MASONRY AND EARTHEN CONSTRUCTION AND STRUCTURES

Paulo B. Lourenço

ISISE, Department of Civil Engineering

School of Engineering

University of Minho, Campus de Azurém

4800-058 Guimarães

Portugal

pbl@civil.uminho.pt

www.civil.uminho.pt/masonry

1. Introduction

The statement of the colloquium includes as objective: 'To develop curricula for an engineering program focused on quantitative techniques and methodologies applied to the engineering evaluation and remediation of heritage structures, and to ensure that students acquire the competencies necessary to address the challenges of the market.'

2. The current state of knowledge

Masonry is the oldest building material that still finds wide use in today's building industries. Innumerable variations of masonry materials, techniques and applications occurred during the course of time. The influence factors were mainly the local culture and wealth, the knowledge of materials and tools, the availability of material and architectural reasons.

The most important characteristic of masonry construction is its simplicity. Laying pieces of stone or bricks on top of each other, either with or without cohesion via mortar, is a simple, though adequate technique that has been successful ever since remote ages. Other important characteristics are the aesthetics, solidity, durability and low maintenance, versatility, sound absorption and fire protection. A drawback is the education of engineers. Because design and field knowledge of masonry is absent or minimal in the programs of most graduations in civil engineering, masonry is being substituted by reinforced concrete or steel as structural materials. Another drawback is, of course, the intrinsic fragility of old masonry structures to earthquake loading, due to a combination of large masses, low tensile strength and, often, friable materials.

Many advances occurred in the last decades regarding aspects detailed in other topics in the colloquium, such as conservation methodology, NDE or repair and strengthening techniques. In the field of “Masonry and Earthen Structures” *per se*, many advances also occurred, mainly related to experimental characterization of historic materials and advanced analysis methods. These recent advances are often difficult to translate to undergraduate and graduate courses, and even to engineering practice.

3. Research questions and potential funding

Some research questions are addressed below, generally with combined focus on experimental and on numerical techniques.

Needs
Durability (particularly with respect to FRP bond, mortars, steel, etc.)
Creep and fatigue, which seem to be related to recent collapses of historic structures under sustained heavy load. Also the distribution of stresses in multi-leaf walls is severely affected by long-term effects.
Characterization and adequate representation of irregular masonry, so that the behavior of historic multi-leaf walls can be predicted, both in plane and out of plane. Assessment and strengthening of multi-leaf walls is one of the most complex issues for modern practitioners.
Multi-scale modeling of masonry, involving a closer link with material science, aiming at developing eco-efficient materials and assessing deterioration.
Stochastic analysis, given the significant variability of masonry materials and the difficulties to characterize them in situ.
Seismic analysis of historic structures is still a true challenge, as linear elastic analysis is inadequate and push-over analysis provides hardly representative results.

The issue of potential funding is complex. Typical funding possibilities are governmental organizations, non-governmental organizations, heritage authorities and the industry.

In the case of governmental organizations, research can be prioritized or not. At European level, research in cultural heritage buildings has specific funding opportunities for decades, due to a societal, economic and cultural demand. Architectural heritage has a large economic value, as the existence of a monument of a monumental compound is often a key attraction of a city. Tourism and leisure will be a major industry in the 3º millennium and it represents about 10% of the GNP. Modern societies require architectural heritage protection, as they believe it is a part of their culture, a part of their history and a part of their memory. Its authentic character is to be maintained and transmitted to the next generations. For the case of the US, if cultural heritage buildings are not considered a priority, lobbying is necessary combining the "importance of the past" with its "economic value".

Several non-governmental and international organizations are involved in culture related issues and can provide funding for research or demonstration. Examples are The Getty, Aga Khan Foundation, World Monument Fund, UNESCO or World Bank.

Heritage authorities tend to have limited funding but protocols and very specialized consultancy can provide good support and experience to drive research and students.

Funding from the industry is usually difficult to attract as the sector is characterized by small and micro enterprises, more than often resorting to traditional materials and techniques. Large contractors today are mostly managing companies involving subcontractors to carry out the works. Large contractors have difficulties to comply with the long execution periods, small quantities and careful execution in cultural heritage buildings, as their overhead costs are too high and they need industrialized production. Most innovative products from large enterprises, e.g. BASF or SIKA, are normally from a very large range of products, where conservation and restoration account for a very small fraction of revenue. It seems that the only way to involve large contractors or large material suppliers is to promote the impact of "cultural aspects" in society, allowing them to consider non-accountable benefits.

4. *Essential competencies*

Topic	Competencies and References
Construction Technologies and Structural Components	Historical masonry materials (stone, brick, bond, adobe, mortar) Function and role of structural elements (walls, foundations, columns and pillars, arches, vaults) Earthen constructions
	Davey, N. (1961), A history of building materials, Phoenix House. Elliot, C.D. (1992), Technics and architecture: The development of materials and systems of buildings, The MIT Press. Houben, H., Guillaud, H. (2001), Earth construction: a comprehensive guide, CRATerre-EAG, IT Publications. Mark, R. (1993), Architectural technology up to the scientific revolution, The MIT Press. Szabó, B. (2005), Illustrated dictionary of historic load-bearing structures, Kriterion & Utilitas.
Overall Structural Arrangement	Lintel (or post-and-lintel) construction Vaulting construction Evolution of monumental construction (false vaulting; Roman; Byzantine; Romanesque and Gothic) Domes The epitome of masonry (Antonelli and Gaudí).
	Adam, J. P. (1989), Roman Construction. Materials and Techniques, Routledge. Fitchen, J. (1989), Building Construction Before Mechanization, The MIT Press. Fitchen, J. (1997), The Construction of Gothic Cathedrals: A Study of Medieval Vault Erection, The University of Chicago Press.
Ancient Rules and Classical Approaches	Ancient construction treatises, geometrical and empirical rules Graphic statics Limit mechanism analysis
	Heyman, J. (1995). The Stone Skeleton. Structural Engineering of Masonry Architecture. Cambridge University Press.

Masonry Structural Analysis	Mechanical properties of masonry Design of structural elements (vertical loading, combined in plane loading, out of plane loading, concentrated loads) Full design of masonry buildings (linear elastic, rigid and flexible diaphragms, push-over analysis for boxed behavior)
	Drysdale, R.G., Hamid, A.A. (2008). Masonry Structures, Behavior and Design, 3rd Edition, The Masonry Society.
Advanced Analysis of Historic Buildings	Advanced analysis (possibilities and types of analysis, how to simulate with FEM) Advanced modeling of masonry (micro and macro modeling, material data, homogenization) Macro-block limit analysis for earthquake loading Examples of application
	Not applicable.

5. Experiential learning opportunities – internships, service learning projects

The topics partly lend themselves to experiential learning opportunities and these are also important for the students, so that they acquire the competencies necessary to address the challenges of the market.

Topic	Experiential learning opportunity
Historic masonry materials	Historic mortars for bedding and repointing Walls / specimens in stone and brick masonry Masonry arches (design, build and test) Adobe and rammed earth

Structural design	Follow a case study, including damage reporting, inspection and diagnosis, structural analysis and definition of a conservation / consolidation design, including specifications, cost estimation and execution drawings.

6. Does the topic lend itself to curriculum modules and/or new courses, and what curriculum additions are necessary to cover the material in sufficient depth

Topic	Curriculum modules and/or new courses
Construction Technologies and Structural Components	All modules addressed in Section 4 can be added to existing courses on “Introduction to civil engineering”
Overall Structural Arrangement	All modules addressed in Section 4 can be added to existing courses on “Introduction to civil engineering”
Ancient Rules and Classical Approaches	All modules addressed in Section 4 can be added to existing courses on “Statics” or “Strength of Materials”
Masonry Structural Analysis	A module on push-over analysis of masonry can be added to existing courses on “Masonry Structures”, if existing. In several universities, a course on masonry structures is not offered. The module requires that the students followed a course on Structural Dynamics previously. Another alternative is to create a module in a course of “Structural Dynamics”. The module requires that the students followed a course on Masonry Structures previously.
Advanced Analysis of Historic Buildings	This requires a fully new course

7. Should the material be presented at the undergraduate and/or graduate level

Topic	Level of studies
Construction Technologies and Structural Components	Undergraduate
Overall Structural Arrangement	Undergraduate
Ancient Rules and Classical Approaches	Undergraduate
Masonry Structural Analysis	Graduate
Advanced Analysis of Historic Buildings	Graduate