THE VALUE OF PRESERVING HISTORIC BUILDINGS IS INCREASINGLY accepted by society, which not only recognizes built cultural heritage as a part of its identity but is also more cognizant of its economic value. In Europe, for example, tourism accounts for 10 percent of the GDP in the EU and 12 percent of employment. Built cultural heritage is a fundamental element of what draws tourists to European destinations.

To a great extent, the value of historic buildings rests in the integrity of their components as unique products of the technology of their time and place. Unfortunately, cultural heritage buildings are particularly vulnerable to disasters, for a variety of reasons. They are often damaged or in a state of deterioration; they were built with materials with low resistance; they are heavy; and the connections among their various structural components are frequently insufficient. The main causes of damage are lack of maintenance, water-induced deterioration (from rain or rising damp), soil settlement, and extreme events such as earthquakes. Earthquakes have caused hundreds of thousands of deaths in the last decade, in addition to the tremendous losses in built cultural heritage.

A METHODOLOGY FOR INTERVENTION

Studies indicate that investment in measures to reduce the vulnerability of buildings yields an average value of four times the amount invested. Retrofitting of buildings to increase earthquake resilience offers a cost-benefit of up to eight times the value of the investment. In the case of built cultural heritage, the structures are invaluable and cannot be reconstituted by post-disaster measures. Earthquakes occur randomly, and they can be larger than those anticipated in safety regulations; it is therefore necessary to take steps, in advance, that can reduce the risk of damage and promote subsequent recovery.

Modern conservation respects the authenticity of a building’s historic materials and structure. In practice, interventions must be based on understanding the nature of the building and the actual causes of damage or change. The goal is a minimum of interventions and an incremental approach; much importance is attributed to diagnostic studies of historical, material, and structural issues. In 2003 these considerations were summarized in recommendations issued by the International Council on Monuments and Sites, recognizing that conventional techniques and legal codes oriented to the design of new buildings may be difficult to apply, or even inapplicable, to heritage buildings. These recommendations...
state the importance of a scientific and multidisciplinary approach to built heritage conservation that involves historical investigation, inspection, monitoring, and structural analysis.

The methodology for completing a project includes data acquisition, structural behavior analysis, diagnosis, and safety evaluation. In particular, diagnosis and safety evaluation of the structure are two consecutive and related stages on the basis of which the need for and the extent of treatment measures are determined. Evaluation of the safety of the building should be based on both qualitative methods (some types of documentation and observation) and quantitative methods (experimental and mathematical) that take into account the effect of seismic activity on the building’s structural behavior. The challenge to professional practice is to ensure the basic principles of durability, compatibility, reversibility, and nonintrusiveness while maintaining sufficient safety measures to prevent collapse and other unacceptable loss.

Historic buildings are often vulnerable to earthquakes, but simple and moderate cost measures can dramatically change the situation. The most important action to reduce the vulnerability of a building is to increase the connections among its structural parts. This can be done by tying walls to each other (for example, by using externally bonded systems or anchoring elements in corners and intersections) or by connecting walls and floors (such as by anchoring wooden joists to the walls). The second most important action to reduce vulnerability is to prevent disintegration during a seismic event (for instance, by mortar repointing, grouting, or anchoring multiple leaves of a wall using polymer or metallic meshes).

The characterization of irregular masonry remains a true challenge, given that the in-plane and out-of-plane behavior of historic walls is not well understood. Additionally, seismic assessment of historic built heritage is complex, since the safety assessment techniques used for modern buildings are not applicable to historic structures; these techniques fail to accurately replicate the true behavior of such structures. Still, significant developments in the last few decades have permitted reliable engineering for safety assessment and the design of efficient and effective intervention measures.

DEVELOPMENTS IN RESEARCH AND PRACTICE

Some advances in research and practice have occurred recently in nondestructive evaluation and in repair and strengthening techniques for historic structures. While these developments are important, they are often difficult to integrate into undergraduate and graduate courses, and even into practice.

One example of an advance is in procedures for the investigation and diagnosis of historic fabric. These techniques can be invasive (such as coring or otherwise opening up the building) or can be fully nondestructive (using elastic waves or electromagnetic waves). Other advances include the methods and simulation tools available for the safety assessment of historic masonry structures. The methods have different levels of complexity (from simple graphical methods and hand calculations to complex mathematical formulations and large systems of equations), different availability for the practitioner (from well-disseminated structural analysis tools accessible to any consulting engineering office to advanced structural analysis tools available only in a few research-oriented institutions and large consulting offices), different time requirements (from a few seconds of computer time to a number of days of processing), and, of course, different costs. Many structural analysis techniques can be adequate, possibly for different applications, if combined with proper engineering reasoning.

There are several approaches—often combining experimental and numerical techniques—that have received substantial attention in research. Key considerations are both durability and the compatibility of new materials with traditional materials (such as stone, lime-based mortar or plaster, and adobe or clay brick). Injection grouts, for example, are a well-known remedial technique, which can be durable and mechanically efficient while preserving historic values. Still, the selection of a grout for repair must be based on the physical and chemical properties of the existing materials. Parameters such as rheology, injectability, stability, and bond of the mix should be considered to ensure the effectiveness of grout injection. The insertion of bars (ideally stainless steel or composite) within the masonry using coring also has been a popular technique to enhance structural capacity.
The development of innovative technologies that apply externally bonded reinforcement systems, using composite materials for strengthening, has gained attention in recent years. Application of fiber-reinforced polymers (FRP) to vaults, columns, and walls has demonstrated their effectiveness in increasing load-carrying capacity and in upgrading seismic strength, even if concerns about durability persist. During the past decade, in an effort to alleviate some drawbacks associated with the use of polymer-based composites, inorganic matrix composites have been developed. This broad category includes steel-reinforced grouts (SRG), unidirectional steel cords embedded in a cement or lime grout, and fabric-reinforced cementitious matrix (FRCM) composites, a sequence of one or more layers of cement-based matrix reinforced with dry fibers in the form of open single or multiple meshes. Currently, natural fibers are becoming more popular for crack control and strengthening, not least because they are “green” materials.

More conservation research is necessary for a fuller comprehension of the behavior of historic masonry buildings and the reasons for their damage from seismic events. Ideally, a conservation professional should be able to adopt a decision process that includes: a comprehensive understanding of the history of the building; diagnostic work (preferably involving nondestructive or minimally destructive techniques) and a safety assessment (often using advanced analysis tools); design and implementation of remedial measures; and control of the implementation.

Earthquakes are, and will remain, one of the most powerful sources of destruction for cultural heritage buildings. Cracking occurs at early stages of loading, and the traditional methods for the assessment of stability cannot be effectively applied to historic structures. Advanced approaches are available, but the number of practitioners experienced in these methods is insufficient for existing needs; thus more training for the field in general is required.

Recent developments in intervention techniques that better confine and tie together building parts—thereby reducing the risk of separation of parts and disintegration of individual elements during a seismic event—are significant. The implementation of remedial measures requires that safety, durability, compatibility, and removability are considered, together with costs and cultural value. Much knowledge has been gained in recent decades. The challenge is to turn this knowledge into practice both by educating professionals and by allocating financial resources for this endeavor.

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