An experimental teaching laboratory for in situ tests in historical churches
A. Breschi, M. Sassu

Abstract.
An experimental teaching experience has been performed by a group of students, previously prepared through an intensive course with a work-study program on historical monuments. The students, after the theoretical course, have been engaged in a stage by Saint Jean Church in Bastia (F) and successively in the elaboration of the collected data, thus obtaining satisfactory results as to historical research, geometrical survey, mechanical and physico-chemical properties of masonry materials; furthermore the group achieved, in a few weeks, a high level of learning.

1 Introduction.
A deep knowledge of our historical heritage is increasingly becoming a matter of great concern particularly for those professionally engaged in it, at any level. With that purpose a pilot teaching laboratory has been organized for students of the "Istituto Tecnico per Geometri B. Buontalenti" in Livorno. The students, approximatively eighteen years old, have been at different times to Corse Island in the town of Bastia (F), thanks to the collaboration of the local authority and to the "Centre de Formation Des Apprentis", in order to survey Sain Jean Church, which is to be restored in the near future.
The activity has been preceded by a course held at the Ente Livornese Scuola Edile, planned to carry out a work-study program. During the classes, teachers assigned to follow the students in the course of survey operations, imparted preliminary information to prepare them for the experimental activity. The aims pursued with the young learners were
both technical training and mainly the development of an european cultural dimension of historical buildings analyses. It is a meaningful sign that such kind of experiences do not occur occasionally any more and it is also important to point out the constant enthusiasm and application of the students, proving that in presence of new data coming from different cultural areas, it is possible to obtain high performances and surprising levels of learning, particularly if compared to the traditional teaching methods.

The teaching activity developed according to a general scheme of analysis of historical buildings, so divided:
- previous theoretic intensive classroom course,
- experimental on site applications,
- check and rendering in classroom of the experimental activities.

Students dealt with the following subjects:
- preliminary historical and architectural analyses of the town and the church using manuscript annals and other documents;
- study of the urban texture and geometrical survey of the church;
- study of the local building typologies and analyses of mechanical and physico-chemical properties of masonry.

2 Historical analysis and geometrical survey.

Saint Jean Church, previously San Giovanni di Terravecchia, dating back to the middle ages, got its present architectural style by will of Pope Pio V, starting from 1618 even if the works were accomplished only in 1863, with the completion of the second of the twin bell-towers. The edification is attested by the "Annales" of the church, manuscripts in latin and italian with graphic representations of the progress in the works, going back for the most part to the period of the Genouese rule on the island.

The students could consult copies of the documents and so re-build the different stages of the edification of the church, that was subjected to the scarce funds of the parishioners and to various historical events. The phases of the construction of the two bell-towers are particularly well recorded by drawings in the archives, dating back to 1854 and recognizable by a different masonry texture of the bells' cell.

The geometrical survey was performed with topographic instruments, a series of photographs and direct measurements. First of all it was acquired the plan of the area surrounding Saint Jean and then we proceeded with the topographic survey from the square on the left side of the main facade composing appropriate polygonal.

A series of photographs along with direct measurements, constituted the bases for further graphic re-constructions of the main views and sections.

3. Experimental investigations.

Mechanical and physico-chemical testings on the masonry texture and coatings of the church were carried out "in situ" and then completed with laboratory tests. Mechanical trials measured the characteristic
compressive strength and the stress-strain law of the masonry walls of the building and particularly the twin bell-towers, besides a temporal monitoring system was installed to control the evolution of the cracks. With phisico-chemical analyses was found out the degree of humidity and of soluble salts present into the coatings, in order to give an exhaustive description of the damage of the masonry and of its deterioration level. Mechanical analyses consisted of:

a) geometrical masonry texture survey;
b) penetrometric PNT-G tests on mortar joints;
c) compressive and sclerometric tests on bricks;
d) cracks monitoring.

Special forms were filled in with the values of the thicknesses of horizontal mortar joints and blocks, measured on ten samples of about 2 m², taken mainly from the inner sides of the bell-towers. The students alternated in measuring, taking notes and locating graphically the surveyed areas. The data processing determined an average value of the ratio \( r = S_b/S_m \) between the thickness of blocks \( S_b \) and that of mortar \( S_m \) equal to about 5, with a relative standard deviation of about 40%.

Penetrometric PNT-G tests were performed on each sample involved in geometrical survey. On each mortar joint were conducted sets of fifteen measurements, trying to single out at least four characteristic joints. The students took turns in direct measurements and graphical survey of the area subjected to the tests carrying out the strength values from the correlation curve. The following data processing showed that the bearing capacity of the mortar of the church is poor almost everywhere equal to about 1.2 N/mm².

From the masonry walls of limestone, constituting the bell-towers, were removed two stone blocks from which were taken two cylindrical cores with 45 mm diameter and 50 mm height. An electric estensimeter was connected to each sample undergoing a trial of simple compression by hydraulic press Instron 200 KN, obtaining 55,000 N/mm² Young modulus and a collapse resistance equal to 43 N/mm². The stone blocks had previously been measured by sclerometric test to compare the values of resistance in situ, with that of the samples of the masonry texture. By comparing the two trials it was possible to check the reliability of the stone blocks removed from the building. At first sight the church showed the absence of important structural damage. In order to gain experience we surveyed two existing cracks on the left side view of the church, utilizing both decimal fessurimeter and removing centesimal mechanic estensimeter, provided the installation of brass repers on the cracks.

Physico-chemical analyses were performed on eleven samples of coating taken from the church walls. They determined the percentage of humidity and the ionium chlorides, nitrates and sulphates as reported on appropriate tables. Students were engaged in taking the samples and elaborating the analyses, so they pointed out a capillary rise effect of humidity on the masonry from the soil. A general decrease of humidity was noticed with the increasing of the observation point height up to approximately 140 cm, where the humidity effect disappeared. Other areas
affected by water infiltrations were examined on the base of the different percentage of soluble salts, particularly the sulphates produced by the presence of gypsum.

4. Data processing and results.

Great remark was given to the graphical rendering of the church whose views, plan of the flooring and sections of the altar and the choir were reproduced faithfully. On the plans it is put into evidence the zones affected by hygrometric damage along with the identification of the corresponding causes. The results of mechanical tests were elaborated following the Hillsdorf pile-model, in which masonry is constituted of regular layers of blocks and mortar joints, both elastics and with a thickness respectively $s_b$ and $s_m$, Young and Poisson moduli $E_b$, $v_b$, and $E_m$, $v_m$. After having determined in correspondence of each sample the vertical pressure $\sigma$ done by the permanent loads, we found out the transverse stresses $\sigma_{xm}$ e $\sigma_{xb}$ on mortars and blocks from equilibrium and congruence equations

$$\sigma_{xm} s_m + \sigma_{xb} s_b = 0 \quad (1)$$

$$\varepsilon_{xm} = \varepsilon_{xb} \quad (2)$$

from which the confining stress on mortar between the brick layers

$$\sigma_{xm} = \sigma \frac{n v_m - v_b}{1 + nr} r \quad (3)$$

where $r = s_b/s_m$ and $n = E_b/E_m$. The compressive in situ strength of the mortar was furnished by

$$f_k = f_{ko} + K \sigma_{xm} \quad (4)$$

where $f_{ko}$ is the characteristic compressive strength deduced from PNT-G tests and $K$ an adimensional coefficient taking into account the confining effect, whose value is in that case 2. Finally the apparent Young modulus $E$ of the masonry was given by

$$E = E_b \frac{1 + r}{n + r} \quad (5)$$

All the graphical and computational operations were performed following the principle of task shifting, allowing each student to check and be checked at every turn of his research by his own mates and by the teaching staff. In such a way the students were stimulated to proceed
properly in the work and to go through the program evenly, in order to facilitate access to their records to those with a similar level of competence.

5. Conclusions.

The pilot experience performed in Bastia (F) by a group of Italian students has constituted an useful teaching laboratory. Learners, ignoring most aspects of historical and geometrical survey and of materials of ancient masonry buildings, after a short classroom training, could apply in situ the technologies acquired, operate in interchangeable project works, reach a satisfactory practical knowledge of the subject and also a high level of learning of these disciplines.

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References


Fig. 1: Vertical main section of Saint Jean Church.
Fig. 2: Lateral view from the square.
Fig. 3: Plan of the Church with trigonometric diagnosis.
Fig. 4: Cover of the Annals and historical drawing of the left bell-tower.
Fig. 5: Historical drawings of the main frontal view of Saint Jean Church.