Evolución tecnológica del material estructural utilizado en edificios: Museo de Ingeniería Civil

Technological evolution of structural material used in buildings: Museum of Civil Engineering

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RESUMEN

El Museo de Ingeniería Civil, de la Universidad de Lisboa, contiene una colección de elementos relacionados con la actividad de la Construcción, y presenta un recordatorio de cómo la tecnología avanzó a las metodologías actuales de trabajo. Se exponen segmentos de materiales antiguos utilizados en la construcción de edificios: un ladrillo de tipo *Ivry-París*, un elemento de hormigón de *caementitium opus*, una muestra del primer tipo de hormigón armado y un panel de pared de tierra. Estos elementos constituyen ejemplos de memoria histórica relacionada con la ejecución de paredes. Estos elementos están preservados y contribuyen a la difusión del patrimonio técnico y a la memoria de la Construcción.

ABSTRACT

The Museum of Civil Engineering, of the University of Lisbon, contains a collection of elements related to the activity of Construction, and presents a reminder of how the technology advanced to the current methodologies of work. Segments of old materials used in the construction of building are exposed: a brick element of *Ivry-Paris* type, an element of *opus caementitium concrete*, a sample of the first type of reinforced concrete and a portion of an earth wall panel. These elements constitute examples of historic memory related to the execution of walls, currently outdated. These elements are preserved and contribute to the dissemination of the technical heritage and to the memory of Construction.

PALABRAS CLAVE: Museo, memoria, técnicas antiguas, hormigón, primer hormigón armado.
KEYWORDS: Museum, memory, antique techniques, concrete, first reinforced concrete.

1. Introduction

The Museum of Civil Engineering of the Instituto Superior Técnico (IST) contains a collection of elements related to the activity of Construction [1]. The didactic heritage, gathered for the Museum, was located in offices, laboratories and classrooms, maintained by teachers and staff of the Department.

Additionally, other pieces of scientific interest and related to the areas of knowledge developed in the Department, have been offered by teachers, alumni and construction enterprises. All objects were restored and kept, scheduled and organized properly. Each piece is identified, characterized and inventoried following a thematic organization related to the different engineering domains: Transport, Bridges, Topography, Architecture, Materials, Drawings, Hydraulic, Construction techniques and Soil mechanics.

Within the aim of the Congress some of the most relevant elements related to the fields of construction techniques, materials and test equipment are described in detail:

- A wooden model reproducing the anti-seismic structure, the *Pombaline* cage, design for the reconstruction of Lisbon, devastated by the earthquake of 1755, is exposed;
- Segments of old materials used in the construction of building are exposed, namely, a brick element of *Ivry-Paris* type, an element of *opus caementitium* concrete, a sample of the first type of reinforced concrete and a portion of an earth wall panel;
- The Museum, in its function of preserving the history of teaching at school, contains some equipment used in evaluation tests of material properties, such as steel or concrete.

2. The Museum

The Museum of Civil Engineering was inaugurated in 1993, and is located in the ground floor of the main Civil Engineering building of the IST (Figure 1). The elements in exhibition in this technologic Museum space, are examples that are preserved and kept in adequate conditions contributing to the dissemination of the technical heritage and to the memory of Construction history.

As the school is a space of several conferences and technical meetings, the Museum became an interesting place for national and international visitors. So, supporting this interest, all elements are identified and linked to texts, in Portuguese and English. The texts provide the functionally or applicability of each sample or equipment, in a historic perspective.

Figure 1: In-side views of the Museum.

The Museum provides: to students, an organized documentation of interest for research works conducted by graduate or PhD students; to teachers, the complementarity of subjects providing support to the programmatic curriculum, with the description of old materials and equipment; to visitors, an important collection of books, photographs, drawings, models and equipment related to the construction industry.

The elements selected in this text, constitute examples of historic memory related to the execution of walls, currently outdated, but representing the base of the reinforced concrete construction essential in the constitution of current buildings. In the context of the subjects concerning construction technics and materials, the considered features complement the curricular program, as they are used to illustrate the historic evolution of methodologies and materials used in the construction of buildings.

In an education perspective, it was drawn up, for all pieces of the Museum, a descriptive text of its features, functionality and period of use; wish is presented in the next items characterizing each element.

3. Construction technics

The study on knowledge related to the physical and mechanical properties of materials in order to identify resistant, was translated into the design of construction systems, as innovative marks of the construction history [2].

3.1 The Pombaline cage

The wooden model of a *Pombaline* cage reproduces the anti-seismic structure type, designed for the reconstruction of Lisbon, devastated by the earthquake of 1755 (Figure 2).

Figure 2: The *Pombaline* cage.

The *Pombaline* buildings presents a structure composed of vertical, horizontal and sloped wooden elements, allowing a good capacity to resist to seismic loads. It was created under the ministry of Marquis of *Pombal*, in the reign of king José I, and it was applied in buildings until the end of the first quarter of the 20th century.

The structure draws a St. Andrew's cross: the *frechais* are horizontal wooden beams, allowing the support of vertical elements; the horizontal locking way is established by *travessanhos*, enclosed in vertical panels, and by spars located over the spans; the link between the cage and the masonry is achieved by hands, which are pieces of wood presenting a tooth shape [3].

The old way of assembling adjacent wood elements is established through finger joints, forming teeth and, eventually, with gatherings and *mechas* (Figure 3). The museum contains drawings and wooden models illustrating this antique assembling solution.

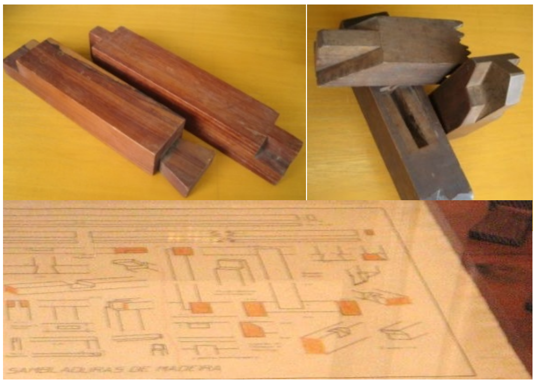

Figure 3: Old systems of assembling wooden elements: models and drawing.

3.2 Wooden workshop

According to the pedagogic notes of *Bensaude* [4], the first director of the IST, "after a practical study, the student proceeds to make a drawing to be manufactured in the wooden workshop". So the precision of the technical drawing should be adequate to support the manufacture of the object. Figure 3 shows a drawing representing assembled elements and the didactic wooden models used to support the sketch process. The models of the *Pombaline* cage and the wooden finger joints were executed in the wooden workshop, by students or by craftsmen based in drawings elaborated by students (Figure 4).

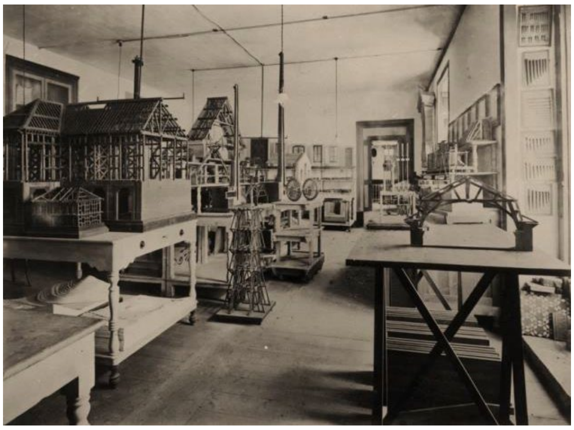

Figure 4: Wooden workshop in the old IST building.

The wooden models served simultaneously as an education strategy more practical, implemented by *Bensaude* in his new school, the IST, in 1911, as it involves the future engineers in their own execution, and also as didactic elements used to support teaching construction methodologies issues.

4. Materials

Some of the most relevant samples of building materials of the Museum are: the massive brick of *Ivry-Paris* type; the *opus caementitium* concrete element; the first type of reinforced concrete; the segment of an earth wall panel. These elements constitute an example of historical memory related to the execution of walls, currently not in use.

4.1 Ceramic brick

The massive ceramic element is a brick produced in the *Lusitania* factory using molds of *Ivry-Paris* (Figure 5). The mold designation refers to the manufacturing installation of stoneware production, founded in 1854 by *Émile Müller* in *Ivry-sur-Seine*, next to Paris.

Figure 5: An *Ivry-Paris* brick and an antique picture of the bullring of *Campo Pequeno*.

The factory was transferred at the beginning of the 19th century, to the site of the current headquarters of a national bank (being visible the chimneys of the ovens), because the land was rich in clay. At that time, the factory provided the bulky order of bricks for the construction of the bullring of *Campo Pequeno*, begun in 1891, designed in neo-arabic style, with bricks covering the whole building. And the factory contributed to the urban expansion of Lisbon in the direction of the current new avenues [5].

4.2 Old and reinforced concrete

The origin of the current reinforced and pre-stressed concrete, indispensable in the contemporary composition of the building structures, is the ancient concrete *opus caementitium*, followed by a first experience of reinforcement concrete. Concrete and mortars have been used as building materials for thousands of years, and then produced by a mixture of clay, marl, sand, gravel and water.

The Roman civilization has had on the design and construction of infrastructures and buildings an enormous influence, which is still quite present today. The sample of old concrete was collected from a roman ruin located in *Vila Moura*, Portugal (Figure 6). The concrete-material is derived from volcanic ash, from the Naples region, and complemented with hydraulic lime, silicon compounds, aluminum and iron oxide [6]. The concrete element features an easily detachable and inert binder material with a rounded configuration.

Figure 6: Fragments of roman concrete and of the first reinforced concrete.

The sample of the first reinforced concrete, manufactured in Portugal, was found in a factory of flour milling (Figure 6). The factory, installed since 1865 in *Cova da Piedade*, undergoes, in 1897, a violent fire and the owner, faced with the fragility of the previous construction, required, for the new building, the innovative material recently introduced in Europe. The reconstruction is carried out, and the first building entirely built with a reinforced concrete reticulate system [6], executed in Portugal. At the time, the factory building was a reference in construction innovation, in the national panorama. The construction was built according to the process of french origin, patented by *François Hennebique*. The success of the *Hennebique* system is associated with the speed in the design and preparation of the work execution and the high quality of the final product.

4.3 Earth wall panel

Natural material, such as vegetable fibers or clay, forms the basis of the construction of *tabiques* or earth walls and mass bricks.

The *tabique* panel fraction was donated to the Museum in 1989, coming from the ruins of the Convent of *S. Francisco*, in *Bragança*, Portugal (Figure 7). The element represents a traditional solution of the construction of wall and it was one of the most used ancient techniques in Portugal [7].

Figure 7: Segment of a earth wall panel.

The *tabique* consists of a simple wooden structure and a layer of mortar of natural elements; its resistant capacity is conferred by the wooden structure and the mortar acts as the filling and coating material. The *tabique* (structural) or the *taipa* (non-structural) are obtained by preaching a bar (horizontal slats) on planks placed vertically, filled and coated on both sides by clayey earth-based material, with possible addition of lime and vegetable fibers [8]. In the sample it is possible to identify the wood elements, the arrangement of fibrous texture and the surrounding mortar

5. Test equipment

The topics taught in the various areas of Civil Engineering have evolved, contributing to empower current students of technological advances achieved. The way to provide innovative materials and carry out laboratory tests has naturally also admitted changes.

Thus, the Museum presents: a *Universal Amsler* test machine; a stretching steel device; a *Vicat* test tool; *a Le Chatêlier* needle.

5.1 Universal Amsler machine

The *Universal Amsler* machine allows testing related to the characteristics of strength and ductility of steel and it was used, until 1990, in the subject of Materials Resistance (Figure 8).

Figure 8: *Universal Amsler* testing machine.

A traction test is carried out over a steel slice, which is driven by vertical and opposite action forces, causing successively increasing displacements, until the material reaches the rupture. The equipment allows creating the respective diagram, on a logarithmic scale, recorded in pencil on a sheet of paper placed over a rotating drum. The graph establishes the relationship between stress and deformation, and from its analysis, it is possible to determine the main characteristics of steel, namely transfer stress, rupture load, total extent under maximum load, elastic energy, plastic energy and striation coefficient.

5.2 Stretching steel device

The wiring equipment is designed to reduce the diameter of steel wires (Figure 9). The ductile metal is cold-drawn under the action of a traction force, causing a reduction of the section of the steel wire and an increasing of its length. Stretching is a mechanical process applied to steel with the aim of giving the element the desired section and at the same time giving it better mechanical properties.

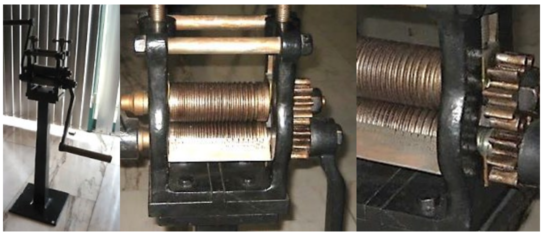

Figure 9: Steel wire stretch equipment.

5.3 Vicat test tool

Vicat tool is used to determine the consistency and time of cement prey in tests where the penetration resistance of a needle is measured on the leaked cement paste in a trunk metal container (Figure 10).

Figure 10: *Vicat* test tool.

Louis Vicat contributed with this device in 1818 to a better knowledge of cement properties [7]. The equipment consists of a metal disc of diameter 10*mm* and a *Tetmajer* needle or probe with its end in a straight section, which penetrates vertically into the fresh paste by the action of its weight. The distance to which the probe is located from the base of the sample, corresponds to the consistency index found for the cement.

5.4 Le Chatêlier's needle

Le *Chatêlier's* needle, dated 1917, is applied to the determination of the hot and cold expandability of the normal consistency cement paste (Figure 11).

Figure 11: *Chatêlier's* needle.

The *portland* cement fastening and hardening mechanism was first explained, in 1887, by *Henry Le Chatêlier* to justify the prey and hardening of the construction plaster [7]. The needle consists of a cylinder of diameter 30*mm* and height 0.5*mm*, and two rods, 150*mm* long, welded laterally. In the preparation of the sample to be tested, the needle is placed on a plate of lubricated glass, is filled with the cement paste, being pressed with balance. The needle is then submerged in water, being measured the removal of the rods at the beginning and end of the test. The enlargement of the distances between the rods of the folder indicates the expandability index of the cement.

5. Conclusions

In the history of the construction, process methodologies and scientific knowledges about material and its behavior, have been evaluating to the actual mode of construct buildings. The Museu, integrated in an engineer school, the IST, has an important role in the dissemination of old construction methodologies contributing to a better understanding of the current building processes and applied materials.

The Museum is currently used as an educational space, as a research archive of old construction technologies and as a room where engineering-related events take place. As so the Museum serves the community and preserves the historical memory of the construction activity and it also supports the historic identity of the school.

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