A Call to Arms: Competency, Education, and Training of Structural Engineers

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The development of structural engineering skills for preservation has been underserved by the profession, licensing bodies, higher education, and public-sector clients. This paper is a plea for urgent action and some suggestions.

Fig. 1. Westminster Hall roof, the Palace of Westminster, British Parliament, London, complex historic structure and materials. The hammer-beam oak roof of 1399 AD by Richard II's master carpenter, Hugh Herland, spans 68 feet (20.7m), is 240 feet (73.2m) long, and weighs 836 tons, including the wooden construction and lead-sheet covering. © UK Parliament www.parliament.uk.

Introduction

This paper is concerned solely with the competency, education, and training of structural engineers in the service of building conservation and historic preservation.[1] In North America the term "preservation engineering" can encompass specialist structural engineering, but it is also used to define the preservation activities of other engineering professions, such as mechanical, electrical, plumbing (MEP) and fire engineers.[2] Those activities lie beyond the scope of this discussion, though similar issues apply.

Interrelated Problems

The paper will attempt to demonstrate that there are two large and interconnected problems that confront the international preservation community with regard to structural engineering:

1. There is a shortage of structural engineers who are expert in preservation engineering.
2. There is an oversupply of well-meaning, though inexpert, structural engineers who possess little understanding of engineering heritage, preservation philosophy, or the specialist engineering techniques suitable for extending the lives of historic structures without detriment to their special values and significance.

Both situations are harmful to the built heritage and threaten its future welfare, since the lack of expertise and the increasing role that engineers play in design- and construction-related activities mean that the technical assessment of structural distress and the design and implementation of remedial actions are not always in the best possible hands. The author has observed situations, for example, where long-standing historic structures have been condemned to demolition on flimsy evidence or have been drastically and unnecessarily altered due to the misunderstanding of construction systems or the strength of ancient structures and materials.

No other profession has neglected its specialist competencies to such an extent and degree as is the case with structural engineering.[3] On a world scale, few educational establishments have addressed the issue. Where structural engineers have managed to receive a generic education in historic preservation, the amount of time devoted to structural-engineering matters related to historic structures is minimal. The problems are occasionally debated but rarely acted upon strategically at either the national or international level.[4]

Significant numbers of buildings remaining from the distant past are not built of steel or concrete, the materials most familiar to engineers today (Fig. 1). The properties of earlier materials and construction are rarely addressed in structural-engineering syllabuses in college, and modern engineering-software programs tend to ignore them completely. The turnover in the numbers of existing buildings being demolished and replaced with new construction is slowing across the developed world as vacant land becomes more difficult to find or use because of environmental and socio-economic factors. So more existing buildings are being retained, repaired, and reused than in the recent past. Yet the curricula of most schools of engineering have not taken this fact into account and remain focused solely on new development.

As a consequence, many structural-engineering solutions to building-conservation questions are unsuitable, inappropriate, or downright damaging — as the author has witnessed and/or ad-

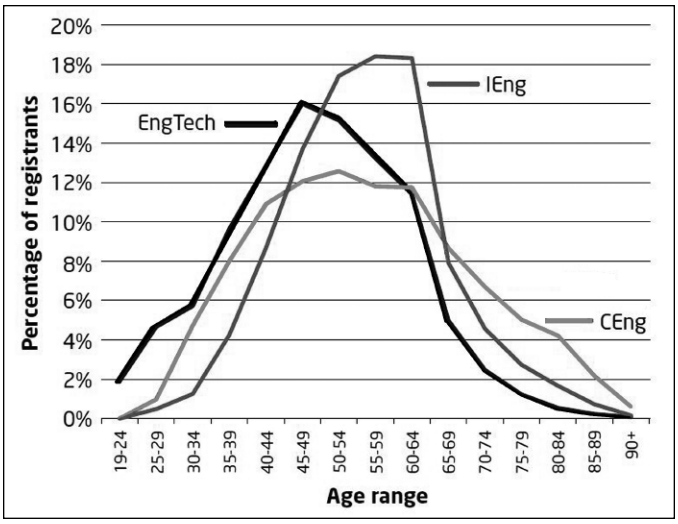

Fig. 2. Age range distribution of chartered and other engineers in the UK, showing significant proportions of experienced people will soon retire with insufficient younger engineers to take their place. © Data source and graph courtesy of the (UK) Engineering Council 2010.

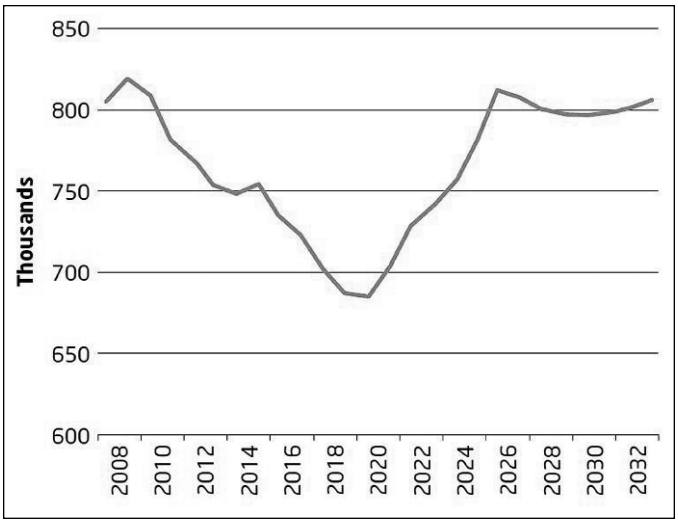

Fig. 3. Predicted 18-year-old population of the UK (2008 base year). © UK Office of National Statistics.

dressed during more than 35 years of specialized preservation practice.[5]

Relevant Statistics

In the UK there are 65,577 members of the Institute of Civil Engineers (ICE). Although structural engineering is seen as a specialist discipline within civil engineering, many chartered (licensed) structural engineers also belong to the independent sister organization, the Institute of Structural Engineering (IStructE), and total fewer than 20,000 members (i.e., 30 percent of ICE membership).[6] The two institutes jointly run an accreditation system to test and acknowledge competence in conservation engineering (described later in this paper), and the total number of preservation experts registered in 2012 was just 33 engineers, or 0.039 percent of the combined engineering membership.

In America there are about 450,000 licensed professional engineers (PE), of which 140,000 (31 percent) belong to the American Society of Civil Engineers (ASCE).[7] ASCE's membership includes a wide span of disciplines, from architectural engineers, construction engineers, engineering mechanics, water engineers, and geotechnical engineers to transportation engineers, but only 20,000 (14 percent) belong to the ASCE's Structural Engineering Institute (SEI).[8] There is no data on the number of state-licensed professional engineers who are structural engineers and specialize in historic preservation, and there is no accreditation or certification process in the U.S. to test, acknowledge, and promote specialist preservation expertise. This contrasts to a limited extent with estimates available for American architects.[9]

The Association for Preservation Technology International (APT) has long argued that the repair, maintenance, adaptation, and improvement of existing buildings (including historic buildings) constitute approximately 47 percent of all construction-related activity. Yet the skill sets and experience necessary to repair, maintain, adapt, and improve existing buildings that have cultural values and significance are generally not being taught, examined, or fostered by the engineering profession or academia.

Background

Until the recent global economic recession, there was an international shortage of general-practice structural engineers in Europe and North America.[10] Some countries are suffering large gaps in their employment demographics, like the United Kingdom, for example, where there are over 6,000 engineering vacancies within the profession's current cohorts because significant numbers of baby-boomer engineers are about to retire (Fig. 2) and there are fewer young people to train as engineers to take their places (Fig 3).[11] It is predicted that by 2016 the UK's need for all kinds of manufacturing and construction engineers will top 600,000.[12] There has been a general 25 to 35 percent downturn in the numbers of students taking vocational education in engineering among developed countries — offset only for mainstream engineering by surges in numbers of Asian students graduating in Pakistan, India, and China and as visiting students graduating in American and European universities.[13]

Most three- to four-year undergraduate engineering education in the United States is undertaken in civil engineering, the broader technical discipline that includes soil and geo-technical engineering, environmental engineering (including water treatment), transport and traffic engineering, land surveying, and structural engineering. So the amount of general structural-engineering input within a bachelor of science in engineering course linked to subsequent practical internship experience and ASCE tutorials before state license examinations for the generic civil engineering PE qualification is relatively modest. Countries such as the UK and a few states in the U.S. distinguish between civil and structural engineers, but generally this is not the case. So academic establishments are

delivering general-practice engineers to the construction industry: Jacks (and Jills)-of-all-trades, but masters of none.

Today civil engineering is a three- or four-year undergraduate program at the American university level and does not require a postgraduate component to achieve professional competency, although some licensing bodies, if not all professional institutes, would like to increase the length of the training to the master's degree level, now more common in the UK.[14]

Internationally, the history of engineering and the repair of older structures and buildings are not taught in undergraduate education, and this situation is a major cause for concern in preservation circles. Recent graduate engineers have no knowledge or awareness of structural-engineering history and no familiarity with traditional materials and construction, including mass masonry, timber framing, cast- and wrought-iron structures, or of composite structures involving these materials. Furthermore, knowledge of the performance and susceptibilities of vernacular materials, such as adobe, are for the most part completely unknown.[15]

Inaction and Tokenism

The debate about this situation has been going on for some time — at least 40 years. For example in 1968 a UNESCO experts meeting in Pistoia, Italy, declared that

> Closer collaboration be developed between architects and specialists in other university disciplines concerned with preserving the heritage of monuments, such as…engineers…etc., by directing or supplementing their training to meet preservation requirements.[16]

The same mantra was heard in Helsinki in 1995: "Engineers should have special training to understand how historic structures work."[17]

These sentiments are being reiterated at gatherings of preservation professionals around the world. But we have not seen much activity by the professional institutes, licensing boards, college accreditation bodies, or academic establishments to correct this situation. Apparently there is little interest in the subject from heritage regulators and owners of historic structures. In short, there have been no significant drivers for change.

The technical aspects of building conservation are taught most seriously in schools of architecture. Although engineers attend such postgraduate training courses (but in extremely small numbers), they receive very limited specialist engineering training.[18] This is because the majority of students taking the courses today are not architects or engineers but more often archaeologists, anthropologists, historians, and planners.[19] Thus the technical content of the courses is presented at a rather low level and may include only a lay understanding of engineering, perhaps totaling less than three to six hours on a one- or two-year full-time course.[20] Obviously engineers benefit greatly from attending postgraduate preservation courses because they learn about the functions of other members of the project team and about conservation ethics, etc. But the actual specialties in engineering per se do not get taught thoroughly, because universities inevitably must cater to their broad constituent market and the technical abilities of mixed groups.

More problematic is the reaction from university schools of engineering, which always complain that there is insufficient time in an already overcrowded curriculum to deliver a minor specialty like preservation. This stance is ironic, since colleges have been slowly pulling away from the requirements of the professional institutes and licensing boards for some time on the grounds of academic freedom. Surely, in the free-market economies of higher education, at least one of America's 415 and the UK's 49 accredited engineering schools could devise optional preservation studios or class units at the undergraduate level and/or at least one specialist postgraduate course as a discrete selling proposition? [21]

Signs of Life

Specialist preservation-engineering courses do exist internationally, but they are relatively recent and too few in number to deliver significant impacts on the world stage. There is an advanced master's course sponsored by the European Commission and taught jointly by the Universities of Minho, Portugal; Padova, Italy; the Czech Technical University in Prague; and the Technical University of Catalonia in Barcelona, Spain (Fig. 4).[22] The Italians have an independent course at La Sapienza University in Rome, and there is a developing specialty in the School of Architecture and Engineering at the University of Bath in England.[23] The International Center for Studies of the Conservation and Restoration of Cultural Property in Rome (ICCROM) has considered putting on a three-month specialist course for structural engineers, but limitations on resources have prevented this idea from being taken forward. This is unfortunate, because in many areas of the world, engineers are the only trained building professionals available for the conservation of historic buildings and archaeological sites, yet current training for this role is totally inadequate or non-existent.

Fig. 4. Structural engineer Peter Vonk of Sydney, Australia, who was one of the early graduates of the European Commission-sponsored Advanced Erasmus Mundus master's degree course in the Structural Analysis of Monuments and Historical Constructions (SAHC) taught on rotation among universities in Minho, Portugal; Padova, Italy; Prague, Czech Republic; and Barcelona, Spain.

In North America the first Forum on Conservation Engineering was convened in Montreal by the Association for Preservation Technology International in 1990. One of the action items identified was the need to develop criteria to enable engineers who had sufficient experience with historic structures to be certi-

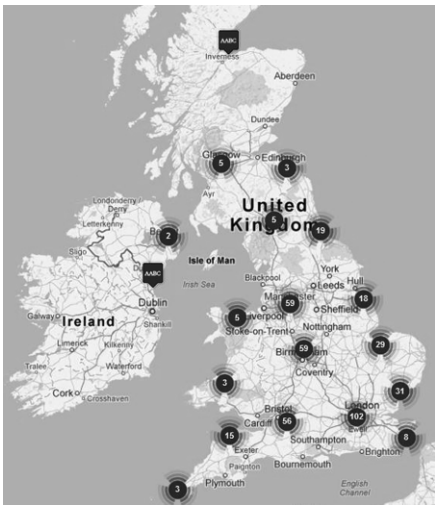

Fig. 5. Distribution map of UK architects accredited in building conservation according to AABC. No similar map is yet available for ICE/IStructE CARE engineers, due to their more limited numbers. © ACON Ltd for AABC Register.

fied. The model suggested at the time was to have criteria for "engineer" and "conservation engineer" written into the National Park Service's definition of qualified professionals and published in the U.S. *Federal Register*, as position classification (job description) standards overseen by the U.S. Office of Personnel Management. But when the National Park Service developed its "Essential Competencies for National Park Service Employees" in 2006, it did not make any such distinctions. Instead, progress was achieved more recently in the U.S. Secretary of the Interior's revised draft of *Historic Preservation Professional Qualification Standards*, which now include a qualification standard for engineering. However, the pioneering work of Hugh Miller and Lee Nelson that set competency standards and training objectives for U.S. National Park Service employment in 1989 now seems to have been forgotten. Earlier competency definitions and training objectives for restoration engineers by Parks Canada were a primer for the U.S. Park Service document and have similarly been overlooked.[24]

Recent Action

The International Council on Monuments and Sites (ICOMOS) established ISCARSAH in 1996 as the International Scientific Committee for the Analysis and Structural Restoration of Architectural Heritage. Its principles, ratified at the 14th General Assembly of ICOMOS in Zimbabwe in 2003, seek to guide those involved with the technical engineering aspects of preservation.

Relatively recent North American initiatives also show promise towards assembling a coherent way forward. For example, APT created the Technical Committee on Preservation Engineering in 2003 to provide a focus for discussing issues relating to engineering and historic preservation.[25] Special engineering issues of the *APT Bulletin* followed, and regular discussions have been held on matters of professional standards and education, both within the multidisciplinary association but also across the engineering community itself.

In the U.S. the National Center for Preservation Technology and Training (NCPTT) has partnered with Michael Henry, PE, and Sam Harris, PE, to develop short-course training modules with mid-career engineers in mind. The modules include materials and older buildings, building pathology, investigations and diagnostics methodology, and treatment strategies and interventions and are being rolled out around the country.

Certain countries have taken decisive action at another level. In Europe, for example, there are accreditation systems already in place for qualified professionals to validate and promote their specialist skills, knowledge, and experience in building conservation at mid-career level. Most of the programs are aimed at architects, but gradually engineering programs are being added. In France there is the long-standing formal training and examination system for the Architectes en Chef des Monuments Historiques.[26] In Italy conservation training is a mandatory unit in the curriculum for all architects in Italian schools of architecture.

In the UK, English Heritage and Historic Scotland started to query self-certification of conservation expertise among building-design professionals in the early 1990s as part of their general concern about the standards and quality of conservation work. For example, English Heritage asked the Royal Institute of British Architects (RIBA) how its membership directory came to cite over 1,475 architects as having "special interest or expertise" in the conservation of historic buildings and was told that the RIBA just published what architects claimed: there was no validation or proof needed to claim expertise.[27]

As a result of formal discussions and lobbying, accreditation schemes that defined, independently tested, and promoted competency in building conservation were then set up by the Royal Institution of Chartered Surveyors (RICS) in 1992; by the Royal Incorporation of Architects in Scotland in 1995; by the Architects Accredited in Building Conservation (AABC) in 1998 (Fig. 5); and by the RIBA in 2003.[28] The accreditation schemes are all based on an independent, peer-reviewed portfolio of work that demonstrates competency in building conservation through awareness, knowledge, skills, judgment, and experience. The process is driven by market forces in that English Heritage and Historic Scotland make it a condition of grant aid that historic-building owners hire only accredited professionals to undertake their conservation work. The professional institutes in the UK have defined competency in association with the national heritage bodies based on the ICOMOS Sri Lanka Guidelines.[29] Guidance for practitioners and materials to foster competency through education, training, and continuing professional development are freely available online at www.understandingconservation.org.

Of particular note is the fact that the UK Institute of Civil Engineers and the Institute of Structural Engineers jointly established an equivalent accreditation scheme for civil and structural engineers in 2004, called CARE (Conservation Accreditation Register for Engineers), which includes a single peer-reviewed assessment system and a public register of specialist professional expertise. As mentioned above, only 33 engineers are currently registered as being accredited in building conservation, a statistic that is extremely disappointing for a program now eight years old. But English Heritage and Historic Scotland are not enforcing the requirement to use only accredited engineers.[30] So all the UK accreditation groups are now preparing to lobby the two organizations and the government for additional support and

Fig. 6. Suggested model showing parameters contributing to competency in preservation engineering where increasing awareness, knowledge, understanding, skills, judgment, and experience develop proficiency and expertise. © John Fidler Preservation Technology Inc.

to seek the collaboration of the highly influential UK Heritage Lottery Fund (HLF) that is now the country's major grant-giver for heritage building projects, distributing more than £1,883 million (US$2.951 billion) in aid since 1994, to enforce requirements for accredited professionals to be hired on staff or as consultants for future conservation projects.[31]

Competency

The accreditation schemes and the nested work on multidisciplinary competency in building conservation are defining what in the UK is considered to be the special expertise necessary for a mid-career professional to practice building conservation to a high standard. Similar programs are taking root in Australia, where the engineering profession is in the lead.[32] Most of the schemes are based on the Dreyfus Model of Skills Acquisition in determining competency levels from novice to expert.[33] The peer-reviewed evaluation of competency levels takes into account the knowledge, understanding, skills, judgment, and experience of the applicant. Competence develops when an individual develops organizing principles to quickly assess particular rules relevant to a task in hand, i.e., through active decision-making (Fig. 6). Proficiency is shown by individuals who develop intuition to guide their decisions and who devise their own rules to formulate plans. Personal development therefore progresses from rigid adherence to rules to an intuitive mode of reasoning based on tacit knowledge, skill, and experience.

In England the accreditation systems for each profession have been tested against one another and have also overcome objections and legal challenges on European Human Rights and Fair Trade grounds, because due notice and fair explanation for the imposition of grant conditions preceded implementation of the programs.

The American Society of Civil Engineers

The American Society of Civil Engineers has been developing its *Body of Knowledge* that seeks to influence educational establishments, licensing boards, and others over questions of competency to practice engineering in the twenty-first century.[34] The corpus of professional practice now recognizes the need to understand historic structures and to sustain the existing built environment as much as to create new developments. But these "feel good" sentiments are wrapped up in a cloudy general requirement for historical perspective and sustainability policies. There have, to date, been no specific requirements to be aware of, to be knowledgeable about, or to understand the history of structural engineering, the ethics of preservation, or the tools and techniques of preservation engineering. And there is no standing forum within ASCE or its institutes to develop these aims and take them forward for recruitment, training, and continuing education of structural engineers.

The author consequently approached the ASCE in March 2011 with a view to taking this qualification forward. After its staff studied the UK's CARE model referenced above, the ASCE agreed in May 2011 to consider setting up a preservation-engineering focus, but only in its Architectural Engineering Institute and not in the Structural Engineering Institute, where arguably it is most needed. Since this discussion more than 18 months ago, nothing has happened.

Conclusions

Apparently no labor-market analysis has been undertaken to determine how many structural engineers with specialist skills in preservation are needed at regional, national, and international levels to sustain the built heritage in effective and sustainable ways. Without this strategic data it is impossible to decide how many and what type of educational programs are needed. Highly influential research in the UK by the National Heritage Training Group on craft-skill development needs led to a similar study on UK Built Heritage Sector Professionals in 2008 and made depressing reading.[35] The research reported that there was only one conservation-accredited engineer in the UK for every 276,364 traditional (pre-1919) buildings and that 80 percent of companies reported relevant skill shortages among engineers. New recruits were generally not thought to be adequately prepared for work in the built-heritage sector. Two thirds (65 percent) of professionals did not feel that their formal education adequately prepared them for working on pre-1919 buildings, including nationally registered (listed) historic buildings. Where is the data for the North American engineering professions?

Several steps have been taken to help define what constitutes competency in the general field of engineering and in the specialist field of preservation engineering. But there is a growing divergence between what expert practitioner employers want of new graduates what the professional institutes will delineate,

Table 1. Hierarchy of engagement with preservation engineering inferring specialization and levels of expertise.

SPECTRUM OF ACTIVITY / EXPERTISE AMONG STRUCTURAL ENGINEERS	
Knowledge, skills and experience, least to greatest	General practitioners who NEVER undertake preservation work
	General practitioners who undertake ANY kind of work, including preservation work
	General practitioners who OCCASIONALLY undertake preservation work but know few of the basics
	More specialist engineers who devote SOME time to preservation work and have more than basic awareness
	Expert structural engineers who undertake preservation work MOST of the time

what licensing boards demand, and what educational establishments are prepared to deliver.

Tensions also remain between general-practice engineers and specialist preservation engineers about the levels of competence required to undertake work on historic buildings (Table 1), and this provides difficulties for professional institutes to remain even-handed for the benefit of their two constituencies of membership.

Recommendations

This special issue of the *APT Bulletin* provides a unique opportunity to address the issues outlined in this paper, to collaborate on labor-market studies, and to refine definitions of specialist preservation-engineering competency within the broader engineering body of knowledge, building on the work of APT's Technical Committee on Preservation Engineering and of ISCARSAH.

APT's committee should open a dialogue with ASCE to lobby to create a standing forum within the organization, especially within the Structural Engineering Institute, and then tackle the issues outlined in this paper: notably specialized professional definition, skills accreditation, promotion of validated skill sets, recruitment, creation and promotion of model specialist postgraduate syllabuses, and the development of continuing education units.

As the U.S. National Park Service calls for public review and amendments to the Secretary of the Interior's revised draft *Historic Preservation Professional Qualifications Standards*, there is an opportunity for APT and ASCE to influence the definitions and criteria for structural and other types of engineers working in preservation and then work towards education and training inputs that help foster such professional services.[36]

The larger national clients for preservation-engineering services — for example, the National Park Service, the General Services Administration, and various State parks systems — could combine to create a market-force solution, demanding that only accredited preservation engineers be hired for future projects commencing three to five years hence (using pre-bid qualification criteria within Requests For Qualifications, thereby avoiding legal challenges on trade restrictions). There is no need to "reinvent the wheel," as UK precedents are available and well published.

This paper suggests that if ASCE defined and accredited structural-engineering competency (based on the work already achieved by others) and if the major employers and clients for preservation-based structural engineering demanded those defined and independently assessed skill sets, then students, practitioners, and employers would respond to market forces and demand that academia and others deliver appropriate education and training.

The growing shortage of specialist engineers is likely to increase as the current generation of experts starts to retire. In this economic climate, there is cause for alarm, surely sufficient for a general call to arms to be organized to address the collective problem?

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Notes

1. A brief synopsis of this paper was read at the two-day colloquium on the development of curricula in historic-preservation engineering sponsored by the U.S. National Park Service's National Center for Preservation Technology and Training (NCPTT) and held at the University of Vermont's School of Engineering, June 22-23, 2009. "Historic preservation" is the term generally used in North American for what in Europe is called "building conservation" and/or "restoration."

2. Europeans now call these professions "building services engineers"; see www.cibse.org

3. For example, concern for specialized training in building conservation among architects surfaced in the UK in 1959 when the late Bernard Feilden and Donald Insall established COTAC (the standing Conference on Training Architects in Conservation, www.cotac.org.uk), now rebranded with broadened scope as the Conference on Training in Architectural Conservation. The Association for Preservation Technology established the Technical Committee on Preservation Engineering in 2003. But the American Society of Civil Engineers has no preservation interest group.

4. See ICCROM, "Conclusions of the UNESCO experts meeting, Pistoia, Italy held between 9-14 September 1968," in Annex 1, Recommendation (2) in *International Meeting of Coordinators of Training in Architectural Conservation held in Rome 2-4 October 1982 under the auspices of UNESCO, ICCROM and ICOMOS* (Rome, ICCROM, 1983), 230. Jukka Jokilehto, "Training Strategy in the Conservation of Cultural Heritage Sites," in *Conservation Training – Needs and Ethics: Seminar Papers of the ICOMOS-CIF Training Committee Meeting held in Helsinki between 12-17 June 1995*, ed. A. Ahoniemi (Helsinki: International Council on Monuments and Sites Finnish National Committee, 1995), 26. Richard Ortega, "Should Preservation Engineering Require Certification," *APT Bulletin* 36, no. 1 (2005): 5-7. B. Kasal et al., "Education in Engineering Evaluation and Rehabilitation of Historic Structures – U.S. Perspective," in *In-Situ Evaluation of Historic Wood and Masonry Structures: A Joint Workshop of US National Science Foundation / RILEM held 10-14 July 2006 Prague, Czech Republic*, ed. B. Kasal, R. Anthony, and M. Drdacky (Bagneux, France: RILEM-SARL, 2009) 3-7. John Matteo, "Preservation Engineering – Towards a New Curriculum," in *Preservation Education and Research*, vol. 4, ed. J. Wells and R. Sheppard (Ithaca, N.Y.: National Council for Preservation Education, 2001), 93-106.

5. The author has been exposed to, and reviewed, many engineering proposals during his lengthy career. He was a case officer in the development-control section of the Greater London Council's Historic Buildings Division (1978-1982), the first historic buildings architect for the City of London (1982-1983), and English Heritage's first conservation officer for buildings at risk (1984-1986). At English Heritage (1986-2006) he had a series of senior roles with responsibility for a multidisciplinary team of architects, conservators, scientists, and civil, structural, and building-services engineers involved in the care of 420 national historic sites and for technical research, advice, standards, publications, and training. During his leadership, and while he was also acting as vice president for programs at ICCROM (the International Center for the Study of the Preservation and Restoration of Cultural Property in Rome), the UK established professional accreditation of architects, engineers, and surveyors for building conservation. His 2006-2007 Getty Scholarship research was devoted to further study of the competency, accreditation, and training of preservation architects and structural engineers, and his attendance at the 2009 University of Vermont colloquium was sponsored by the Getty Conservation Institute. He also served on the conservation-grants committee of the Getty Foundation (2001-2008) and more recently on the California Preservation Foundation's Awards Panel (2007-2009), where he also

reviewed engineering solutions to preservation problems.

6. See http://en.wikipedia.org/wiki/Institution_of_Structural_Engineers, where worldwide IStructE membership is given as 27,000. Extrapolating from the Institute of Civil Engineers' data (ICE, 2011), approximately 17 percent of the IStructE members work overseas, so it is likely that the number of UK-based structural engineers is under 22,400 in all classes of membership (including students, technicians, etc.) and chartered (licensed) structural engineers total about 20,000.

7. U.S. statistics for 2012 for resident PE registrants per state can be found on the (U.S.) National Council of Examiners for Engineering and Surveying (NCEES) web site, at http://ncees.org/licensure/number-of-licenses-by-state. However, the data is imprecise because not all engineering residents are licensed in the state where they live; some states (e.g., Vermont) do not distinguish in their records between state residents and non-residents; some records (i.e., for Puerto Rico) have not been updated since 2003, and only Illinois distinguishes between structural and civil engineer registrations. See www.asce.org. Many professional engineers do not belong to the ASCE because they do not belong to the architecture, engineering, and construction (AEC) industry: for example, process engineers, electronics, aviation, and naval engineers.

8. See http://content.seinstitute.org

9. There were 104,301 licensed architects in the USA (NCARB, 2011), of which the American Institute of Architects (AIA) membership is 80,000. The AIA says that 6.25 percent of its members claim an interest and/or expertise in preservation. So by extrapolation, the total number of preservation-interested architects in the U.S. is about 6,520. As there is no AIA or other independent accreditation process for these self-claims, no conclusions can be drawn about the overall levels and distribution of expertise.

10. See the March 1, 2012, commentary on U.S. STEM (Science, Technology, Engineering and Math) studies and careers and President Barack Obama's strategic concerns at www.edn.com/electronics-blogs/other/4369012/Engineering-the-next-generation-of-STEM.

11. The Engineering Council (www.engc.org.uk) is the UK's sector skills-development body for all forms of engineering. Its report, "Engineering UK 2011," provides an overview of the demographic and other problems and solutions. For example, the UK will suffer an eight percent reduction in the number of 15- to 24-year-olds over the next ten years while the existing workforce ages, with more than 27 percent of the working population currently aged 50+ (p. 210).

12. See www.guardian.co.uk/technology/2009/nov/29/manufacturing-engineering-recession-recovery.

13. "Engineering UK 2011."

14. For example, the U.S. National Council of Examiners for Engineering and Surveying (NCEES) added language to its model (licensing) laws and rules in 2006 requiring master's level degree requirements, but this does not appear to have been taken up by any state licensing board. See www.ncees.org. There are 29 MSc courses in structural engineering in the UK's 134 universities. Information from www.whatuni.com.

15. Notable exceptions are postgraduate engineering and architecture courses in the School of Engineering at the Pontifical Catholic University of Peru (PUCP) in Lima and at CRA-Terre (International Center on Earthen Architecture) in the National Superior School of Architecture, Grenoble, France.

16. ICCROM, 230.

17. Jokilehto, 26.

18. In the UK, for example, there are six master's level courses in architecture schools, two in departments of building surveying, and two in departments of archaeology. Information provided by COTAC, www.cotac.org.uk. In the author's experience, as a master's degree course validator, external examiner, lecturer on programs in the UK and U.S., and, up until 2007, as vice president for programs at ICCROM, structural-engineer numbers on preservation courses generally lie in the one to three percent range and consistently so since the 1980s until today. For example, Hugh Miller, FAPT, reports that of Goucher College's 113 students graduating from its master of arts in historic preservation program over the last 12 years, only two (1.7 percent) are engineers.

19. UK information from ARCUK research provided by Roger France, ARIBA, MRTPI, convener and chairman of the (UK) Conservation Course Directors Forum, 1991-2008. Little published data appears to be available for the U.S., though the author's observations when lecturing at various American courses lead to the same conclusion. Hugh Miller reports that over the last 12 years at Goucher College, of 113 graduating students (median age of 30 years), one-third were already working in preservation (but only seven were architects and two were engineers); another third came from allied professions (museums, the arts, etc.,) and the last third were mid-career changers (from psychiatric nursing, dietary planning, accounting, copyright law, etc.).

20. For example, the two postgraduate degree courses that the author took at the Victoria University of Manchester and at the Architectural Association in London; in the States, compare the curriculum for Columbia University's M.S. in Historic Preservation in the Graduate School of Architecture, Planning and Preservation, New York, and the University of Vermont's M.S. in Historic Preservation in the History Department in the College of Arts and Sciences.

21. U.S. information from http://educationnew.org/career-index/engineering-schools; UK information from www.university-list.net/uk/rank/univ-9016.htm.

22. See www.msc-sahc.org for the EC Erasmus Mundus Master's Course in Structural Analysis of Monuments and Historic Constructions.

23. See the Centre for Structural and Architectural Engineering in the Department of Architecture and Civil Engineering, University of Bath, UK, www.bath.ac.uk/csae/new/home.html.

24. Attar Ghassan, "A&E Restoration Engineering Priority Skills, Parks Canada" (Ottawa: Environment Canada, March 1988), internal publication.

25. The current total membership of APT's Technical Committee on Preservation Engineering (which includes all types of engineers including architectural, civil, MEP, and structural engineers) is 30 (approximately two percent of APT membership): information from Timothy M. Crowe, RA, SE, associate principal at Wiss, Janney, Elstner Associates, Inc., and the current co-chairman of the committee.

26. Formal two-year postgraduate training and examination, after qualification as an architect, is through l'École de Chaillot, formerly known as the Centre for Advanced Studies in the History and Conservation of Ancient Monuments (CESHCMA), founded in Paris in 1887.

27. This number was 5.3 percent of 28,000 RIBA members then working in the UK's 5,200 architectural practices.

28. See www.rics.org/uk/join/member-accreditations-list/building-conservation-accreditation-scheme. Architects Accredited in Building Conservation (AABC, www.aabc-register.co.uk) is an independent foundation that piloted accreditation systems for architects in England under the guidance of the late Harry Fairhurst, FRIBA, Emeritus Surveyor-of-the-Fabric of Manchester Cathedral and consultant cathedrals architect to English Heritage. See www.architecture.com/UseAnArchitect/ConservationRegister/ConservationRegister.aspx.

29. Bernard Feilden, *International Guidelines on Education and Training in the Conservation of Monuments, Ensembles and Sites* (Colombo, Sri Lanka: ICOMOS, 1993), http://cif.icomos.org.

30. Information recently supplied to the author by the chairman of the RIBA's Conservation Architecture Group, who attends joint meetings of the UK professional accreditation bodies.

31. Heritage Lottery Fund, *A Lasting Difference for Heritage and People: The Heritage Lottery Fund Strategic Framework, 2013-2018* (London: Heritage Lottery Fund, 2012).

32. See the National Professional Engineers Register (NPER), "Guideline Heritage and Conservation Engineering," devised by the Institute of Engineers Australia (EA), the Association of Professional Engineers, Scientists and Managers, Australia (APESMA) and Consult Australia with representation from both state and territories' government, community and professional associations, www.engineersaustralia.org.au/nerb/heritage-and-conservation-engineering.

33. H. L. Dreyfus and S. E. Dreyfus, *Mind over Machine: The Power of Human Intuition and Expertise in the Age of the Computer* (Oxford: Basil Blackwell, 1986).

34. ASCE, *Civil Engineering Body of Knowledge for the 21st Century* (Reston, Va.: American Society of Civil Engineers, 2008).

35. See www.nhtg.org.uk/nhtginitiatives/publications/research/index.aspx on national and regional labor market studies for traditional building crafts for England, Scotland,

Wales, and Ireland. See www.nhtg.org.uk/uploads/NHTG_skillsresearch_professionals_2008_fullreport_tcm27-11117.pdf for skill-needs reports on the professions.

36. See http://ncptt.nps.gov/articles/c2a/soi-professional-qualification-standards.

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Robert Thorne, "Educating the Engineer." In *The Education of the Architect, Proceedings of the 22nd Annual Symposium of the Society of Architectural Historians of Great Britain*, edited by D. Brady. London, SAHGB, 1993, 22-26.

Web Resources

AABC (register of architects accredited in building conservation)
www.aabc-register.co.uk

ACMH: La Compagnie des Architects en Chef des Monuments Historique
http://acmh.info

COTAC (guidance on knowledge, skills, judgment, and experience needed to be accredited in building conservation as a professional in the UK)
www.understandingconservation.org

CARE (accreditation system for members of the UK Institutes of Civil and Structural Engineering)
www.ice.org.uk/downloads/principles%20of%20operation.pdf

The International Center for Studies of the Conservation and Restoration of Cultural Property in Rome (ICCROM)
www.iccrom.org

International Council on Monuments and Sites (ICOMOS) International Scientific Committee for the Analysis and Structural Restoration of Architectural Heritage (ISCARSAH)
www.iscarsah.icomos.org

La Sapienza University in Rome
www.disg.uniroma1.it

National Heritage Training Group (NHTG)
www.nhtg.org.uk

Royal Incorporation of Architects in Scotland
www.rias.org.uk/services/conservation

UK Heritage Lottery Fund (HLF)
www.hlf.org.uk

U.S. Federal Register
www.federalregister.gov

U.S. National Center for Preservation Technology and Training (NCPTT)
www.ncptt.nps.gov

U.S. Office of Personnel Management Position Classification Standards
www.opm.gov/fedclass/html/gsclass.asp

U.S. National Park Service "Essential Competencies for National Park Service Employees"
www.nps.gov/training/npsonly/npsescom.htm

U.S. Secretary of the Interior's revised draft Historic Preservation Professional Qualification Standards
www.nps.gov/history/local-law/gis/html/quals.html

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