Structural Restoration of Architectural Heritage," broadly outlined a principled approach to engineering assessments of historic constructions. The ISCARSAH recommendations are a companion to the ICOMOS Charter, "Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage," ratified by the ICOMOS 14th General Assembly (ICOMOS-ISCARSAH 2003).

Following these efforts, a European program of advanced study was developed. The Advanced Masters in Structural Analysis of Monuments & Historical Constructions represents a big step forward for preservation engineering internationally and sets a precedent for educators in the United States. Initiated in September 2007 and sponsored by several European universities,[5] the one-year study program is composed of eight units, including history of construction and of conservation; structural analysis techniques; seismic behavior and structural dynamics; inspection and diagnosis; repairing and strengthening techniques; restoration and conservation of materials; an integrated project; and a dissertation. However, adding broader concerns for historic preservation in the United States will be important in developing both technical skill and philosophical sensitivity.

These advances are but a sampling of the recent momentum. In American universities, individuals have made a number of significant contributions to the field, and now courses and programs for preservation engineers are being created. Perhaps one of the greatest challenges in taking the next steps will be to balance the need to develop specialized expertise that can be applied within a broader perspective. Coursework will need to develop technical proficiency in preservation engineering while preparing students to translate their expertise to a lay community.

TECHNICAL EDUCATION WITHIN A DIVERSE COMMUNITY

Preservation of the recent past, as exhibited in modern buildings, demands a recommitment to communication and to an integrated approach for assessment and design. For example, curtain wall and cladding systems shown in Figure 1 are a clear physical manifestation of the separation of or specialization within engineering and architecture. The seemingly neat separation of roles, embodied by the physically separated components, can lead us down the path of less communication. However, the communication between cladding and structure, between architect and engineer, is essential to the successful performance of the building. A focus on this interface, on the physical communication between specialized components, and on the communication between specialized professionals, is critical as our modern heritage grows older.

As early as 1874, Eugène-Emmanuel Viollet-le-Duc portrayed the separation of engineer and architect in a parable of twin masons, whose "narrow-minded" father made them divide their work for the sake of efficiency, with one working only above the ground while the other worked only below (Viollet-le-Duc 1874, 224-226). Lewis Mumford offered his 1924 perspective on the World's Columbian Exposition of 1893 with similar concern:

> Behind the white staff facade of the World's Fair buildings was the steel and glass structure of the engineer: the building spoke one language and the "architecture" another. If the coming of the skyscraper had turned masonry into veneer, here was a mode of architecture which was little but veneer (Mumford 1924, 128-129).

Michael Tomlan, director of the Historic Preservation Planning Program at Cornell University, addressed a similar issue of academic separation, in this case between architecture and preservation, in his 1994 article entitled "Historic Preservation Education:

Fig. 1. Marble cladding suffering from failure of original and retrofit connections, as exhibited on a building in Rome (All illustrations by author).

Alongside Architecture in Academia." Tomlan provides a summary of the development of historic preservation programs in America, explores the connections and divisions in architecture programs, and ultimately claims that "the importance of an active interaction between architecture and preservation remains paramount, because both professions will continue to focus on the rehabilitation of our built environment." Preservation graduate students historically comprise architects on the one side and social and art historians on the other, Tomlan notes. "The students who held a B. Arch. had already developed their drawing talent and had the ability to present their ideas visually.… The non-architects, on the other hand, had the ability to express their thoughts in writing" (Tomlan 1994, 189). To both support and expand upon this proposal, I add the importance of preservation engineering, an outgrowth of engineering more generally, working closely with both architects and preservationists. And, like the other two components of this triad, the students of preservation engineering bring their own language into this polyglot community, expressing their ideas primarily in mathematics.

It is perhaps surprising that coursework in building technology was an important early component in the historic preservation curriculum, with Charles E. Peterson teaching a course at Columbia University as early as 1968 and with William B. O'Neal teaching a course on the history of technology at the University of Virginia in 1972 (Tomlan 1994, 188-189). However, neither Peterson nor O'Neal were engineers by training. That technology topics were addressed very early emphasizes their perceived importance to historic preservation. That architects and architectural historians were teaching these topics was perhaps a reflection of their non-engineering audience.

Independent of architecture and historic preservation, David P. Billington used case studies in teaching structural engineering in Princeton University's civil engineering department in 1974. The course attracted students of engineering and the humanities as it focused on large-scale structures where the carrying of forces becomes the primary form-determining function. Billington's work, which has influenced a whole generation of engineering educators, linked engineered works to their historic and humanistic context. Significantly, the mathematical caluculation of efficiency of material use is inherent to Billington's engineering aesthetic. His coursework focuses on learning from the past in order to abstract principles and develop sound approaches for designing the new—perhaps akin to the value of architectural history and theory to the field of architecture. And even so, the history of engineering within architecture remains largely outside its purview, as do the technical skills involved in the preservation of these significant engineering works. The inclusion of these aspects in future curriculums is essential for the preservation engineer who will be challenged to sustain the engineering value of diverse constructions through application of engineering methods particular to preservation.

An effort is needed to bridge the apparent gap between the technical and humanistic; that is, to make specialized knowledge accessible at a meaningful level to a broader community. Given the diverse professional community working in historic preservation, this is a fitting teaching strategy.

LOST (AND FOUND) IN TRANSLATION: A PROBLEM (AND SOLUTION) IN LANGUAGE

> Most of the fundamental ideas of science are essentially simple, and may, as a rule, be expressed in a language comprehensible to everyone (Einstein, 1938: 27).

One of the challenges in communication between engineers, architects, preservationists, and the public at large is rooted in the nature of traditional engineering education, which uses mathematics as its primary "language." Andrew Saint, in his 2007 book *Architect and Engineer—A Study in Sibling Rivalry*, explores the relationship of architect and engineer and notes in conclusion "It is plausible, then, to ascribe the widening gulf between architectural and engineering skills to more complex materials and structures and the need for specialized calculations" (Saint 2007, 488). Mathematics is certainly an essential component of engineering education, both historically and today; it is a model of consistency and measurability in representing scientific principles and interpreting empirical studies. Bruce Seely, in his article "Research, Engineering, and Science in American Engineering Colleges: 1900-1960," presents a detailed history of engineering education in the United States and comments on the theoretical shift in twentieth-century education: "By 1960, however, engineering education looked very different. The emphasis on rules of thumb learned through practical experience had given way to an education stressing scientifically derived theory expressed in the language of mathematics" (Seely 1993, 345). And yet, despite the centrality of math, the primary products of engineering practice are words (reports and specifications) and drawings, thereby making translation between mathematics, words, and drawings a fundamental challenge. Whether assessing an existing construction or envisioning a new one, the design professional must access multiple languages to interpret the physical signs and symbols that make up the visual language of architecture. Acknowledging this intrinsic nature of communication within the building arts and industry, language and translation can provide a conceptual framework for a new curriculum.

In the practice of preservation engineering, engineering, and architecture, there are three broad categories of language from which the discourse of architecture and building grows: speech, graphics, and mathematics. The text and graphics in the familiar Venn diagram (Fig. 2) may be interpreted to represent this concept. The zones of translation among the three languages are in the overlapping areas, with the most dynamic area of communication occurring toward the center. Acknowledging that each of these languages plays a part in our understanding of architecture is a first step in developing the curriculum. Developing some degree of fluency in each is a second step. Mastery of each language is not necessary, however, successful communication and translation between them should be the goal. Therefore, achieving fluency in translating the three languages, in order to mediate the inherent approximations and modifications, becomes a most valuable and marketable skill. This is particularly true for preservation engineering where, beginning with visual observations of an existing structure, the translation to mathematical analysis must then be translated again to communicate with a broader audience.

Some noted figures in the history of architectural criticism have similarly categorized the means of description and communication. Umberto Eco, in his essay "Function and Sign: The Semiotics of Architecture" in Broadbent, Bunt and Jencks' *Signs, Symbols and Architecture* discusses three forms of architectural description: "two-dimensional (through a set of drawings or a photograph), verbal (through an oral or written description), mathematical (through a series of equations), etc" (Eco 1980, 49). Although Eco's reference to graphical description does not foresee the three-dimensional modeling that is commonplace today, both two-dimensional representations or a three-dimensional model may be considered modes of graphical communication. Likewise, his descriptions via mathematical equations may today more commonly be in the form of structural or mechanical computer models. James Marston Fitch describes "verbal/literary" and "pictorial/aesthetic" as the two main phyla from which architectural discourse grows. These categories correspond, generally, to the languages of speech and graphics. Interestingly, the footnote following the naming of these two phyla addresses the "missing" third phylum of architectural theory, which corresponds to what we have defined as the language of mathematics: "There is, of course, a third phylum of architectural theory which

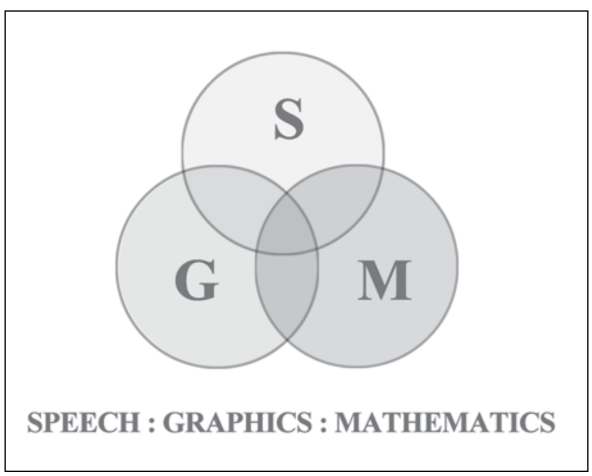

Fig. 2. Languages of discourse for the building arts.

deals with the science and technology of building design, construction and performance" (Fitch 1988, 9). These languages may be applied to the assessment of an existing building or the design of the new—the vocabulary may change somewhat but the languages are the same. These two activities will be described as analysis and design. Figure 3 shows how the three languages may be employed toward a new design or to envision a history of performance for the assessment of existing construction. This framework shared by analysis and design may be likened to a person behind the wheel of a car traveling through the time and space of the built environment.[6] In engineering or architecture, and most dramatically in preservation engineering, the future would not be taught without a past (we use the rear-view mirror); nor would the past be taught without a future (we drive ahead).

Figure 3 also indicates a discernible space between the work of architecture and our means of communication, a space mediated by analysis or design. Our languages, however poignant, precise, or poetic, are but approximations of the physical reality. This does not detract from the vitality and history of the discourse itself—its words may rise to poetry, its graphics may be considered art, its mathematical formulations may be groundbreaking, and yet these languages remain distinct from the physical objects they describe.

This is important for the engineer and the architect to remember. The engineer needs to develop designs or make determinations on existing buildings based on empirically proven methods that produce results within an acceptable level of reliability. For preservation engineering, approximations must typically accommodate a broader range of unknowns than in new construction and, as such, warrant an iterative, multifaceted approach to safety evaluation. Therefore, it is essential to include empirical evidence of past performance side by side with evaluations reflecting current analytical methods and standards of risk and reliability.

INTRODUCING PRESERVATION TO ENGINEERING UNDERGRADUATES IN THE UNITED STATES

Introducing undergraduate engineers to preservation engineering is critical to the sustainable development of the profession. The field of civil engineering, where significant work is being done on the development of an academic curriculum projecting to the year 2025, suggests ways of cultivating preservation engineering skill sets and philosophies.

The broad effort of committees of the American Society of Civil Engineers (ASCE) has led to the development of a detailed study entitled *Civil Engineering Body of Knowledge for the 21st Century: Preparing the Civil Engineer for the Future* (ASCE 2008). Civil engineering is already a broad area of study that encompasses structural, geotechnical, hydraulic, and transportation engineering, as well as surveying and water resources. This makes balancing the simultaneous need for breadth and specialization particularly challenging. Adding another layer to this equation seems a daunting task. The 2008 *Body of Knowledge* study, here referred to as BOK2 (the first BOK study was published in 2004), aims toward the admirable goals of sustainability, global thinking, and broadening the exposure of engineers to the humanities and social sciences, while maintaining a strong focus on technical subjects.

Sustainability is a recurrent theme in the vision for civil engineering in 2025: "An ever-increasing global population that is shifting even more to urban areas

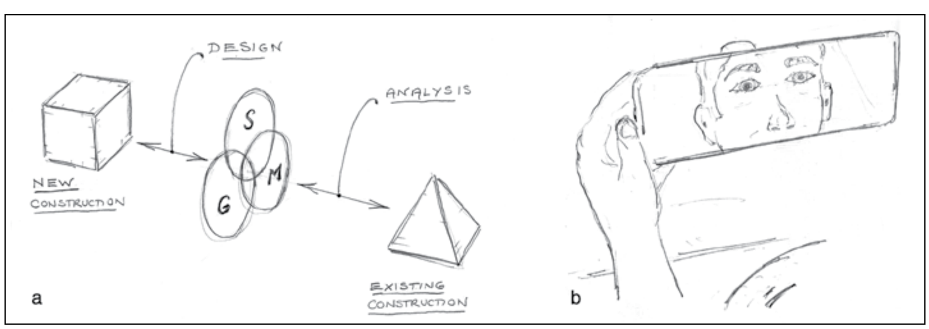

Fig. 3. Looking both ways: analysis of the existing influences in the design of the new.

will require widespread adoption of sustainability" (ASCE 2008, 6). However, the sustainable value of working with what we already have, the existing built environment, has not been clearly articulated as part of the future curriculum. Take, for example, the definition of civil engineering itself, adopted by the ASCE in 1961 and reiterated in the BOK2 document:

> The profession in which a knowledge of the mathematical and physical sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the progressive well-being of humanity in creating, improving and protecting the environment, in providing facilities for community living, industry and transportation, and in providing structures for the use of humanity (ASCE 2008, 6).

Let us propose the following simple revisions that would help embrace the stated goals of sustainability:

> in providing**,** preserving, and sustaining facilities for community living, industry, and transportation, and in providing, preserving, and sustaining structures for the use of humanity.

Acknowledging that civil engineering, like architecture, does not start with a blank slate but instead builds on a history of engineering and an existing context is a seemingly easy first step.

The BOK studies assess and measure the levels of student achievement using a standard developmental taxonomy initiated by Bloom et al. Bloom's taxonomy describes three domains of learning: cognitive, affective, and psychomotor:

> …the cognitive domain…includes those objectives [that] deal with the recall or recognition of knowledge and the development of intellectual abilities and skills.…the affective domain…includes objectives [that] describe changes in interest, attitudes, and values.…the psychomotor domain…includes "…the manipulative or motor skill area" (ASCE 2008, 14).

A generalized connection may be drawn between these domains and the three languages of speech, graphics, and mathematics. In alignment with the order of learning domains presented in Bloom's taxonomy, the cognitive domain for engineers is primarily addressed by mathematics, the affective domain by speech, and the psychomotor domain by graphics. It is interesting that the BOK2 study concludes with the recommendation for moving from the predominant one-dimensionality of the current set of goals in civil engineering education, which focuses mainly on the cognitive domain, toward a two-dimensional approach, extending the realm of pedagogy to include both the cognitive and affective domains (ASCE 2008, 92). This seems an appropriate step, but why stop there? A three-dimensional system of measures can actually be observed in many current programs and could readily be envisioned or articulated to establish parameters for future programs, particularly for preservation engineering.

Considering this work focuses on the three-dimensional built environment, with the critical fourth dimension of time, there are many opportunities to become educated and set educational goals within the psychomotor domain. This already happens in most programs, although is perhaps not articulated as such. Some examples might include the mixing of concrete, mortar, or the building and testing of a physical model in a laboratory and using active monitoring to evaluate performance. For preservation engineering in particular, the acts of walking around and through an existing building while absorbing the three-dimensional assembly of its structure, observing the signs of physical behavior and material durability that exist as a response to the environmental context, and the physical act of translating these observations into a graphical form—a hand sketch—are all ways we learn about the built environment from the built environment.

A broadened perspective appropriate to preservation engineering can be introduced to the undergraduate engineering curriculum in a number of ways, three of which are suggested here. Common to all three recommendations is an emphasis on core literacies. With mathematics well established as the primary language for engineering education, additional emphasis is recommended in teaching verbal/written and graphical communication. One course dedicated to each is recommended, such as technical writing and engineering graphics. In addition, assignments and class work should be designed to exercise the three languages throughout the curriculum.

The first recommendation is to include examples of existing construction alongside examples of new construction in design classes. Existing examples may well be historic or otherwise significant structures that can be memorably associated with a particular analysis or design problem, so that the differences in design and material standards can be emphasized. This approach could broadly highlight a perspective, an attitude, or an ethic, focusing on working with existing or new construction in an integrated manner.

Another path could be the addition of a special topics course designed to introduce preservation engineering as a future specialization and/or possible career. This introductory course could be organized according to building materials and associated systems, tracing the evolution of design standards over time and leading to basic approaches to intervention. The course could also develop along the lines of the successful work of David P. Billington at Princeton University, as discussed previously, which uses case studies to highlight both the history and technical skills associated with significant works.

A third approach is the integration of existing or historic constructions into an upper level design project. I have applied some of these ideas in the capstone senior design course in the civil engineering department at Johns Hopkins University, entitled Design and Synthesis II. The class explores the inherent role of precedent and existing constructions as a vehicle for design in a historic context. Lectures focus on the application of engineering to evaluate existing structures as the starting point for the design process and explore the role of the engineer through design and construction. The first assignment emphasizes the need to develop communication and translation skills by asking students to document and describe "structural remnants." Examples of structural remnants, depicted in Figure 4, are available in class for hands-on survey and assessment. Students work in groups of two to four, one group for each remnant, to observe and gather data. The assignment asks students to describe the material, form, and function of their structural remnant in a three-page document, with page one a written narrative, page two a sketch or sketches, and page three mathematical calculations of geometric parameters and/or physical capacities. The students are also required to present their findings orally. Figure 5 shows a sample assignment for a Guastavino clay tile that represents the ceiling system of the hallway outside their classroom.

A MASTER'S PROGRAM IN PRESERVATION ENGINEERING IN THE UNITED STATES

The development of an academic program in the United States, such as a Master of Science in Preservation Engineering (MSPE), is needed to meet the changing demands of both the building industry and the sensibilities of communities embracing

Fig. 4. Structural remnants for in-class assessment: (a) terra cotta foundation block (1938); (b) steel I-beam (1913); (c) wood joist and connection (1810).

Assignment #1

The Guastavino tile is a red clay tile that is slender in elevation. These tiles, layered in a staggered pattern across the arched ceiling as well as into the depth of the ceiling support the first floor of the Latrobe Hall corridor. The tiles are 4 inches by 1 inch by 9 inches and contain ribbing on two sides. These ridges help to create a bond between tiles that is more shear resistant than a smooth surface bond would be. The tiles are light weight, so in combination with the mortar, the tiles do not carry a lot of dead weight in the ceiling.

The manner in which the tiles are staggered create a lattice that allows the ceiling to function as a unit. The shape of the ceiling is assumed to be a parabolic arch with a span of 110 inches and a maximum height of 15 inches. This arch acts as a member in pure compression when it is subjected to uniform loads, as it in this situation. The sides of the wall apply a reaction force to the bottom of the arch allowing for it to function as a compression member.

Under a dead load of 100 psf the ceiling composed of Guastavino tiles can also support a maximum live load of 255 psf. This figure is based on the calculation of a parabolic arch in two dimensions, using ASD parameters and no load factors.

The arched ceiling undergoes no out-of-plane bending when it is idealized as a parabolic arch under uniform loading. At the end of each segment of ceiling, there exist sections of brick that rise from the top of the wall to the top of the arch creating a buttress-like structure to secure the continuous arch. Therefore, the only moment that needs to be considered is the bending moment that the ceiling experiences.

a

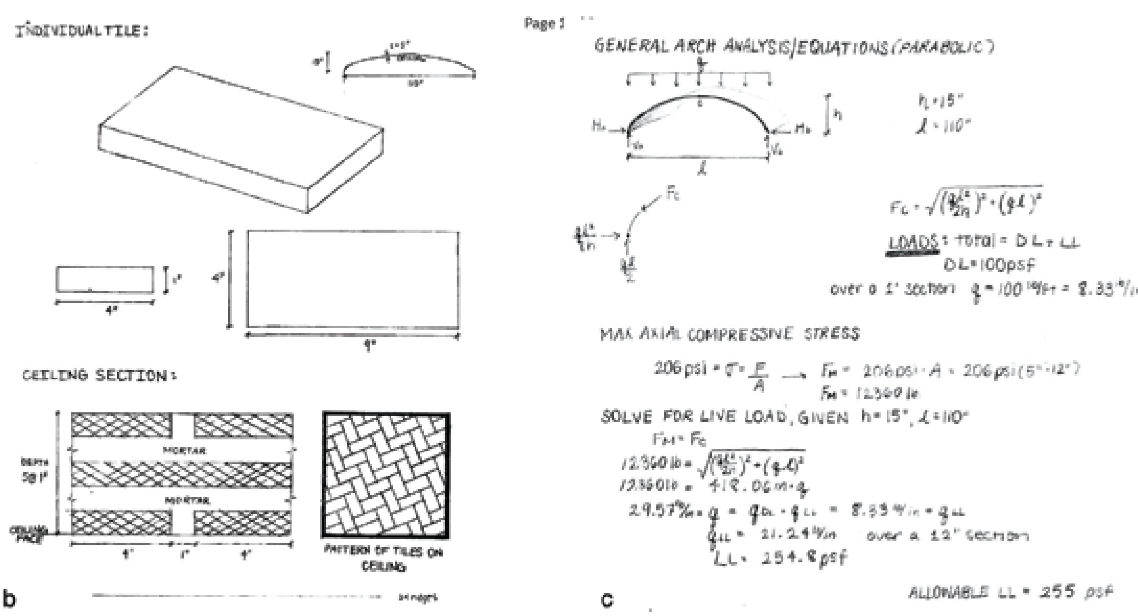

Fig. 5. Sample assignment: structural remnants for in-class assessment.

their historic resources. This program could offer the opportunity for engineers interested in historic structures and/or preservation issues to develop concentrated study in this technical specialization, with the opportunity to broaden their perspective on history and philosophy.

The MSPE would ideally be developed within the multidisciplinary context of existing engineering, architecture, and historic preservation programs. Given the integrated nature of historic preservation and the relatively isolated focus on technical issues for engineering undergraduates, situating this master's program within a diverse academic community reflective of the profession is important, and arguably critical, to the learning process. Regardless of whether existing departments are in place, the professional community can help fill gaps in representative diversity. A two-year program, with the first year consisting of a core curriculum requiring broader interaction and communication with students and faculty across departments, would be most effective. The second year could allow increased specialization in preservation engineering and include a thesis project. The European master's program, noted earlier, offers a precedent for this second year of specialized study. The presence of active engineering, architecture, and historic preservation programs within academic institutions could offer opportunities for shared resources such as laboratories, libraries, studios, and faculty.

To sketch out the parameters of such a program, it is important to consider fundamental questions. What does the profession need? What are the common processes of work in preservation engineering? How do we assess an existing building, translate our observations into a mathematical model, make evaluations of the findings, and then communicate these results to the client, the owner, or the public? And then, how do we use our knowledge to effectively implement any changes while minimizing the loss of the resource we already have?

The first phase of the preservation engineering investigation is analysis-based and relies on an iterative "communication" with the existing construction, very much distinct from the typical design approach engineers learn to create new structures (Ortega 2005, 5). This process is thoughtfully described in the 2003 recommendations produced by ISCARSAH. The guidelines emphasize the importance of communication between the preservation engineer and a multidisciplinary group, using both qualitative and quantitative evaluations. The useful analogy of preservation engineers as "building doctors" helps frame the gathering of information and the development of treatment recommendations (Kelley and Look 2005). These guidelines can also help define the goals of a preservation engineering curriculum.

Developing the basic skills to take each of these professional steps may be likened to the development of "literacies" for communicating with, and about, the built environment—not only developing the vocabulary and basic grammar to translate visual experience but also recognizing the subtleties of interpretation beyond the surface and its visual limits. For example, in the field of structural engineering, the visible expression of structural performance, as design intent or physical record, may be presented to students using a linguistic analogy. Considering design intent, elements such as column, beam, arch, vault, and buttress can be seen as structural vocabulary conferring a sense of strength and stability in their literal function, while also integrating with symbolic meanings in architectural compositions. Rome's Palazzo della Civiltà Italiana, a Fascist-era interpretation of the Colosseum at the Esposizione Universale di Roma (EUR) site, is a unique example of a transitional construction between literal load-bearing arches and vaults and the movement toward a modern cladding systems (Fig. 6). The accompanying study sketch depicts the general construction of the building at its corner, with a reinforced concrete frame set within a separate but self-supporting masonry of brick and travertine on the exterior. Moving from right to left, the sketch shows an evolution of building systems that might be used to achieve a similar outward appearance, from a stone construction to a marble-clad Roman concrete construction and finally, to the far left, a system that we might use today with reinforced concrete frame clad with thin stone on light-gauge secondary support. Each system represents different load paths and behavior to be interpreted by the preservation engineer. Considering the physical record of performance, signs such as cracks, deflections, and material conditions are among the vocabulary used to construct historic narratives. The structural engineer may term this visual sensitivity as "reading strength." Other branches of engineering, architecture, and historic preservation will similarly engage sets of vocabulary in their particular readings of the historic building, all adding to the complex story of a building's past, present, and future.

The first year of the MSPE program must allow for diversity in engineering student backgrounds and diversity in the broader academic community, reflective of the team environment in the professional world. A course on investigation techniques and condition assessment, including monitoring and diagnostics, is recommended for the first semester to get students learning immediately from the built environment. Coursework on architectural and engineering history is also essential to develop better understanding of social and technological contexts. Courses on historic building materials and systems can be designed to include students of diverse backgrounds and interests, with the flexibility to exercise these differing strengths. In addition, an introduction to the broader field of historic preservation and its guiding philosophies will offer a dynamic environment with diverse perspectives. In all of this, core language skills must be emphasized.

Speech

Preservation professionals need to communicate to the broader community, with its limited experience translating mathematical findings or traditional graphical representations, such as architectural and engineering drawings. The ISCARSAH guidelines discuss the production of an explanatory report as a means of communicating the nuances and limits of the engineering assessment particular to the details of the project (ICOMOS-ISCARSAH 2003, 2). Given the typical engineer's limited exposure to written exercises, this will represent an important challenge for many students. A poorly written summary of a good mathematical analysis will inevitably be poorly received by those who rely on this translation. The use of words in a sentence may be considered analogous to a mathematical calculation; a misused or poorly chosen word in a sentence, like a number in a calculation, can significantly skew the results. The subtleties of written and spoken language, with connotation and intonation, can present challenges to the student accustomed to the seeming linearity of meaning in mathematics. These challenges should be embraced rather than avoided, with good writing instruction and the regular inclusion of writing, even in mathematics-oriented courses.

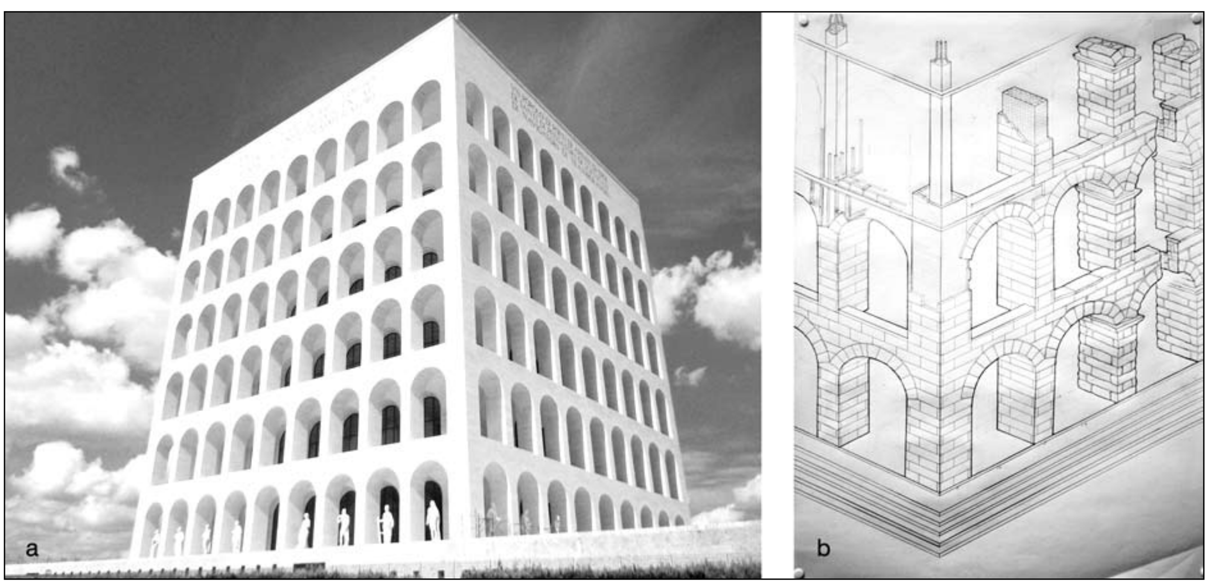

Fig. 6. Palazzo della Civiltà Italiana, Rome, 1938-1943.

Graphics

Graphical representation of buildings and constructions, in all their diverse forms, is an essential language of communication in the profession and thus is clearly essential in the education of future professionals. Standard engineering curriculums offer very little practice in this area. Historically, graphical training has been a significant component of the architect-engineer's curriculum. For example, as presented by Ulrich Pfammatter in his work *The Making of the Modern Architect and Engineer—The Origins and Development of a Scientific and Industrially Oriented Education*, a normal week's study schedule for first-year students in the École Polytechnique was very regimented in 1818, with up to twelve hours of free study in drawing studio and four additional hours of figural and landscape drawing (Pfammatter 2000, 92-93). With today's professional emphasis on three-dimensional building information modeling as an increasingly important tool in the design and coordination process, a return to greater graphical training for engineers is even more critical.

In historic preservation and preservation engineering, varying levels of graphical representation are commonly employed, from a hand sketch in the field, to computer-aided design and drafting (CADD), to building information modeling (BIM), to more elaborate renderings or forms of media. Depending on the resources available for a particular project, various paths of graphical representation may be taken. A first-year foundation course in graphics may be organized around varying scenarios and the process of translating between different graphical formats. In a multidisciplinary classroom, engineering students can learn much from their first-year interactions and collaborative work with architectural students, who likely come with significant graphical skills and training.

A particular challenge for preservation engineers is to explain how physical behavior relates to their mathematical findings. From a structural perspective, representations such as those in Figure 7 can help the layperson visualize the forces and physical responses that may require repair, further study, monitoring, or some other accommodation.

Mathematics

How does mathematical analysis get integrated into building assessment and how, therefore, should it be taught? A nuanced quantitative analysis can be useful for explaining observed conditions and manifestations of past performance, as well as for projecting future performance. Engineering judgment is required since "modern" analysis of historic constructions does not always narrow to one approach, and our analytical methods are infused with inherent assumptions, simplifications, and approximations, leading to predictions of varying reliability. Historic building systems typically have limited representation in current building codes, and reference to the corresponding historic design approach or tabulated capacities based upon empirical testing is of significant value in rendering opinions on safety and performance.

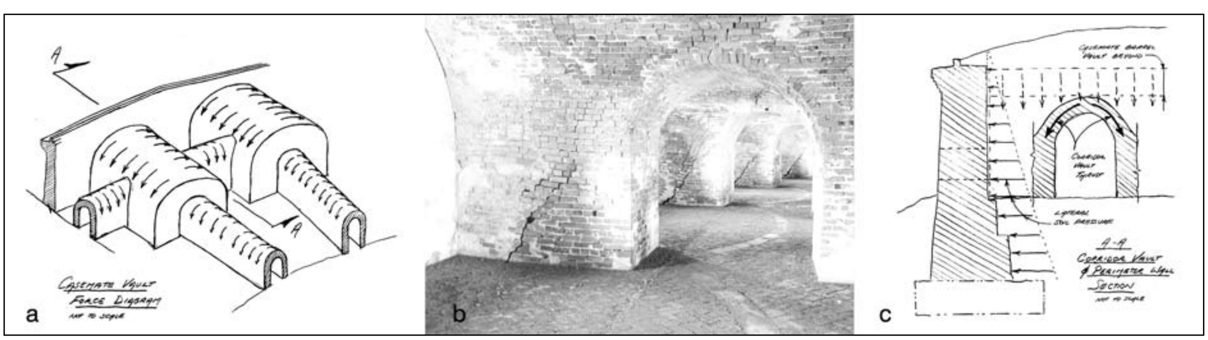

Fig. 7. Graphical representations of physical behavior: vault assessment at Fort Pike, New Orleans, LA.

In addition, the definition of material properties must account for both uncertain levels of variability in historic production and variability due to time and exposure. From the proverbial "back-of-the-envelope" calculation (often useful during preliminary assessments) to three-dimensional computer analysis, the use of multiple analytical approaches, with varying levels of complexity, can build confidence in mathematical predictions. Any approach, however, must acknowledge time and history in its formulation and generally requires multiple iterations to reach a satisfactory convergence between mathematical prediction and observed physical form and condition (ICOMOS-ISCARSAH 2003, 4).

The second semester of the program can refocus the broadened perspective of preservation engineering students on their areas of technical specialization. A course in building codes and preservation engineering is recommended to address the changing approaches to risk and safety factors inherent in changing design and analytical methods. How historic lateral force-resisting systems can meet with current understanding of loading and associated risk is a critical area for both coursework and research. The energy performance of historic buildings, particularly in response to modifications of systems and the thermal performance of the exterior envelope, is critical to understanding life-cycle costs, which can weigh heavily in fundamental preservation decision making. Courses on modern interventions should emphasize both the risks and opportunities of introducing changes in materials or demands on building systems.

BROADENING VISIONS

> ...Seeing that all this would not put me in a speedy way to master my profession, and being so fortunate as to have a few hundred pounds left me, I resolved to travel—to study architecture in actual buildings, and no longer in those shown me on paper. I set myself to observe, to compare, to see practical men at work, to examine buildings that were crumbling to pieces, that I might discover *in anima vili* the causes of their ruin (Viollet-le-Duc 1874, 82-83).

The conclusions of this study are multifaceted in detail yet singular in spirit. The academic study of preservation engineering, an important and growing part of the profession, merits inclusion in the curriculum. The value of existing and historic engineered systems must be understood and communicated for the sustainable growth of the built environment. The skills and training of the preservation engineer encompass ways of seeing and ways of translating, in words, graphics, and numbers. In the spirit of Viollet-le-Duc, students of engineering, architecture, and preservation must see, and learn from, what we already have. This will broaden their vision and the base from which they learn to design and create for the future.

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ENDNOTES

1. This research has been supported by the Samuel Kress Foundation through the James Marston Fitch Charitable Foundation and was completed by the author during research at the American Academy in Rome as 2010 National Endowment for the Arts Rome Prize Fellow in Historic Preservation and Conservation.

2. Woodcock states that work to existing buildings exceeds 50% of total professional work and a significant percentage of national construction budgets. The 2002 economic census from the U.S. Department of Commerce reports that approximately 33% of the "value of construction work" for total construction, and total building construction, falls under the categories of additions, alterations, reconstruction, maintenance, or repair.
3. National Center for Preservation Technology and Training. Retrieved January 28, 2011 from http://www.ncptt.nps.gov/Architecture-and-Engineering/Engineering-for-Historic-Buildings.aspx.
4. University of Vermont, College of Engineering and Mathematical Sciences. 2009. "School of Engineering Hosts Historic Preservation Colloquium." Retrieved July 8, 2011, from http://www.uvm.edu/~cems/?Page=News&storyID=14463.
5. University of Minho (Portugal), Czech Technical University in Prague, Technical University of Catalonia (Barcelona, Spain), University of Padova (Padova, Italy), and the Institute of Theoretical and Applied Mechanics (Czech Republic).
6. Reyner Banham employs the metaphor of the driver in *Los Angeles: The Architecture of Four Ecologies* (1971) with Chapter 1 entitled "In the Rear-view mirror."

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