SIMPLE FIELD TESTS IN STONE CONSERVATION
EVALUATION OF STONE WORKS DETERIORATION WITH NONDESTRUCTIVE METHODS

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ABSTRACT
Stone was a material widely used in historic heritage due to the high strength of rocks. Despite this physical characteristic, the composite stone materials are not indestructible and deteriorate over time, especially if exposed to weather and other destructive processes as biological colonization. Study and evaluation of weathering that affects this heritage are important subsidies for its conservation and need for potential restores.

Within this context, it is presented here the study that aims to assess the conservation status of the “Monumento a Ramos de Azevedo” located in the Cidade Universitária at São Paulo – Brazil, specifically the part formed by the Itaquera Granite that composes its base, with eight Doric columns and architrave.

Nondestructive methods were used. Equipment used: ultrasound devices, Schmidt hammer, Karsten tube and spectrophotometer. Such methods, when used together, enable to determine the overall state of the monument. Results obtained in situ were compared with laboratory data obtained in fresh rock samples.

The results obtained so far are related to ultrasound and spectrophotometer tests. The first shows that the granite studied is not homogeneous, since results vary considerably along the same single stone block. It should be noted that this has enclaves of biotite granite with different dimensions. Comparing the results obtained in situ and those observed in fresh rock, the last are larger, showing that the monument rock is weathered, even though this is not visible. The spectrophotometer test showed that there is great absorption in violet wavelength (400 nm). Cleanup was held with a neutral detergent and water in a small area of 30 x 40 cm, the color tests were repeated and showed greater uniformity of color and brightness increase, indicating that the luminosity decreases due to the presence of dirt and pollutants.

Other tests will still be made for more thorough evaluation of the monument stone conservation state.

1. INTRODUCTION
Monuments are important records of mankind history as part of its heritage for having historical, sentimental and cultural values and, as such, should be preserved. Conservation is a complex topic since the identification of the sort of all material is necessary in order to enable interventions that will curb the factors causing damages to stones and result the least possible impact in both aesthetic and structural aspects, thus valuing the importance of the monument.

There are several methods to analyze stone deterioration status and quantify its properties. Having in mind the importance of minimal intervention to keep the integrity of monuments and cultural heritage, in this study, only nondestructive methods were used, which is in other hand of low cost.

The study presented here evaluates the degree of conservation of the Monument to Ramos de Azevedo, which is constituted by Itaquera Granite, through nondestructive analyses such as: color measurement, P-wave velocities and Schmidt hammer, based on the mapping of the
weathering forms. This monument is a landmark in the city of São Paulo (Brazil) and is currently placed on the University of São Paulo Campus.

2. MONUMENT HISTORY

Ramos de Azevedo was the architect who designed and built the most valuable edifications in the beginning of the 20th Century in the city of São Paulo. The construction of the Monument to Ramos de Azevedo (Figure 1) was an initiative of contractors and laborers who had worked with Ramos de Azevedo to honor him after his death at the age of 77. The monument was raised by the painter, architect and sculptor Galileo Emendabili, who was born in Italy in 1898 and immigrated to Brazil in 1923. The monument, which took five years to be built, was inaugurated on January 25th, 1934, the city's anniversary. This fact shows the intimate relationship of the architect with the modern and civilized environment that São Paulo gained with his work. Formerly the monument was placed on Tiradentes Avenue in front of Pinacoteca, headquarters of Liceu de Artes e Ofícios (school of arts), where it remained until 1967. It was then taken out by the Electromechanical Industry S.A. (IEMSA) due to works in the North-South subway line and extension of Tiradentes Avenue (Martins 2006). It remained abandoned for years in a park Jardim da Luz, where the statue had even lost a finger and the allegories lost some attributes such as the architecture compass, the painting brushes and the chisel plane. In 1972, the monument was moved to the University of São Paulo Campus and on December 17th, 1975, the monument was reopened. The square where it is now located has named after the architect.

The monument is composed of eight Doric columns in Itaquera Granite, widely used in historical monuments and buildings of São Paulo in early 20th Century, topped by an architrave, which in turn holds a bronze winged horse, having a total height of 25 meters. It has 6 other bronze figures, representing engineering, sculpture, painting, architecture, builders and the statue of Ramos de Azevedo. The basis of the monument is made of the same granite of the columns, with dimensions 15.50 m X 5.60 m X 13.0 m (Comissão de Patrimônio Cultural 1997, Gordinho 2000).

In the northwest face (see Figure 2), there is a base block that was replaced by Grey Granite Mauá, another widely used stone at that time. No record of this repair has been found.

![Figure 1. Monument to Ramos de Azevedo (Font: personal archive).](image)

3. METHODS

For a better data presentation, the monument was divided into 4 faces since weather and local traffic have distinct impacts on the different sides (Figure 2).
Figure 2. Satellite image of the Monument to Ramos de Azevedo and its position in relation to the geographic North. (Source: maps.google.com)

4. MAPPING OF WEATHERING FORMS

To describe the monument’s alteration forms the ICOMOS glossary (2008) was used, which was conceived as a way to standardize the terminology and thus avoid communication problems between researchers and conservators. The mapping carried out is shown in Figures 9 to 12.

The observation of the alteration forms was performed through the naked eye and with the help of a 10X magnifying hand lens. In all the monument’s faces, above the inferred line drawn in Figures 9 to 12, the mapping of weathering forms was accomplished by deduction since these parts were out of range, with no direct access due to their height.

The weathering forms mapped in the monument are as follow:

- **Soiling**: thin exogenous particle deposition, such as soot, resulting in a dirty aspect of the stone surface (Figure 3);
- **Alga**: thin surface layer of algae or lichens of greenish color (Figure 4);
- **Graffiti**: paint application or similar material on the stone surface;
- **Fissure**: fissure (Figure 5) is a type of fracture, where at least one of the ends does not reach the outline of the object, whilst the fracture involves the division of the rock, which can lead to the separation of the affected parts of the material;
- **Concretion**: the mortar that join the stone blocks can be leached and re-precipitated in stalactite forms (Figure 6);
- **Deposit**: occurs when copper leached from bronze is transported and deposited in the mortar of the granitic monument stone. Copper reacts with the carbonate in the mortar precipitating the copper carbonate, which is greenish in color. This precipitation can occur in the mortar itself, or on the surface of the granite (Figure 7);
- **Staining**: change in one of the three parameters of stone coloring: hue, value or chroma. This can occur due to water absorption or vapor condensation; and
- **Missing part**: missing pieces on the ends of the stone blocks.

The following descriptions were added to complement the characterization of the alteration forms mapped. This was due to the lack of terms to define these weathering forms in the glossary utilized.

- **Anthropic action**: the use of epoxy or cement to fill in missing pieces or rebuild them.
- **Chlorinated rubber**: paint used on street pavement (Figure 8).
Additionally, it has been observed that the sculpture of Ramos de Azevedo presents chlorinated rubber stains, which had already been found in the restoration that took place in 1999. These stains were not efficiently removed at that time (Esteves 1999).
Mortar was widely used to replace missing pieces of stone or even fill fractures, fissures or impermeable grout during restoration. In some cases the restoration produces a bad aspect, with loss in aesthetics, which occurs in small proportions throughout the monument. Some of the grout was fixed with epoxy mass, which, over time, collapses, leaving empty spaces which can store water and promoting the growth of algae and deposition of leached copper on it.

The mapping result is shown in Figures 9, 10, 11 and 12.

In general, the mapping of alteration forms shows that the monument is in good condition, requiring only a cleaning up to remove pollution.

![Diagram of the monument with mapping results]

**Figure 9.** Face 1 - mapping of weathering forms.
Figure 10. Face 2 - mapping of weathering forms.

Figure 11. Face 3 - mapping of weathering forms.
5. SPECTROPHOTOMETRY

One of the most widely used methods to quantify colors numerically is the CIEL*a*b System developed in 1976 by the Commission International d'Eclairage (CIE), which classifies light into 3 parameters: lightness, represented by the letter L* (100 identifies white and 0 black); a*, which represents green (negative values) and red (positive values); and b*, which represents blue (negative values) and yellow (positive values). The total variation of color ($\Delta E$) is given by:

$$\Delta E_{ab}^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Eq. 1

The spectrophotometer used is a Konica Minolta 2500d and the parameters chosen were D65 illuminant (which uses the daylight for calculations, including ultraviolet region spectrum), specular component included (SCI) and excluded (SCE), since there are rough surfaces, $\text{10}^5$ observer and viewing aperture diameter of 8 mm. The software On Color (Cyber Chrome Inc.), version 5.4.5.1 was used for data analysis.

On each stone face 20 measurements were carried out in three different areas (left, right and center of each face), totaling 60 measurements. The value was established according to the bibliography consulted, which suggests that 14 measurements are sufficient to obtain reliable data (e.g. Prieto et al. 2010) and 25 to 30 measurements to obtain a stable average value (e.g. Souza et al. 2008). The cleaner parts of the monument were chosen for the data acquisition,
excluding areas with dirty aspects or with biological colonization and biotite enclaves, which are common in the Itaquera Granite.

According to the data obtained, a greater absorption is observed at violet wavelength (400 nm) in all faces of the monument (Charts 1, 2, 3 and 4).

The variation of the three parameters together (Eq. 1) yielded the following values to ΔE: 2.87 for face 1, 1.82 for face 2, 5.73 for face 3 and 2.59 for face 4, showing that the largest range is observed on face 3 and the smallest on face 2.

We should point out that faces 1 and 3 have stairs for the access of visitors. In these areas there are marks due to skateboarding practice and the circulation of people may cause increased dirt and color alterations. It can also be observed that face 2, which shows less total variation, is that receive more direct sun light.
6. ULTRASOUND PULSE VELOCITY

Ultrasound technique is widely used as a nondestructive method that aims to determine the P-wave velocities inside the studied material that correlate with the existence of fractures, discontinuities or internal uniformity.

The equipment used was a V-Meter Mark III (James Instrument Inc.) at 3 pulses in 2 seconds, 54 kHz transducers and an ultrasound gel for coupling. Only the semi-direct transmission was used as the size of the monument did not allow for the application of the direct method. The measurements were repeated three times on each point and it was used the most constant value or in other cases, the average value. The distance between the measuring points was 10 cm. The measurements were carried out to the fullest extent of the blocks studied, so the number of measurements varied, with an average of 10 measurements. Where the surface was very irregular or where it was difficult to stabilize the measured value, the measurements were discarded.

Data were collected on all sides of the monument, and the average values obtained are (Chart 5): face 1 = 4.85 km/s, face 2 = 4.49 km/s, face 3 = 3.81 km/s and face 4 = 4.68 km/s. The results show that the most dispersed values obtained for the P-wave velocities are on face 1 and on face 4.

![Chart 5](chart.png)

Chart 5. Minimum, medium and maximum values of P-wave velocities in the monument.

7. SCHMIDT HAMMER

Schmidt Hammer is a portable and low-cost nondestructive equipment, which displays the surface hardness of the material, thus it can be used in the laboratory or in the field. It also serves to determine the mechanical properties of stone and can be used when there is only one face available for testing (Basu & Aydin 2004, Aydin & Basu 2005, Yagiz 2008).

Data collection was performed with a Schmidt hammer model W-D-2005 L Type (James Instrument Inc.).

Tests were conducted only in the laboratory, on fresh samples, since the equipment leaves marks when used on rough surfaces as it is the case of Monument to Ramos de Azevedo, promoting a certain damage on it.

The sclerometric index average obtained was 50, which according to the classification proposed by Basu et al. 2008, would be a Grade II category. This description corresponds to a stone with mild to moderate discoloration, vitreous to sub-vitreous luster and intact grain contours.
8. CONCLUSIONS

The Monument to Ramos de Azevedo, made of Itaquera Granite, is a tribute to one of the most important names in São Paulo’s architecture and urbanism of the last century.

The mapping of weathering forms indicates that the monument is in good state of conservation, but requires cleaning up to remove the dirt caused by the pollution, which can contribute to accelerated decay of the monument, and for a better visualization and aesthetics maintenance.

The chromatic variation of the monument is not significant, despite the heterogeneity of the Itaquera Granite, except in the areas with presence of dirt, which reiterates the need for cleaning.

In relation to the P-wave velocities, the values obtained are compatible with slightly weathered granite, which is corroborated by the measures taken with the Schmidt hammer.

This monument, unlike many of the monuments of the city of São Paulo, is still not vandalized, which contributes a lot to the preservation of this heritage.

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REFERENCES


