EDUCATION AND PRESERVATION ENGINEERING

Keeping Our Heritage Structures Safe

BY PAULO B. LOURENÇO

EUROPE HAS LONG BEEN INFLUENTIAL in the preservation of cultural heritage buildings, from the Renaissance, to the Scientific Revolution, to the first restoration theories. The twentieth century saw the internationalization of cultural heritage conservation with the establishment of organizations such as ICOMOS (the International Council on Monuments and Sites), the development of charters to guide practice, and the growing recognition that conserving built heritage is an important economic issue—for instance, in Europe tourism accounts for 10 percent of the GDP and 12 percent of employment. Preserving this heritage requires dedicated and trained professionals, including not only architects and conservators, but also structural engineers.

WHAT IS A STRUCTURAL ENGINEER?

According to a past definition in the official journal of the UK-based Institution of Structural Engineers, "Structural engineering is the science and art of designing and making, with economy and elegance, buildings, bridges, frameworks, and other similar structures so that they can safely resist the forces to which they are subjected." This definition concludes with the idea of safety, which is ultimately the most important objective. Mistakes in engineering that cost a single life are no longer acceptable, even if, in the past, such mistakes were fundamental in the development of empirical knowledge. The idea of structures being safe if they can resist forces to which they may be subjected is simple—but understanding how that safety can be achieved is complex. The resistance of materials varies and is not precisely known. Predicting the stresses to which a structure may be subjected at any future time is not easy, particularly those caused by earthquakes and other natural hazards.

Engineers address risk evaluation for the built environment by assessing the level of hazard, the building vulnerability, and the level of exposure. A hazard is a natural or human-caused event that can impact people, buildings, infrastructure, agriculture, environmental assets, and communities, such as an earthquake or a flood. Building vulnerability measures the impact a hazard has on the built environment, given the magnitude of a certain hazard scenario, such as the 475-year return period earthquake or the 100-year flood. Finally, exposure refers to the elements at risk from a hazard event, such as the number of people affected or the change in the economic value of a building. Within this holistic approach, building vulnerability is the most important factor, not only because of the physical consequences of a disaster, but because it is where engineering can intervene, reducing vulnerability and consequently the extent of life loss, physical damage, and economic loss.

In earlier times—before there were distinctions between the professions of architecture and engineering—the empirical knowledge of building crafts, taught by masters to apprentices, provided the tradition and theory upon which structural design was based. Medieval masons in their apprenticeship were introduced to the geometrical techniques required to lay out plans and prepare the templates and models from which stonework would be cut. The transformation of massive stonework into the delicate tracery characteristic of Gothic architecture is clear evidence of the powerful logic of the trial and error methods employed by the medieval builders—a triumph of skill over probability. It seems evident that these builders did not employ any form of modern structural analysis. Medieval masons apparently discovered the margins of safety through observation and experience.

In the transition from medieval masons to modern times, it is interesting to recall Andrea Palladio, who began his career as an

SAHC class of 2013/14 on a study visit to Poblet Monastery in Catalonia, Spain—a UNESCO World Heritage Site built in the twelfth to fifteenth centuries. Photo: SAHC Program, University of Minho.

An SAHC student integration project team conducting a survey and inspection at the Roman Temple of Évora, Portugal, dating from the first century CE. The temple is located in the Historic Centre of Évora—a UNESCO World Heritage Site. Photo: Daniel Oliveira, University of Minho.

apprentice to a sculptor and later worked as a mason, before becoming one of the most influential Western architects in history. In the Renaissance, theoretical explanations began to be developed and valued. Today, preservation engineering must balance the realities of construction with the discipline of structural engineering. The former is largely empirical, based on experience gained in building and the skills of the building crafts. The latter, usually expressed in mathematical terms, is founded on theoretical knowledge, experience, and the profession's responsibility for public safety. Today's building codes and regulations are based on scientific analysis. Demonstrating how historic buildings can perform to necessary standards is important to confirm their viability and use, either as living or as dead monuments, and this is what structural engineering provides.

TRAINING IN HERITAGE STRUCTURAL ANALYSIS

Recent decades have witnessed great strides in experimental and numerical engineering methods. In the context of structural engineering, the ICOMOS Charter–ISCARSAH (International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage) Principles and *Recommendations for the Analysis, Conservation, and Structural Restoration of Architectural Heritage* (both from 2003) provide the modern technical and scientific context, stating clearly that not only are the appearance and materials of historic structures to be preserved, but their resisting mechanisms also are to be investigated, understood, and preserved. This difficult task requires an approach and skills different from those employed in designing new construction—a task for which engineers and architects are insufficiently trained or not trained at all. Many advanced education programs in the preservation of built heritage exist around the world, but until recently none was specifically focused on training engineers and technical architects in the structural analysis of heritage structures. Structural engineering specializing in historic building conservation emerged as a specific area of practice in the second half of the twentieth century. Initially it sought to combine empirical work with practical knowledge based on assessments of a building's past performance.

The international Masters Course in Structural Analysis of Monuments and Historical Constructions, or SAHC (msc-sahc.org) started in 2007 and is coordinated by the University of Minho, Portugal. Since its inception, it has educated more than four hundred students from seventy-one countries, with the greatest numbers coming from Italy, Greece, the United States, Spain, Canada, and India. Students are expected to have a BS with four years of training or a BS and MS with five years; most already have an MS, and a few have a PhD. About 50 percent of the students are civil engineers, 25 percent building or architectural engineers, and 25 percent architects with a solid background in structures. The impressive motivation of the students and the mix of age, cultural background, education, geographic location, and experience are important aspects of the program.

SAHC ran for ten years as an Erasmus Mundus Masters Course, cofunded by the Erasmus+ program of the European Union, which provides European students with the opportunity to experience student life in one of the thirty-three program countries. SAHC is now running as a self-sustainable masters course, without financial support from the European Union.

The University of Minho's partners in SAHC are the Czech Technical University in Prague, the Polytechnic University of Catalonia (UPC) in Barcelona, the University of Padua, and the Institute of Theoretical and Applied Mechanics of the Academy of Sciences of the Czech Republic. This collaboration reflects the need for greater training of engineers in confronting structural challenges posed by historic buildings. Lecturers come from all partner institutions. Students have coursework for seven months in Guimarães, Portugal, a UNESCO World Heritage Site with more than a thousand years of history. Many students then move to a second location in Europe (Barcelona, Padua, or Prague) to spend four months developing their theses. The program utilizes advanced software and experimental tools to prepare future professionals with the ability to process information from different scientific areas, to communicate orally and in writing, to manage stress and anxiety, and to work in groups, among other relevant skills. SAHC students spend eight hours a day at the university's facilities, with classes in the morning and individual and group work in the afternoon.

The focus of this one-year training, taught in English, is the application of scientific principles in analysis, innovation, and practice, in the preservation of monuments and historical structures, combining recent advances in research and development with activities oriented to professional practice. SAHC integrates the diversity of expertise at leading European universities in the field, offering education oriented to a multidisciplinary understanding of structural preservation through the involvement of experts from complementary fields. Students learn top-level structural analysis in a research-oriented environment that also includes close cooperation with industry and a focus on problem-solving, making this program unique.

SAHC provides a cross-disciplinary education comprising engineering-oriented issues (structural analysis techniques, seismic behavior and structural dynamics, repairing and strengthening techniques, inspection and diagnosis, survey and monitoring, and materials science) with more general methodological and philosophical concepts, such as the history of construction and preservation. The balance between theory and practice is made—in addition to a long-running integrated project in each unit—by linking the conceptual framework in parallel with professional applications. These connections include joint scrutiny of case studies in which the lecturers have participated, visits to case studies during execution works, visits to case studies for survey and mapping, and hands-on laboratory and computer assignments.

In addition to six regular courses, the program includes a group integrated project and an individual dissertation that can be research or profession oriented. Many international engineering programs include such a senior project or "capstone" project in their curriculum, with characteristics such as: being based on real-world projects, usually design oriented; a mentor assigned to the project, requiring the students to interact with other experts as necessary; the opportunity for students to work across disciplines; students as interns on campus; and students working as a team, not individually (so no student handles the entire project). This integrated project lasts seven months and is primarily an assessment project with conservation, repair, and strengthening included. Each group has about five students, and different materials and typologies are considered, so the students integrate knowledge from the program and, at the same time, learn and share expertise with each other. Students and lecturers meet for presentations and discussions three times throughout the project, before a final presentation is made.

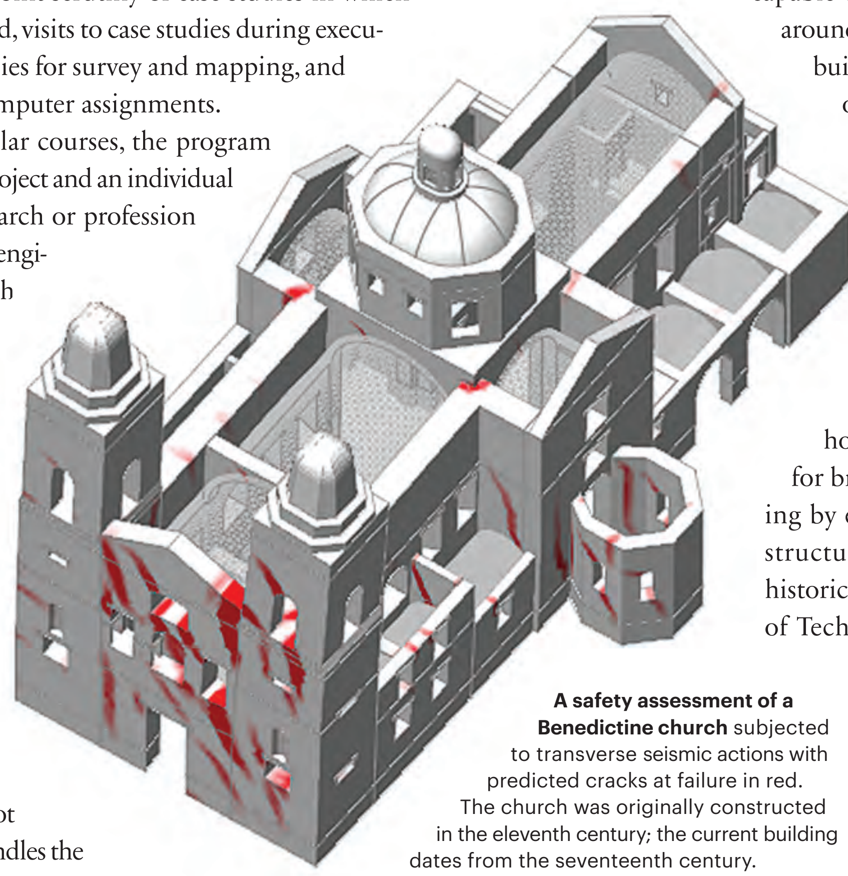
THE NEED FOR PRESERVATION ENGINEERS

Conservation of historical structures with an engineering focus is indeed necessary. Our built heritage is at risk, and this crisis requires professionals who have the ability to protect our shared heritage from various threats, including natural decay, human interventions, climatic changes, and natural hazards. Specialized expertise is necessary to advance protection of built cultural heritage—formerly a niche area, now increasing in importance.

We need professionals able to understand structural systems in different cultural contexts, and we must encourage them to develop their expertise with a valuable international perspective. These highly trained professionals have their own intrinsic market value, with knowledge often not possessed by regularly trained engineers and architects. This knowledge includes techniques of seismic retrofitting that can be extended into any existing building, not just historic fabric; forensic engineering skills such as inspection, diagnosis, and arrest of deterioration and damage in various forms of historic construction; in-depth knowledge of survey techniques; and good writing and communication skills.

We also need an international network of leaders in the field, capable of disseminating best practices around the world, helping to keep our built heritage safe. It has been demonstrated that theory and practice can progress together, offering a testing ground for the latest research and ensuring that the field provides the feedback necessary to define research directions.

The success and popularity of the University of Minho program is indicative of a need for broader and deeper understanding by engineers of how best to solve structural problems associated with historic buildings. The Indian Institute of Technology Madras in Chennai is another university seeking to meet this need, within the Asian context, as is the Pontifical Catholic University of Peru in Lima, for Latin America, to name just two. Leading academics in the field are established around the world, including North America. Our hope is that in the near future universities in regions beyond Europe will respond to this need and, in so doing, provide practitioners worldwide with the necessary understanding of the physical nature and behavior of historic structures, so that greater numbers of significant buildings are conserved—and fewer lives are lost.



A safety assessment of a Benedictine church subjected to transverse seismic actions with predicted cracks at failure in red. The church was originally constructed in the eleventh century; the current building dates from the seventeenth century. Credit: Rafael Ramírez, University of Minho.

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