GLOBALSTONE congress 2023

7th EDITION

MOSTEIRO DA BATALHA

BATALHA, PORTUGAL

PROCEEDINGS

18TH - 23RD OF JUNE 2023

ASSIMAGRA
MINERAL RESOURCES OF PORTUGAL

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UNIVERSIDADE DE ÉVORA

GLOBAL STONE CONGRESS 2023 | BATALHA, JUNE 18 – 23

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NEW CHALLENGES ON DIMENSION STONES, FROM PORTUGAL TO THE WORLD

Responsibility for the information and views set out in this publication lies entirely with the authors

Luís Lopes, Marta Peres, Célia Marques (Organizers)

Edition: Departamento de Geociências da Escola de Ciências e Tecnologia da Universidade de Évora

Cover: Inês Ribeiro, Luís Lopes
Back cover: Luís Lopes

Graphic design and pagination: Luís Lopes
Publication date: June 2023
Support Type: eBook
I.S.B.N.: 978-972-778-327-4

How to cite publications in this proceeding's eBook (example):

N. Careddu, L. Pia, O. Pandolfi, N. Santoro, S. Dündar. 2023. Study for the Implementation of an Integrated Monitoring System in Marble Quarries. Proceedings of the VII Global Stone Congress, Batalha, Portugal, 18-23 June 2023. Luís Lopes, Marta Peres, Célia Marques (Eds.). Departamento de Geociências da Escola de Ciências e Tecnologia da Universidade de Évora, Portugal. pp. 30 – 35. ISBN: 978-972-778-327-4

GLOBAL STONE CONGRESS 2023 | BATALHA, JUNE 18 - 23

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POSTER SESSION: JUNE 19 - 21 (08:30 - 14:00)

CLOISTERS OF THE MONASTERY OF BATALHA

MINERAL ALTERATIONS CAUSED BY LIGHTNING IN THE CHRIST OF THE REDEEMER SURFACE, RIO DE JANEIRO, BRAZIL

Roberto Carlos Ribeiro*, Nuria Fernández Castro and Rosana Elisa Coppedê Silva

Researchers from Centre for Mineral Technology – CETEM, Av. Pedro Calmon, 900, Ilha da Cidade Universitária, Rio de Janeiro, RJ, Brazil (55) (21) 38657264, rcarlos@cetem.gov.br; ncastro@cetem.gov.br and coppede@cetem.gov.br

Summary:

Christ the Redeemer is an Art Deco statue of Jesus Christ with open arms in Rio de Janeiro, Brazil, built between 1922 and 1931. The statue is located at the peak of the 700 m height Corcovado's Mountain in the Tijuca Forest National Park. It is a hollow structure of reinforced concrete, covered with small pieces (tesserae) of steatite (soapstone), which protect the monument structure against water infiltration. This stone was chosen due to its already-known characteristics of hydrophobicity and high resistance to extreme temperatures. The statue, by its location, at one peak of a coastal and urban city, is exposed to several natural agents like solid winds, solar radiation, rain (acid due to the sea-salt aerosols and pollution), and especially to lightning.

The monument has a lightning arrester system in the form of a crown over the statue's head, but it is hit by lightning several times yearly. In a technological research carried out in 2010 to analyse a proposed water-repellent's effect on the monument covering, samples of the monument's original tesserae (1931), substitutes placed in 2000, and fresh ones extracted from the quarry in 2010 were characterised. It was found that the stone's porosity increased from 0.41% (fresh samples) to 3% (original samples). The samples were extracted from the monument's body, below the arms. It was concluded that the microbiological action was the primary decay agent on the soapstone, and the proposed water-repellent was tested on all the samples with satisfactory results.

During that research, it was observed that the arms and head of the statue were the most deteriorated areas, with many missing parts and tesserae showing more mass losses and water absorption of around 20%, strikingly higher than in the rest of the monument. As those areas were not prone to microbiological action because of the washing effect of rain and solar exposure, it was thought that a possible cause for the deterioration could be the lightning. XRF, XRD, SEM-EDS, FTIR, and TGA analyses showed new calcium and magnesium carbonate minerals formed on the samples and a porosity of 8%. These results corroborate that lightning changed the mineral composition and consequent hydric properties of the steatite, so conservation treatments and products tested on or specific for soapstone may not be effective on the head and arms tesserae where the stone composition and properties differ from those in other parts of the monument. Technological support to properly characterise the tesserae cover of the statue's upper part and treatment products' compatibility will be necessary to prevent further damage to the monument.

Key words: *Christ The Redeemer, soapstone, mineral alteration.*

1. Introduction

1.1 Soapstone

Soapstone is a metamorphic rock, rich in magnesium, with essential mineralogy of talc and chlorite. This rock has a high density and shades of colour, varying from green to grey. Besides talc and chlorite, usually, the soapstone contains amphiboles, micas and some carbonate. This rock can be originated from ultramafic rocks, magmatic rocks, volcanic rocks and dolomite. The steatite's properties vary depending on the protolith and geological environment. For example, soapstones derived from ultramafic rocks have homogeneous structures and serpentine in their mineralogical composition, which does not happen when soapstone originates from some intermediate rocks. Steatite has some properties that make this stone suitable for monuments. For example, the large amount of talc and softness are characteristics that make the stone very easy to carve [1]

1.2 Christ the Redeemer

Christ the Redeemer is an Art Deco statue of Jesus Christ in Rio de Janeiro, Brazil, created by French sculptor Paul Landowski and built by the Brazilian engineer Heitor da Silva Costa in collaboration with the French engineer Albert Caquot. It is 30 m tall, not including its 8-meter pedestal, and its arms stretch 28 meters wide.

The statue, weighing 635 metric tons, stands at the peak of the 700 m Corcovado Mountain in the Tijuca Forest National Park overlooking the city of Rio de Janeiro. As a symbol of Brazilian Christianity, it has become an icon for Rio de Janeiro and Brazil. The statue was constructed in reinforced concrete and dressed with a soapstone mosaic between 1922 and 1931.

Landowski produced a miniature of the statue and the actual head and hands and shipped them out to Rio de Janeiro. Considering that the real-life statue is 38 meters high, it is remarkable that Landowski could produce even these few sections at his Paris studio.

One hand alone weighed eight tons. Interestingly, the sculptor modelled Christ's hands after a woman's – those of his assistant.

Since there was already a rack railway leading up the steep, hunchback-shaped Corcovado, from which it derives its name, the building materials could easily be brought all the way up to the summit so that the main body of the statue could be constructed in situ. The monument was made essentially of concrete, its surface studded with thousands of small pieces of shimmering green or grey soapstone [2].

Small pieces of soapstone (Figure 1) (tesserae) cover the monument functioning as protection for the structure because that rock is hydrophobic, preventing water entrance.

1.3 Alterations in the monument

With time taking its toll, the mosaics gradually worked loose and whole sections of the concrete detached. Corrosion of the inner metal structure was to blame.

However, before the 2010 restoration intervention, it was perceived that both the steatite tesserae and the mortar water absorptions had substantially increased, allowing the water percolation, which damaged the monument's concrete structure [3]. Soapstone weathering and decay patterns in monuments of the State of Minas Gerais and studies aiming at that stone conservation had already been developed at that time [4, 5], as it is the most representative heritage stone of that state [6]. Several other studies have been conducted since then [7, 8].

In the year 2010, during the last restoration, CETEM was responsible for the technological support and carried out a study that could detect that one of the causes of tesserae's degradation was the significant microbiological proliferation that generated acids in its metabolism, thus destroying the tesserae, which started to present water absorptions in the order of 6%, where it should be around 1% [9]. In addition, because of the monument's location, on one the highest points of Rio de Janeiro, at Corcovado Hill, the monument suffers constant attacks of electric discharges. They primarily affect the head, fingers and chin tesserae, possibly altering their structure or exposing composing minerals less resistant to weathering, thus creating susceptible points for degradation.

Specifically in those areas of the monument, the water absorption and porosity values, often reaching 20%, proved the high decay degree.

The Christ Redeemer is exposed to several phenomena, like heavy rain, sometimes acid, strong winds and salt spray, as Rio is a coastal city. Besides that, the monument's position at the top of Corcovado favours lightning strokes. The arms and the head of the statue are the most deteriorated. The monument's soapstone dressing, a hydrophobic rock, protected the structure over the years [10], but the high water absorption values found in the tesserae would undoubtedly lead to the reinforced concrete deterioration [11].


Figure 1: Christ of the Redeemer Surface. Figure 2: Several lightning in the monument (Source: Agência Brasil. [12]).

1.4 Importance of Technological Support in Restoration

Heritage stones or mortars' characterisation is vital to acquire knowledge about the material, determining the causes of changes, and proposing methods to avoid or delay the monument's degradation [13]. Several places in the world have already had their stones or mortars characterised, including those from the Byzantine period from the sixth to the tenth centuries [13]. Many techniques have been successfully applied in the characterisation, including X-ray diffraction [14–26], macroscopic observation [25], petrography [25, 26], physical analysis [25], infrared spectroscopy [13,17], chemical analysis [23-25], thermos-gravimetric analysis (TG-DTG) [13-25], mechanical tests [24], and granulometry [13,24,26].

2. Objective

This work aims to verify whether lightning in The Christ of the Redeemer causes mineral alterations in the monument's soapstone tesserae.

3. Methodology

For the research, 56 soapstone samples were used: 16 original tesserae from the 1930s, collected near the monument's feet, 16 tesserae used in the restoration of 2000, 16 tesserae used in the restoration of 2010 and 8 fragments of tessera present in the arms after a lightning strike. Tesserae from 2000 and 2010 were stored inside the monument.

In this paper, sample identifications are Tesserae 1930, Tesserae 2000, Tesserae 2010 and Lightning.

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Figure 3: Tesserae's extraction.

3.2 Methods

The samples were first observed macroscopically for characteristics identifiable by the naked eye, such as colour, texture, shape and size.

The microscopic description used a Schneider magnifying glass with a Carl Zeiss lens, zoomed in from 6.5× to 60× and fluorescent light. Raman analyses were carried out using a BWTEK Raman device to support the previous observations. The equipment covers a spectral range in Raman displacement of 150-3000 cm^{-1}, with a spectral resolution of 5 cm^{-1}. Spectra were acquired using commercial software provided by B&W TEK.

The remainder of each sample was manually ground using an agate mortar and pestle, sieved up to 105µm and characterized using X-ray Powder Diffraction (XRPD), Fourier Transform Infrared Spectrometry (FTIR) and Wavelength-Dispersive X-ray Fluorescence Spectrometry Panalytical WDS-1 spectrometer.

X-ray diffraction spectra were obtained by a Bruker D4-Endeavor instrument (40 kV, 40 mA) with a CoKα wavelength from 10 to 100° in 2θ, step size of 0.02° and 3.6 s/step scan.

For the application of the Fourier transform infrared spectrometry (FTIR) to the qualitative identification of compounds present in the samples, a Perkin Elmer Spectrum 400 was employed. The pellets, about 13 mm in diameter, contained approximately 2.0% of the sample; they were well mixed with 300 mg of potassium bromide.

The light staining area was also evaluated through SEM-EDX analyses. For this, a Hitachi scanning electron microscope was used. The instrument was equipped with a Bruker X-Flash energy dispersive X-ray spectrometer, with MIN SVE detector and scan generator connected.

The samples for WDXRF analysis were dried in an oven at 100°C; then, about 7 g of each sample were pressed into uniform pellets (20 mm in diameter) using a Vaneox automatic press machine under 20 tons of pressure with a standing time of 30 s, using boric acid as a base. All the measurements were carried out on an AXIOS Panalytical WDS-1 spectrometer.

TGA was performed using NETZSCH thermos-gravimetric equipment. Approximately 12 mg samples were weighed in an aluminium crucible and heated between 40 and 560 °C (10 °C min^{-1} rate) under a nitrogen atmosphere, with a flow rate of 50 mL min^{-1}.

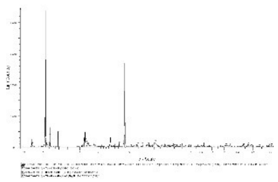
4. Results and Discussion

The results of XRF (Table 1) indicate that the natural soapstone presents percentages of silica that reach ~60% and magnesium ~30%. The tesserae removed from the arms (lightning) present about 10% silica, the magnesium content is significantly higher (50%), possibly associated with the carbonate, since there is an increase in the PPC value to 26%.

Table 1: XRF results of the samples (%).

	MgO	Al_2O_3	SiO_2	CaO	Fe_2O_3	PPC
1930	31.2	1.0	57.0	1.9	3.6	4.8
2000	33.2	0.6	58.9	0.0	2.5	4.6
2010	32.6	0.5	58.8	0.0	3.0	4.8
lightning	54.1	0.3	10.8	8.0	0.4	26.3

As illustrated in Figures 4-6, the X-ray diffraction analyses carried on the tesserae (1930, 2000 and 2010) present peaks of talc and tremolite. Figure 7 shows the X-ray diffraction of the arms (lightning) samples, where is possible to see peaks of calcite and dolomite. This is credited to the dissociation of magnesium or calcium silicate and transformation in magnesium or calcium carbonate, at the high temperature and pressure of storm. Samples from the regions of the monument that suffer from lightning rays (head and arms) present mineral alterations, with dolomite or calcite formation. It is possible that the high pressure and temperature of the rays, promote the chemical bonding of the magnesium present in the soapstone structure with the atmospheric CO_2, indicating the formation of calcium carbonate or magnesium.



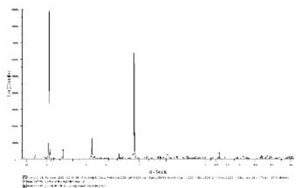


Figure 4: Tesserae 1930 XRD. Figure 5: Tesserae 2000 XRD.

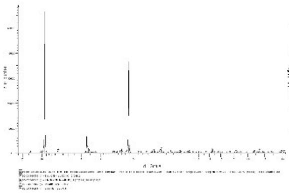
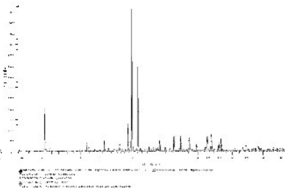
 

Figure 6: Tesserae 2010 XRD. Figure 7: lightning XRD.

Figure 8 shows the structure of the natural soapstone, evidencing the presence of talc. In Figure 9, from the arms and head samples, the defragmentation of the talc sample and the visualization of new minerals such as dolomite and calcite are observed.

Studies in the area of High Voltage indicate that the action of the pulses caused by the rays are able to disorient and defragment several materials, allowing their better application in several industrial sectors, such as recycling and recovery of precious metals in electronic scrap and recovery of glass fibre sector. However, to date there are no papers in the literature on mineralogical changes caused by the action of lightning at high pressures and temperatures [10-13].

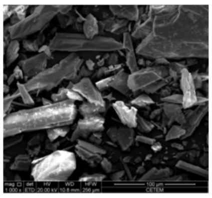
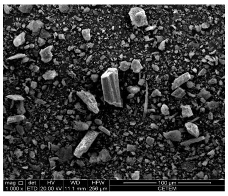
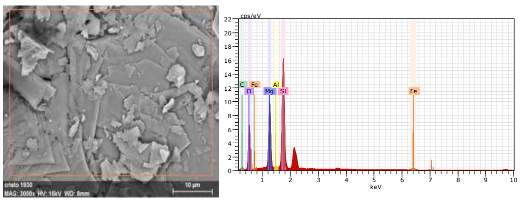
 

Figure 8: SEM image of tesserae 2010 (1000x). Figure 9: SEM image before lightning (1000x).

Figures 10, 11 and 12 shows the SEM results for 1930, 2000 and 2010, respectively. They show the presence of Si, Al, Mg and Fe in the mapping and EDS corroborating the results of FRX and XRD.

Figure 13 shows the SEM/EDS result of the sample of lightning where calcium carbonate or magnesium formation can be inferred from the presence of carbon, magnesium, calcium and oxygen. This results agrees with the theory of those minerals formation in the monument.



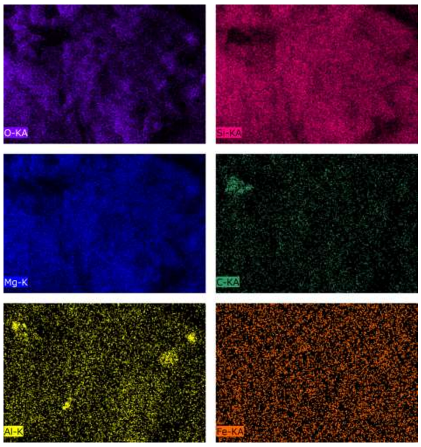
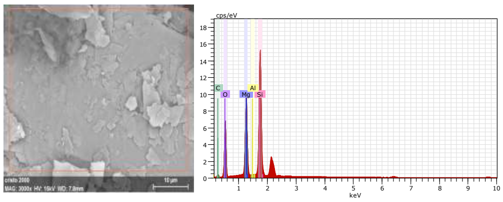


Figure 10: SEM /EDS mapping Tesserae 1930.



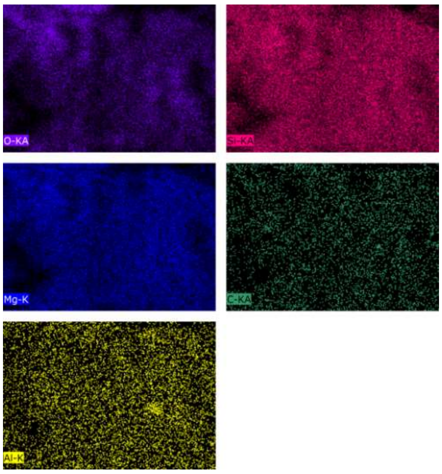
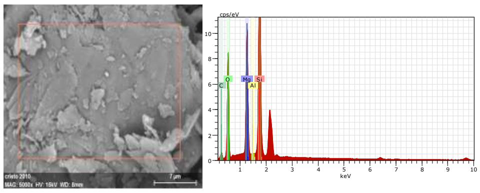


Figure 11: SEM /EDS mapping Tesserae 2000.



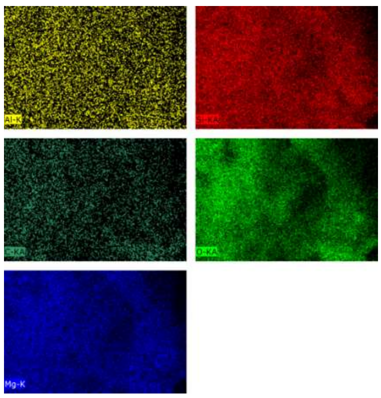


Figure 12: SEM/EDS mapping Tesserae 2010.

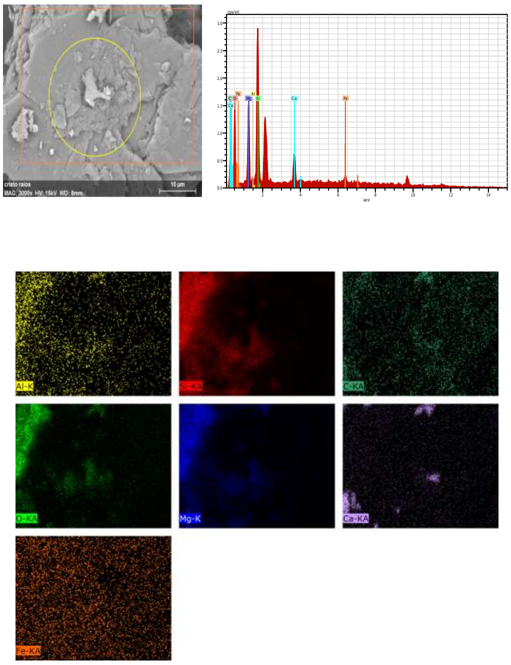


Figure 13: SEM /EDS mapping Tesserae lightning.

Figure 14 shows the FTIR results where is possible to verify, between 1,400 and 1,500, characteristic peaks of the formation of carbonates (Mg and Ca) in the sample that was attacked by the lightning-rod (green line), confirming the formation of these minerals due to the alteration of the soapstone at high pressures and temperatures.

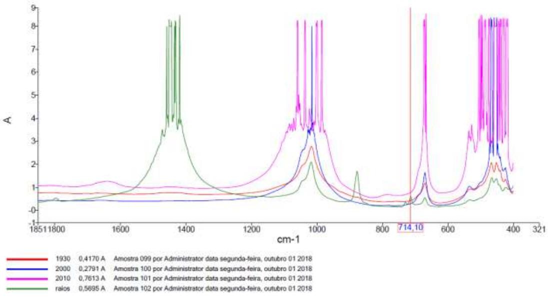


Figure 14: FTIR results of samples.

Figure 15 shows the results of the TGA evaluation of the samples, where it can be observed that the tesserae of 1930, 2000 and 2010 are very stable, with a mass loss around 5% at 1,000 ºC. On the other hand, the sample attacked by the lightning, presents a differentiated behavior, with mass loss of more than 60% at 900ºC, supporting the previous results, once again, of the possible carbonates formation, and alteration of the soapstone.

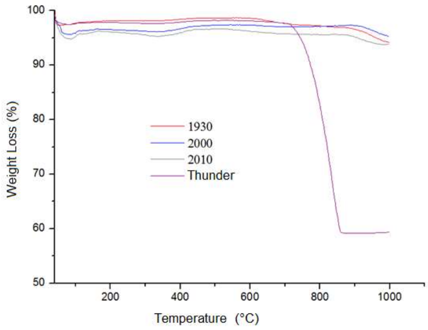


Figure 15: TGA results of samples.

Several authors have described mineral changes due to building stones weathering, especially regarding the roles of atmospheric sulfur and NaCl. Sulfur may form gypsum over the stones, where calcium from mortars or even other rocks is associated with that pollutant, generating the mineral and forming black crusts. In addition, NaCl's action on stones' deterioration is well known; this salt from the sea deposits on the rocks' surfaces and migrates to their interior through their pores, causing significant changes in the pore structure that can even break the stones [14-16].

The porosity and water absorption of tesserae (1930, 2000 and 2010) are around 1% and 0.3%, respectively. The values of the tesserae extracted from the arms and head of the monument (lightning) show values of 21 and 15%, respectively. As discussed in this paper, the formation of calcium and magnesium carbonates due to the electrical discharges of lightening on steatite could explain such water absorption values. The soapstone carbonates content increase in those parts of the monument by this alteration would make that stone much more absorbent than the original.

Some international studies on soapstone do not report these types of mineral transformation [17-18].

5. Conclusions

The main conclusion is that the rays reaching the soapstone may form or expose new minerals more susceptible to decay, facilitating the degradation of the monument's structure. In addition, the protective agents applied to the monument may not effectively prevent its deterioration. Those products' efficacy would have been explicitly tested for the original composition of soapstone, which could have changed significantly due to the formation of calcium and magnesium carbonates. A proper characterization of the steatite in the higher part of the monument shall be carried out before choosing the protective product.

All the results from this work point to the carbonates' neoformation by a lightning stroke on steatite. FRX, XRD, MEV, EDS, TGA and water absorption results of the monument's head and arms tesserae, where the lightning strikes, support that theory.

6. References

1. STOREMYR, P., USBETH, A., HENRIKSEN, J., ANDA, O. & WALDUM, A. (1992) Diagnosis for integrated conservation of the Nidaros cathedral,Trondheim, Norway, 7th international Congress on deterioration and conservation of stone, Lisbon, Portugal, 15 - 18 June 1992.

2. Wacker-chemie GmbH, Preserving a Heritage, Munchen, Germany, 1997.

3. GOUGON, H. (2014) Um mosaico de braços abertos sobre a Guanabara: Mosaico de revestimento no Cristo Redentor. In: Mosaicos do Brasil. Agosto, 2009. Disponível em: <http://mosaicosdobrasil.tripod.com/id108.html>. Acesso em: 12 maio 2014.

4. SILVA, M. E. (2007). Avaliação da susceptibilidade de rochas ornamentais e de revestimentos à deterioração: um enfoque a partir do estudo em monumentos do barroco mineiro. 132 f. Tese Doutorado - Curso de Geociências, Departamento de Geologia Econômica e Aplicada, Universidade Federal de Minas Gerais, Belo Horizonte, 2007.

5. IDEAS. (1994). Investigation into devices against environmental attack on Stones, a german-brazilian Project, GKSS-Forschungszentrum Geesthacht GmbH, Geesthacht, Germany.

6. COSTA, A. G. (2009). Rochas e Histórias do Patrimônio Cultural do Brasil e de Minas. Belo Horizonte: Bem-te-vi, 2009. 291 p. (ISBN: 9788588747319)

7. ANDRADE, B; T., MENDES, C. M., SANTOS JR., J. O., BELLON, O. R. P AND, SILVA, L., (2012) 3D preserving XVIII century baroque masterpiece: Challenges and results on the digital preservation of Aleijadinho's sculpture of the Prophet Joel, Journal of Cultural Heritage 13, 210–214

8. MURTA, J. F.; FIGUEIREDO JUNIOR, J. C. D. (2016). Consolidação de material pétreo por meio do processo sol-gel híbrido. Geonomos, 24(2), 238-244, 2016

9. RIBEIRO, R. C. C, CASTRO, N. F. e QUEIROZ, J. P. C., (2010), Verificação do efeito de hidrofugantes na superfície das tesseraes de pedra-sabão (esteatito) que recobrem o monumento do Cristo Redentor, Relatório Técnico, CETEM, Rio de Janeiro.

10. SANTOS, P. E., MONTE, M. B. M., RIBEIRO, R. C. C., (2014) Efeito de descargas elétricas na estrutura mineralógica da pedra sabão que recobre o Cristo Redentor, Rio de Janeiro, Brazil. XXII Jornada de Iniciação Científica, CETEM, Rio de Janeiro, Brazil.

11. GOUGON, H. Um mosaico de braços abertos sobre a Guanabara: Mosaico de revestimento no Cristo Redentor. In: Mosaicos do Brasil. Agosto, 2009. Disponível em: http://mosaicosdobrasil.tripod.com/id108.html

12. http://www.em.com.br/app/noticia/nacional/2014/01/20/interna_nacional,489854/apos-incidente-com-raio-arquidiocese-anuncia-reforma-e-manutencao-do-cristo.shtml

13. Bakolas, A.; Biscontin, G.; Moropoulou, A.; Zendri, E. Characterization of structural byzantine mortars by thermogravimetric analysis. Thermochim. Acta 1998, 321, 151–160, doi:10.1016/S0040-6031(98)00454-7.

14. Chiarelli, N.; Miriello, D.; Bianchi, G.; Fichera, G.; Giamello, M.; Memmi, I.T. Characterization of ancient mortars from the S. Niccoló archaeological complex in Montieri (Tuscany Italy). Constr. Build. Mater. 2015, 96, 442–460, doi:10.1016/j.conbuildmat.2015.08.023.

15. Gleize, P.; Motta, E.; Silva, D.; Roman, H. Characterization of historical mortars from Santa Catarina (Brazil). Cem. Concr. Compos. 2009, 31, 342–346, doi:10.1016/j.cemconcomp.2009.02.013

16. Moropoulou, A.; Bakolas, A.; Bisbikou, K. Characterization of ancient, byzantine and later historic mortars by thermal and X-ray diffraction techniques. Thermochim. Acta 1995, 269, 779–795.

17. Moropoulou, A.; Bakolas, A.; Bisbikou, K. Investigation of the technology of historic mortars. J. Cult. Herit. 2000, 1, 45–58. doi:10.1016/S1296-2074(99)00118-1.

18. Biscontin, G.; Birelli, M.P.; Zendri, E. Characterization of binders employed in the manufacture of Venetian historical mortars. J. Cult. Herit. 2002, 3, 31–37, doi:10.1016/S1296-2074(02)01156-1.

19. Freidin, C.; Meir, I. Byzantine mortars of the Negev Desert. Constr. Build. Mater. 2005, 19, 19–23, doi:10.1016/j.conbuildmat.2004.05.001.

20. Zeng, Y.; Zhang, B.; Liang, X. A case study and mechanism investigation of typical mortars used on ancient architecture in China, Thermochim. Acta 2008, 473, 1–6. doi:10.1016/j.tca.2008.03.019.

21. Adriano, P.; Silva, A.S.; Veiga, R.; Mirao, J.; Candeias, A. Microscopic characterisation of old mortars from the Santa Maria Church in Évora. Mater. Charact. 2009, 60, 610–620, doi:10.1016/j.matchar.2008.11.008.

22. Budak, M.; Akkurt, S.; Bke, H. Evaluation of heat treated clay for potential use in intervention mortars. Appl. Clay Sci. 2010, 49, 414–419, doi:10.1016/j.clay.2009.11.031.

23. Sanjurjo-Sánchez, J.; Trindade, M.; Blanco-Rotea, R.; Garcia, R.B.; Mosquera, D.F.; Burbidge, C.; Prudêncio, M.I.; Dias, M.I. Chemical and mineralogical characterization of historic mortars from the Santa Eulalia de Bóveda temple, NW Spain. J. Archaeol. Sci. 2010, 37, 2346–2351. doi:10.1016/j.jas.2010.04.008.

24. Martínez, I.; Castillo, A.; Martínez, E.; Castellote, M. Physico-chemical material characterization of historic unreinforced masonry buildings: The first step for a suitable intervention. Constr. Build. Mater. 2013, 40, 352–360, doi:10.1016/j.conbuildmat.2012.09.091.

25. Lezzerini, M.; Legnaioli, S.; Lorenzetti, G.; Palleschi, V.; Tamponi, M. Characterization of historical mortars from the bell tower of St. Nicholas Church (Pisa, Italy). Constr. Build. Mater. 2014, 69, 203–212, doi:10.1016/j.conbuildmat.2014.07.051.

22. Maria, S. Methods for porosity measurement in lime-based mortars. Constr. Build. Mater. 2010, 24, 2572–2578.