**Centro de Tecnologia Mineral - CETEM**
**Ministério da Ciência, Tecnologia, Inovações e Comunicações - MCTIC**
**Coordenação de Rochas Ornamentais e Minerais Industriais - COROM**

# ANAIS DO VI CONGRESSO INTERNACIONAL DE ROCHAS ORNAMENTAIS - GLOBAL STONE CONGRESS 2018

**Organizadoras**

**Nuria Fernández Castro**

**Maria Heloísa Barros Oliveira Frascá**

Rio de Janeiro

Outubro/2018

**CLV 0001-00-18 -** Livro dos ANAIS do VI Congresso Internacional de Rochas Ornamentais, 26 a 29 de abril de 2018, Ilhéus - BA. 266p.:il.
ISBN 978-85-8261-082-4

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# PROCEEDINGS

# GLOBALSTONE CONGRESS2018

## ILHEUS (BAHIA) BRAZIL

April 26-29, 2018

# CONNECTING MINDS IN THE WORLD OF STONE

**April 26-29, 2018 / *26-29 de abril de 2018***
**ILHEUS (BAHIA) - BRAZIL**


*Organizers*
Nuria F. Castro
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Pegmatite (Ouro Campo Company). Photo: Nuria F. Castro, 2008


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PROCEEDINGS

# GLOBAL STONE CONGRESS 2018

## CONNECTING MINDS IN THE WORLD OF STONE

## VI CONGRESSO INTERNACIONAL DE ROCHAS ORNAMENTAIS

PROCEEDINGS ORGANIZERS: Nuria Fernández Castro & Maria Heloisa Barros de Oliveira Frascá

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Global Stone Congress 2018 (6: 2018: Ilhéus-BA)

Global Stone Congress: Connecting Minds in the World of Stone – VI Congresso Internacional de Rochas Ornamentais/Nuria Fernández Castro, Maria Heloísa Barros Oliveira Frascá (Orgs). – Rio de Janeiro: CETEM/MCTIC, ABIROCHAS, 2018.

266p.: il.

1. Rochas ornamentais. 2. Rochas e Minerais Industriais I. Centro de Tecnologia Mineral. II. Associação Brasileira da Indústria de Rochas Ornamentais III. Castro, Nuria Fernández (Org.). IV. Frascá, Maria Heloisa Barros de Oliveira (Org.)

ISBN 978-85-8261-082-4 CDD 553

# FOREWORD

The city of Ilheus, Bahia, received the **Global Stone Congress 2018** (GSC), entitled **Connecting Minds in the World of Stone**, from April 26 to 29. The sixth edition of the event, organized by the Brazilian Association of the Dimension Stones Industry (ABIROCHAS) and the Centre for Mineral Technology (CETEM), brought together about 170 participants, among researchers related to the stone sector through Brazilian and foreign institutions, architects, designers, engineers, geologists, undergraduate students, as well as representatives of the productive sector, with the objective of sharing knowledge and discussing the challenges for sectoral development. Speakers from Saudi Arabia, Argentina, Brazil, Chile, Spain, Finland, England, Iran, Italy, Portugal, Czech Republic and Sweden honored the event. There were 17 lectures and 54 papers in the technical sessions and three round tables. The event was supported by Apex-Brasil, the State Government of Bahia, through the Secretariats of Economic Development and Tourism and the Baiana Mineral Research Company (CBPM), the Ilhéus City Hall and the Gestra company, a Czech industry of stone splitting machines, and the Brazilian company Apollo Logística.

The Global Stone Congress is consolidating as the main technical-scientific event in the world of natural stone. It had its first edition in 2005, in Guarapari - ES, Brazil, while it was still designated International Congress on Dimension Stones (ICDS). The event arose from a partnership between the Centre for Mineral Technology (CETEM), a research institute of the Ministry of Science, Technology, Innovation and Communication (MCTIC) and the Center for Technology of Marble and Granite (CETEMAG), with the support of the Brazilian Association of the Dimension Stone Industry (ABIROCHAS) and associates of the Brazilian Dimension Stones Technology and Quality Network (RETEQ-ROCHAS). Other editions of the event were subsequently held in Italy (2008), Spain (2010), Portugal (2012) and Turkey (2014), adopting the formal name Global Stone Congress in Spain (2010).

The lectures, workshops, technical sessions with oral presentations and posters, special topics and round tables focused on the themes of Architecture, Technology and Sustainability. At the end of the congress, the participants made a technical visit to two quarries of two types of natural stones in the State of Bahia: the blue granite (sodalite) quarry of the Somibrás company, in Potiraguá, and the pegmatite quarry of the Ouro Campo company, in Macarani. The visit allowed the participants, in addition to observing the quarrying process, to understand some of the geological context that led to the formation of those rocks in the region. Other companies made their quarries available for visitation, but for logistical and schedule reasons, this was not possible. They were: Marmífera (Blue Bahia granite), MAG-BAN & EXIDO (marble), SUS's & PRS Mining (brown syenite) and Ouro Campo (white and blue quartzite).

The architect's role as a specifier of stone products, acting as a fundamental link between the producer and the increasingly demanding consumer, was a theme widely discussed on the first day of the event, as well as the issue of teaching about natural stones in Architecture courses and the need for greater interaction between research centers, universities, architecture professionals and industry. The importance of the adequate stones conservation to ensure their durability, especially of those used in monuments and historical buildings was also discussed. It was also presented, by members of the IUGS Heritage Stone Subcommission the concept and examples of World Heritage Stones, rocks of recognized interest for their historical use throughout the centuries and, therefore, fundamental for the restoration of buildings and monuments of global cultural importance.

Discussions on the second day brought conflicting opinions about the application of the Industry 4.0 model to the stone sector, which involved both the need for the natural stone industry to join this model and the difficulty, due to the characteristics of this industry and the materials worked, to adhere to model 4.0. The need for new alternatives to remain in the market was also raised, given the growing trend of international production and commercialization of artificial stones and ceramic products in detriment of natural stones. At

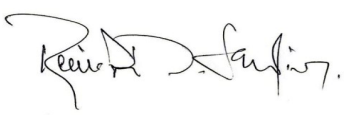
the morning workshop, latest quarrying, processing and waste-rock recycling technologies were presented, an also the Industry 4.0 model applied to the natural stones production, the Brazilian Industry 4.0 Program of the Brazilian Industrial Development Agency - ABDI and the Export Processing Zone - ZPE of Ilhéus. The technical sessions included production automation technologies, processing technologies, database softwares, robots use, as well as insights on the workforce in the stones sector, and about the world market, with emphasis on the Middle East.

Reflections on sustainability took place on the last day of the congress. A workshop on upmarket in the world of stone opened the conference, with the presentation of the International Institute of Marble - IS.I.M addressing the new technologies and solutions for the use of stone wastes and the sustainable project for small producers in Patagonia. Representatives of the Brazilian company, Pettrus Mineração, showed the outstanding company's *modus operandi* of corporate social responsibility aiming at sustainability, including the use of renewable energy, controlled production to make the most of their deposits, due to the exclusivity of the exotic materials extracted from their quarries, research on wastes recycling and environmental education actions. The presentation emphasized the importance of the professionals to the better knowledge of the materials extracted, to the quarries operation planning and to the adequate processing and use of stones.

Throughout the presentations, sustainable solutions to be applied to the stones production were demonstrated, such as waste water treatment systems and alternatives for waste recycling, such as new products that use in their composition stone residues, as well as new applications for this waste in civil construction and agriculture, in the latter being used as fertilizer, among others. The issue of circular economy in the ornamental stone industry was another topic widely covered in various presentations, as well as the application of the Life Cycle Assessment (LCA) and Building Information Modeling (BIM) tools.

This event has great importance, as it brings together international research groups and promotes the worldwide diffusion of knowledge, for the benefit of the industrial sector. This edition certainly represented a milestone in the industry-research interaction, with presentations of both technical, from representatives and consultants of the industry, as well as of a more scientific nature, from representatives of research institutions, covering all aspects of current interest of the natural stones sector. From the debates and discussions generated, many new ideas and global partnerships emerged, thus living it up to the desired goals and justifying the name Global Stone Congress. Satisfied with the good results, we thank all the participants and sponsors, whishing that in the next editions of the GSC we can see results of the ideas that have emerged in Ilheus, oriented to the academy-industry integration in favor of the natural stones sector development.

Rio de Janeiro, August, 2018



Reinaldo Dantas Sampaio
President of ABIROCHAS

Fernando A. Freitas Lins
Director of CETEM

ABIROCHAS
Brazilian Association of the Dimension Stone Industry

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# APRESENTAÇÃO

A cidade de Ilhéus, na Bahia, recebeu o **Global Stone Congress 2018** (GSC), intitulado ***Connecting Minds in the World of Stone***, entre os dias 26 e 29 de abril. A sexta edição do evento, organizada pela Associação Brasileira da Indústria de Rochas Ornamentais (ABIROCHAS) e pelo Centro de Tecnologia Mineral (CETEM) , reuniu cerca de 170 participantes, entre pesquisadores ligados ao setor de rochas ornamentais através de instituições brasileiras e estrangeiras, arquitetos, designers, engenheiros, geólogos, estudantes universitários, além de representantes do setor produtivo, com o objetivo de compartilhar conhecimentos e discutir os desafios para o desenvolvimento setorial. Palestrantes da Arábia Saudita, Argentina, Brasil, Chile, Espanha, Finlândia, Inglaterra, Irã, Itália, Portugal, República Tcheca e Suécia prestigiaram o evento. Foram apresentadas 17 palestras e 54 trabalhos nas sessões técnicas e houve três mesas redondas. O evento contou com o apoio da Apex-Brasil, do Governo Estadual da Bahia, por meio das Secretarias de Desenvolvimento Econômico e de Turismo e da Companhia Baiana de Pesquisa Mineral (CBPM), da Prefeitura Municipal de Ilhéus e da empresa Gestra, indústria tcheca de máquinas cortadoras de pedras, e da empresa brasileira Apollo Logística.

O Global Stone Congress está se consolidando como o principal evento técnico-científico mundial do setor de rochas ornamentais. Teve sua primeira edição em 2005, em Guarapari - ES, quando ainda era designado International Congress on Dimension Stones (ICDS). Na ocasião, o evento resultou de uma parceria entre o Centro de Tecnologia Mineral (CETEM), instituição de pesquisa integrante do Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC ), e o Centro Tecnológico do Mármore e Granito (CETEMAG), com apoio da Associação Brasileira da Indústria de Rochas Ornamentais (ABIROCHAS), e de outras instituições filiadas à Rede Brasileira de Tecnologia e Qualidade em Rochas Ornamentais (RETEQ-ROCHAS). Outras edições do evento foram subsequentemente realizadas na Itália (2008), Espanha (2010), Portugal (2012) e Turquia (2014), adotando-se, a partir da Espanha, a designação formal Global Stone Congress.

As palestras, workshops, sessões técnicas com apresentações orais e de pôsteres, tópicos especiais e mesas redondas focaram nas temáticas Arquitetura, Tecnologia e Sustentabilidade. Ao término do congresso, os participantes realizaram visita técnica a duas pedreiras de extração de dois tipos de rocha ornamental no Estado da Bahia: o Granito Azul (sodalita) da empresa Somibrás, em Potiraguá, e o pegmatito da empresa Ouro Campo, em Macarani. A visita permitiu aos participantes, além de acompanhar o processo de extração, compreender um pouco do contexto geológico que levou à formação das rochas na região. Outras empresas disponibilizaram suas pedreiras para visitação, mas por motivos logísticos e de tempo, não foi possível. Foram estas: Marmífera (granito Azul Bahia), MAG-BAN & EXIDO (mármore), SUS's & PRS Mineração (sienito marrom) e Ouro Campo (quartzito branco e azul).

O papel do arquiteto como especificador dos produtos de rochas, atuando como elo fundamental entre o fabricante e o consumidor final cada vez mais exigente, foi um tema amplamente discutido no primeiro dia do evento, assim como a questão do ensino de rochas ornamentais em cursos de arquitetura e a necessidade de maior interação entre centros de pesquisa, universidades, profissionais de arquitetura e a indústria. Foi também discutida a importância da correta conservação das rochas para garantir sua durabilidade, especialmente, daquelas utilizadas em monumentos e edificações históricas e apresentado o conceito de Rochas do Patrimônio Mundial (*Global Heritage Stone*), rochas de reconhecido interesse pelo seu uso histórico ao longo dos séculos e, portanto, fundamentais para a restauração de edifícios e monumentos de importância cultural global.

As discussões do segundo dia trouxeram à tona opiniões contraditórias acerca da aplicação do modelo de Indústria 4.0 ao setor de rochas ornamentais, que envolveram tanto a necessidade da adesão da indústria de rochas ornamentais a este modelo quanto a dificuldade, em virtude das características próprias dessa indústria e dos materiais trabalhados, para aderir ao modelo 4.0. Também se aventou a necessidade de

buscar novas alternativas para se manter no mercado, diante da tendência crescente de produção e comercialização internacional de rochas artificiais e produtos cerâmicos em detrimento das rochas naturais. No workshop matinal, foram apresentadas tecnologias de aproveitamento de estéreis de pedreiras, a Indústria 4.0 aplicada à produção de rochas ornamentais, o programa brasileiro Indústria 4.0 da Agência Brasileira de Desenvolvimento Industrial - ABDI e a Zona de Processamento de Exportação - ZPE de Ilhéus. Nas sessões técnicas foram apresentadas, ainda, tecnologias de automação da produção, tecnologias de processos, softwares de bancos de dados, uso de robôs, além de reflexões sobre a força de trabalho no setor de rochas ornamentais, e o mercado mundial, com destaque para o Oriente Médio.

Reflexões sobre sustentabilidade tiveram espaço no último dia do congresso. Um workshop sobre a exclusividade no mundo das rochas ornamentais abriu os trabalhos, com a apresentação do Instituto Internacional do Mármore – IS.I.M abordando as novas tecnologias e soluções para o aproveitamento de resíduos de rochas ornamentais e o projeto sustentável para pequenos produtores na Patagônia. Destacou-se a apresentação de representantes da empresa brasileira de extração e beneficiamento de rochas, Pettrus Mineração, que expuseram o modus operandi de responsabilidade social corporativa da empresa visando à sustentabilidade, incluindo o uso de energia renovável, a produção controlada para o máximo aproveitamento dos maciços, dada a exclusividade dos materiais exóticos extraídos das suas minas, os estudos para aproveitamento de resíduos e ações de educação ambiental. A apresentação ressaltou a importância dos profissionais no conhecimento dos materiais extraídos, no planejamento de lavra e seu melhor beneficiamento e utilização.

Ao longo das apresentações, foram demonstradas soluções sustentáveis a serem aplicadas no processamento das rochas, como, por exemplo, sistemas de tratamento de águas residuais do processo e alternativas para reaproveitamento dos resíduos gerados, tais como novos produtos que utilizam em sua composição resíduos de rochas, assim como novas aplicações para este resíduo na construção civil e na agricultura, nesta última podendo ser utilizados como fertilizante, entre outros. A questão da economia circular na indústria de rochas ornamentais foi outro tema amplamente abordado em diversas apresentações, assim como a aplicação das ferramentas de Avaliação de Ciclo de Vida (ACV) e Modelagem de Informações de Construção (BIM – *Building Information Modelling*).

A realização deste evento é de grande importância, por aproximar grupos de pesquisa internacionais e por promover a difusão mundial de conhecimentos, em benefício do setor industrial. Esta edição, certamente, representou um marco na interação indústria-pesquisa, com apresentações tanto de cunho técnico, de representantes e consultores da indústria, quanto de cunho mais científico, de representantes das instituições de pesquisa, abrangendo todos os aspectos de interesse atual do setor de rochas ornamentais. Dos debates e discussões gerados, surgiram muitas novas ideias e parcerias globais, atingindo-se assim os objetivos desejados e fazendo-se jus ao nome Global Stone Congress. Satisfeitos com os bons resultados, agradecemos a todos os participantes e patrocinadores, desejando que nas próximas edições do GSC possamos ver resultados das ideias surgidas em Ilhéus, orientadas para a integração academia-indústria em prol do setor.

Rio de Janeiro, agosto de 2018

Reinaldo Dantas Sampaio
Presidente da ABIROCHAS

Fernando A. Freitas Lins
Diretor do CETEM

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# KEYNOTE ADDRESS
# DISCURSO DE ABERTURA

Syenite (SU'S Company) - Photo: Nuria F. Castro (2018)

**KEYNOTE ADDRESS OF THE GLOBAL STONE CONGRESS**

I would like to salute his Excellencies the Major of Ilheús, Dr. Mario Alexandre Sousa, and the Vice-Major, José Nazal; Mr. Rafael Avena Neto, director of the Companhia Baiana de Pesquisa Mineral (CBPM), representing the Governor of the estate of Bahia; the Chief of Staff of the Secretary of Geology, Mining and Mineral Transformation of the Ministry of Mines and Energy, Frederico Bedran Oliveira; the diretor of Industrial and Mining Development of the Secretary of Economic Development of the estate of Bahia, Ricardo Eugênio Porto Vieira; the Mining Coordinator of the Secretary of Economic Development of the estate of Bahia da, Ana Cristina Franco Magalhães; the Regional Superintendent of the City of Salvador, José Ulisses Pinheiro, on behalf of the Director's Office of the Geological Survey of Brazil; Adiel Veras, on behalf of the Superintendent of the National Agency of Mining of the estate of Bahia; the manager of the project Brasil Original Stones of ABIROCHAS in partnership with APEX Brasil, Márcia Gomide; the director of SINCOCIMO of the estate of Rio de Janeiro, Armando de Souza; the vice-president of ABIROCHAS, Marcos Regis; the director of SINROCHAS of the estate of Minas Gerais, Eduardo Carvalho Felix; the president of SINDPARAÍBA, Antônio Fernando Holanda; the ABIROCHAS representative in the estate of Ceará, Geraldo Silvério dos Santos; the president of SIMAGRAN-BA, Carlos Alberto de Araújo; the president of SINDIROCHAS of the estate of Espírito Santo, Tales Pena Machado; the president of SIMAGRAN Paraná, José Georgevan Gomes de Araújo; other authorities and public institution heads, my compliments also to all researchers and visitors from other countries, my compliments also to university professors and visitors present and special compliments to Dr. Fernando Lins, General Director of CETEM, partner entity of ABIROCHAS in this and other projects of great interest for the industry and which honor us, ladies and gentlemen,

Before giving you my thoughts, I would like to officially declare the opening of the Global Stone Congress. My initial idea is to present:

- Industry analysis in Brazil and the world;
- Statistical performance data;
- Evaluate the extraordinary growth in the last decades;
- Future scenarios; and
- Challenges of the competition and competitive condition.

I would also like to detail ABIROCHAS' contributions over the last twenty years, whose anniversary was last January 23rd. I imagine that this is a natural expectation for this moment.

With respect to ABRIROCHAS, I would like to inform that the commemoration will happen this year on a date to be defined and communicated to all present, who are hereby invited. The party will be to celebrate together with the success of some important projects, such as:

- The Global Stone Congress, which starts today;
- Release of the "Competitiveness Study – Strategy for an Industrial Development Policy", which will happen in Brasilia, at the Apex-Brasil Auditorium (Brazilian Agency for Exports and Investments), May 16, invitation for which will be sent to all present here;
- Development of the Domestic Market Project, aiming to promote the "stone culture" in the academic and trade circles, with the objective of expanding the presence of Brazilian stones in national architecture;
- The agreement with national SEBRAE, oriented for qualification and management of marble fabricators on a national scale;
- Renewal and expansion of the Apex-Brasil agreement, whose purpose is the expansion of Brazilian dimension stone exports;
- The progress of the projects for the so-called "third export wave", which had the objective of inserting the Brazilian dimension stone exports into the large contractor market or final products in the US and Middle East, among others.

In spite of the importance of all these facts, which could, as I said, be the heart of my presentation, the following disturbing thought came to mind:

**In this time of so many industrial possibilities, do society and contemporary architecture desire stones as a covering element?**

This was the same question I asked myself thirty years ago, then a partner in a business group, responsible for feasibility studies for investments. I was informed that it was the intention of one of the companies to invest in an innovative project in the dimension stone industry.

**Will there be a promising future for dimension stones and coverings?**

The reason for this question is the fact that stones, like all other merchandise, have a "useful value", i.e., the capability to be useful and satisfy human needs or desires; however, they also possess an "exchange value", determined by the "quantum" of social work needed for their production and transformation of raw material into objects that can be used, exchanged and desired. The exchange value depends on the historically achieved technological stage and that defines the place of goods in competition with other alternative goods, a relation that varies over time and place.

The challenge contained in this question imposes itself, and tonight I will try to answer it in a more elaborated fashion:

I begin by remembering that stones have, for thousands of years, been an indistinguishable element of survival, growth and, if we can denominate it as such, sustainability of our ancestors. Since the use of caves as shelters, the first rudimentary tools, passing through to imposing constructions that characterize landmarks of process of civilization until the

present times, stones have been present as a source of humanity's protection, shelter and esthetic refinement.

Stone materials have had their use at the dawn of human civilization in Europe, Asia and Africa. In the territory Russia presently occupies, around 200 cities in the Paleolithic Period, i.e., 2.5 million years ago, there were houses and tombs made of stone.

Five thousand years ago, the Egyptians opened the first quarries to remove the limestone blocks and granite with which the extraordinary pyramids were constructed; in the largest of them, 169 meters high, that of Khufu (or Giza), 4.5 million cubic meters of stone were used. We could highlight many other buildings raised in stone that are marks in the passage of humans on Earth, such as, for example:

- the Inca fortress of Sacsayhuaman in Peru – transported 20 km to the hill of Cuzco, three thousand years ago;
- the Port of the Sun in Tiwanaku, Bolivia – built 2.2 thousand years ago;
- the grottos of Longyou, Zheijiand Province, China – a mystery as to their origin;
- the Stonehenge, in Salisbury, England – built three thousand years ago;
- the Great Wall of China, with its 21,196 km – built over 20 centures;
- the Victory of Samothrace statue in Greece, attributed to Pythokritos – dated 640 b.c.

It can be observed that the development of forces of production and its reflexes on civilization has not distanced humans from stone; on the contrary, it has drawn Man closer to it, not only through the dissemination of uses in architecture and works of art in engineering, but allowing the esthetic refinement resulting from the new mental standard of society to be registered forever in human history. Just as a reference, I mention the enchantment expressed in the works of one of the greatest Renaissance sculptors, Michelangelo Buonarotti, such as La Pietà, Il Giorno and la Notte and David; in the art of Giovanni Strazza and Raffaelle Monti, with their marble sculptures that seem surrounded in veils of silk; or in the iconic construction of our time…

This sense of permanence and, at the same time, of contemporary, modern life, is basis for using stones in everyday living of peoples since the beginning until present day and, certainly in the future. It indicates that the innovation provided by science and technique, in the quarrying, beneficiation, application and maintenance phases of stones as a covering and decorative element have followed society's technological development as a whole. In several stages of civilization's development, next to the advances of technique and taking advantage of it, stones have become a "cultural" element, common to all peoples. Here, I use the concept of renowned American anthropologist Leslie White, who defines culture "as a class of things or events that depend on symbolization, which are products of symbologization…" In human matters, things are only meaningful within the terms of their context. And stones are stones, however, they can be seen as merchandise or as a source of nobility, in such a way, without losing their original significance, acquire other meanings:

- In temples, with their majestic architecture, stones symbologize both temporal power, as well as the spiritual power of religions;
- In the cemetery, they symbologize the sense of permanence of the loved one in the face of inevitability of death;
- In large contemporary buildings, they symbologize economicity, esthetic sophistication and nobility.

If it is a fact that Michelangelo, while contemplating the perfection of his work, David, became overwhelmed with emotion to the point of having said "**Adesso, parla!**", that moment serves as example the synthesis of the exclusive capability of a human being to attribute meaning to things and happenings in the outside world and of living in a symbolic universe that is the basis of the building of a culture, **which is the human experience *par excellence***. Stones translate comprehension of meaning because they express and dialogue with history and the deeds of peoples, human subjectivity, and their abilities to invent and innovate!

In this manner, social systems, over thousands of years, crystallized this relationship of humans with stone in an apparently inborn manner, a heritage of ancestors, but, in reality, as Norber Elias, one of the greatest sociologists of the 20th century, reminds us that, in spite of having an ancestral part in all of us humans, the greater part of what we think and do comes from interaction with our fellow humans and with the world, perfected in social relationships and which are seated in the incessant evolutionary process of human capabilities, determined by the development of productive forces and that, in fact, mold social systems.

The conclusion we can arrive at is that stones have maintained their presence in the history of peoples, not only for the utility and for the ancestral fascination of humans for natural beauty and authenticity of stones, "value of use", but, above all, also for the stone industry's capacity to correspond to the challenges place upon it by technological evolution, bringing innovative solutions to the constant advances and demands of construction standards, causing their "exchange value" to vary over time, which has allowed to expand the space in competition with other coverings materials.

I attribute the sense of **authentic, genuine beauty** to stone, to differentiate it from the untiring artificial imitation of industrialized goods. They are artificialities of all sorts produced by the ceramic industry or the so-called "quartz" under the pretense of appearing natural, but, only stone can provide to those who appreciate it, the perception of taking advantage of a unique material, such as a diamond, generated million of years ago and that are around, accessible and at the service of their comfort, pleasure and security.

**It's been like that until now. And in the future, what will it be like?**

We live in a time of uncertainty and insecurity as a rule. In the words of Polish sociologist, Zygmunt Bauman, these are **liquid times, of a liquid society, of liquid Money and even of liquid fear and love.** The liquefaction of the labor world, of national interests, liquefaction of

traditional industry and all these transformations, conducted under the hegemony and hand-to-mouth logic of **financial capital** – liquid money. Even more serious is that all of this forges the **liquefaction of solidarity**, essential condition for balance in the context of "the individual society", as the already mentioned German sociologist, Norbert Elias, defined well.

It is also a time of uncontrollable, incessant human creativity, where everything seems to be made for rapid moral and technical obsolescence. Will there be a place for goods that carry them the trait of durability and permanence?

Perhaps the challenge is continuous technological advancement of our industry, on a path that lead to complete domination of goods made of stone, creating the perception that stones have achieved "fluidity" and "malleability" in the figurative sense; molding cuts, re-cuts, finishing and so many other forms, making it appear that a stone is freed from its rigidity and toughness in an apparent liquefaction; an effect of perception in a time when perception can be worth more and be more believable that the actual fact.

It's not only that. The stone itself reinvents itself by force of the technology, assuming other forms no less important of its usefulness, or of its "useful value". In Brazil, which has one of the most highly developed agribusiness industries in the world, we can contribute to a new green revolution, based on the use of *in natura* stone dust for re-mineralization and soil fertilization. Experiments in *Embrapa* – the Brazilian Agricultural Research Company, have already proven the efficiency and efficacy of this new product, potentializing the action of biological agents to capture the substances contained in stones.

This new technological vein will bring the possibility in the near future of formation of "agricultural clusters" in the areas of influence of production arrangements, at the same time, signaling a revolutionary environmental solution for the solid waste of our industry.

Another technology front to be developed will be the insertion of our industry in the complex dimension called "Industry 4.0". We are at the initial stage of understanding with the National SENAI and with ABDI (Brazilian Agency for Industrial Development) for definition of an adequate strategy to be implemented.

In this manner, if the reflections I have made here make sense, we can congratulate ourselves with the Global Stone Congress, the international congress that promotes the encounter of scientific intelligence, held for the first time in Brazil in 2005 in the State of Espírito Santo and afterwards in Italy, Spain, Portugal and Turkey, and which now returns to Brazil to take place in the beautiful city of Ilhéus, Bahia, the cradle of the Brazilian nation.

Thus, the Science and technology, added to the enterprising spirit of the businesspersons in the industry are the answer to the future challenges of dimension and covering stones, allowing us to foresee that we will undergo a "new stone age" in global architecture!

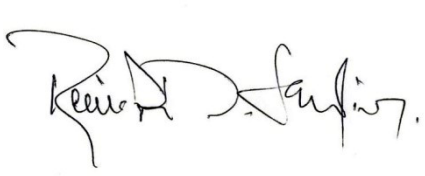
The Global Stone Congress is justified, definitely justified, making worthwhile all the efforts undertaken and all the support received, particularly those conceded by the Economic

Development Secretariat through the CBPM – Bahian Mineral Research Company, and the Ilhéus Municipal Government, reiterating our thanks and debt of gratitude to their respective leaders.

Finally, I would like to thank all of those who answered our invitation, to the authorities present. I also make special mention of the institutional support of the Bahia State Industrial Federation. I thank my friends in the industry, academics, researchers and scientists from several parts of the world who are present here and, finally, in a very special fashion, the partnership of members of CETEM and to the businesspeople and institutional leaders of the industry, to all the colleagues in ABIROCHAS, board members, consultants and collaborators, without which it would not have been possible to hold this great event.

Obrigado a todos e sucesso ao **Global Stone Congress!** Thanks to all and success to the **Global Stone Congress!**

Ilhéus, Bahia, April 26, 2018



Reinaldo Dantas Sampaio
President, ABIROCHAS
Brazilian Dimension Stone Industry Association

**DISCURSO DE ABERTURA DO GLOBAL STONE CONGRESS 2018**

Gostaria de cumprimentar os Excelentíssimos Senhores Prefeito de Ilhéus, Dr. Mario Alexandre Sousa, e Vice-Prefeito, José Nazal; o senhor Rafael Avena Neto, diretor da Companhia Baiana de Pesquisa Mineral (CBPM), representando o governador da Bahia; o chefe de gabinete da SGM/MME, Frederico Bedran Oliveira, representando o secretário de Geologia e Mineração do Ministério de Minas e Energia; o diretor de Desenvolvimento Industrial e Mineração da Secretaria de Desenvolvimento Econômico da Bahia, Ricardo Eugênio Porto Vieira; a coordenadora de Mineração da Secretaria de Desenvolvimento Econômico da Bahia, Ana Cristina Franco Magalhães; o Superintende Regional de Salvador, José Ulisses Pinheiro, representando a Diretoria do Serviço Geológico do Brasil – CPRM; Adiel Veras, representando o Superintendente da Agencia Nacional de Mineração do Estado da Bahia; a gestora do Projeto Brasil Original Stones da ABIROCHAS em parceria com a APEX Brasil, Márcia Gomide; o diretor do SINCOCIMO do Estado do Rio de Janeiro, Armando de Souza; o vice-presidente da ABIROCHAS, Marcos Regis; o diretor do SINROCHAS de Minas Gerais, Eduardo Carvalho Felix; o presidente do SINDPARAÍBA, Antônio Fernando Holanda; o representante da ABIROCHAS do Ceará, Geraldo Silvério dos Santos; o presidente do SIMAGRAN-BA, Carlos Alberto de Araújo; o presidente do SINDIROCHAS do Espírito Santo, Tales Pena Machado; o presidente do SIMAGRAN Paraná, José Georgevan Gomes de Araújo; demais autoridades e dirigentes de instituições públicas. Meus cumprimentos também a todos os pesquisadores e visitantes de outros países, aos pesquisadores brasileiros, professores e alunos de universidades presentes e os cumprimentos especiais ao Doutor Fernando Lins, diretor geral do CETEM, entidade parceira da ABIROCHAS nesse e em outros projetos de grande interesse para o setor e que só nos engrandece, senhoras e senhores empresários, minhas senhoras e meus senhores,

Ao iniciar a elaboração das reflexões, que gostaria de fazer na cerimônia de abertura do Glogal Stone Congress, a ideia inicial era apresentar:

- a análise setorial no Brasil e no mundo;
- os dados estatísticos de desempenho;
- avaliar seu extraordinário crescimento nas últimas décadas;
- cenários futuros; e
- os desafios da concorrência e da competitividade.

Detalhar também as contribuições da ABIROCHAS nos seus vinte anos de existência, completados no dia 23 de janeiro. Imagino ser esta uma expectativa natural para esse momento.

Sobre a ABIROCHAS, gostaria de informar que a comemoração ocorrerá este ano em data a ser definida e comunicada a todos os presentes, desde já, nossos convidados. A festa será para comemorar conjuntamente com o êxito de alguns importantes projetos como:

- o Global Stone Congress, que hoje se inicia;
- o lançamento do "Estudo de Competitividade – Estratégia para uma Política de Desenvolvimento Setorial" que ocorrerá no auditório da Apex-Brasil – Agência

Brasileira de Exportações e Investimentos, em Brasília, no dia 16 de maio, cujo convite será também enviado a todos os presentes**;**

- o desenvolvimento do Projeto de Mercado Interno, voltado para difundir a "cultura da pedra" no ambiente acadêmico e mercadológico, objetivando ampliar a presença das rochas brasileiras na arquitetura nacional;
- o convênio com SEBRAE nacional, orientado para capacitação e gestão das marmorarias, em âmbito nacional;
- a renovação e ampliação do convênio com a Apex-Brasil, cuja finalidade é a expansão das exportações brasileiras de rochas ornamentais;
- os avanços dos projetos denominados "terceira onda exportadora", que objetivam a inserção da indústria brasileira de rochas no mercado de obras ou de produtos finais dos EUA e do Oriente Médio, dentre outros.

Apesar da importância de todos esses fatos, que poderiam, como eu disse, ser o cerne da minha apresentação, me ocorreu a seguinte e inquietante pergunta:

**Neste tempo de tantas possibilidades industriais, a sociedade e a arquitetura contemporâneas desejam a pedra como elemento de revestimento?**

Era a mesma pergunta que me fiz, quando há 30 anos, então sócio de um grupo empresarial e responsável pelos estudos de viabilidade dos investimentos, fui informado que era pretensão de uma das companhias investir em um projeto inovador no setor das rochas ornamentais.

**Haverá um futuro promissor para a rocha ornamental e de revestimento?**

A razão dessa pergunta é o fato que a pedra, assim como todas as mercadorias, possui um "valor de uso" – ou seja, a capacidade de ser útil e satisfazer necessidades ou desejos do ser humano; mas também possui um "valor de troca" – determinado pelo "quantum" de trabalho social necessário à sua produção e transformação da matéria-prima bruta em objetos que podem ser usados, trocados e desejados. O valor de troca depende do estágio tecnológico historicamente alcançado e que define o lugar de um bem, na competição com outros bens alternativos; uma relação que varia de tempo e de lugar.

O desafio contido nessa pergunta se impôs e, nessa noite, tentarei respondê-la de modo mais elaborado:

Inicio lembrando que a pedra tem sido há milhões de anos um elemento indissociável da sobrevivência, do crescimento e, se podemos assim denominar, da sustentabilidade dos nossos antepassados. Desde a utilização das cavernas como abrigo, as primeiras ferramentas rudimentares, passando pelas portentosas construções que caracterizam os marcos do processo civilizatório até os nossos dias, a pedra tem estado presente como fonte de proteção, de abrigo e de refinamento estético do ser humano.

Os materiais rochosos tiveram seu uso na aurora da civilização humana, na Europa, Ásia e África. No território onde atualmente é a Rússia, em cerca de 200 cidades do período paleolítico, ou seja, há 2,5 milhões de anos, casas e túmulos foram feitos em pedra.

Há cinco mil anos, os egípcios abriram as primeiras pedreiras para delas retirar os blocos calcários e os granitos com os quais construíram as extraordinárias pirâmides; na maior delas, com 169 m de altura, a de Kufu (ou Quéops), foram utilizados 4,5 milhões de metros cúbicos de rocha. E poderíamos destacar tantos outros registros erigidos em pedra, que são marcos da passagem do ser humano pela terra, como por exemplo:

- a fortaleza inca de Sacsayhuaman, no Peru – transportadas por 20 km até a colina de Cusco, há 3 mil anos;
- a Porta do Sol em Tiwanaku, na Bolívia – construída há 2,2 mil anos;
- as grutas de Longyou, província de Zhejiang, na China – um mistério quanto à sua origem;
- as ruinas submersas de Yonaguni, no Japão – estima-se entre 8 a 11 mil anos, a sua origem;
- o monumento de Stonehenge, em Salisbury, Inglaterra – com 3 mil anos de existência;
- a Muralha da China, com seus 21.196 km construídos ao longo de 20 séculos;
- a estátua de Vitória de Samotrácia, atribuída a Pithókritos, na Grécia – datada do ano 640 a.C.

Observa-se que o desenvolvimento das forças produtivas e seus reflexos civilizatórios, não distanciou o ser humano da pedra; ao contrário, aproximou-o ainda mais, não somente através da disseminação do seu uso na arquitetura e nas obras de arte da engenharia, mas, adicionalmente, permitindo que o refinamento estético decorrente do novo padrão mental da sociedade ficasse registrado para sempre na história humana. Apenas como referência, recorro ao encantamento expresso nas obras de um dos maiores escultores renascentistas, Michelângelo Buonarroti, como La Pietà, Il Giorno e la Notte e o David; na arte de Giovanni Strazza e Raffaelle Monti, com as suas esculturas em mármore que parecem envoltas em véus de seda; ou ainda, nas icônicas construções do nosso tempo...

Esse sentido de permanência e ao mesmo tempo de contemporaneidade e modernidade, fundamenta a utilização da pedra no cotidiano dos povos desde os seus primórdios até os dias atuais e por certo no futuro, indicando que as inovações proporcionadas pela ciência e pela técnica, nas fases de explotação, beneficiamento, aplicação e manutenção das rochas como elemento de revestimento e ornamento, acompanharam toda a evolução tecnológica ocorrida na sociedade. Nas diversas etapas civilizatórias, ao lado dos avanços da técnica e dela servindo-se, a pedra se tornou um elemento “cultural” comum a todos os povos. Aqui utilizo o conceito consagrado pelo antropólogo norte-americano Leslie White, que define cultura, “como uma classe de coisas ou eventos que dependem de simbologização, que são produtos da simbologização...”. No âmbito humano, as coisas só são significantes em termos de seu contexto. E a pedra é uma pedra, mas pode ser vista como mercadoria ou como fonte de nobreza, de modo que, sem perder a sua significação original, adquire outros significados:

- nos templos com suas majestosas arquiteturas, a pedra simbologiza, tanto o poder temporal quanto o poder espiritual das religiões;

- na arte cemiterial, simbologiza o sentido de permanência do ente querido diante da inevitabilidade da morte;
- nas grandes edificações contemporâneas simbologiza economicidade, sofisticação estética e nobreza.

Se é fato que Michelângelo, contemplando a perfeição da sua obra, o David, se emocionou a tal ponto que houvera dito "**Adesso, parla!**", aquele momento serve de exemplo síntese da capacidade exclusiva do ser humano de atribuir significados a coisas e acontecimentos do mundo externo e de viver em um universo simbólico que está na base da construção da cultura, **que é a experiência humana por excelência.** A pedra traduz compreensão de significado porque ela expressa e dialoga com a história e os feitos dos povos, as subjetividades humanas, as suas habilidades de inventar e inovar!

De modo que os sistemas sociais, ao longo de milhares de anos, cristalizaram essa relação do ser humano com a pedra de um modo aparentemente atávico, uma herança dos ancestrais, mas, na realidade, como nos lembra Norbert Elias, um dos maiores sociólogos do século XX, apesar de haver uma parte ancestral em nós humanos, a maior parte do que pensamos e fazemos, decorre da interação com os semelhantes e com o mundo, aperfeiçoada nas relações sociais e que se assentam sobre o incessante processo evolutivo das capacidades humanas, determinado pelo desenvolvimento das forças produtivas e que de fato, moldam os sistemas sociais.

A conclusão que podemos chegar, é que a pedra se mantém presente na história dos povos, não somente pela sua utilidade e pelo ancestral fascínio do ser humano pela **beleza natural e autêntica da pedra**; pelo seu "valor de uso". Mas, acima de tudo, pela capacidade da indústria da rocha corresponder aos desafios postos pela evolução tecnológica, trazendo soluções inovadoras aos constantes avanços e exigências dos padrões construtivos, fazendo variar no tempo, o seu "valor de troca" o que permitiu ampliar seu espaço na competição com outros materiais de revestimento.

Atribuí à pedra o sentido de **beleza autêntica, genuína,** para diferencia-la da incansável artificialidade imitativa dos bens industrializados. São artificialismos de toda sorte produzidos pela indústria cerâmica ou dos denominados "quartzos" na pretensão de parecer natural, mas, somente a pedra pode proporcionar aos que dela se servem, a percepção de estar usufruindo de um material único, como um diamante, gerado há milhões de anos e que está ali, acessível e a serviço do seu conforto, prazer e segurança.

**Tem sido assim até aqui. E no futuro, como será?**

Vivemos um tempo de incerteza e insegurança como regra. Nas palavras do sociólogo polonês morto recentemente, Zygmunt Bauman, são **tempos líquidos, de uma sociedade líquida, do dinheiro líquido e até mesmo, do medo e do amor líquidos.** Liquefação do mundo do trabalho, dos interesses do estado nacional, liquefação da indústria tradicional e todas essas transformações, conduzidas sob a hegemonia e a lógica imediatista do **capital financeiro – o dinheiro líquido.** Ainda mais grave**,** é que tudo isto forja a **liquefação da solidariedade**

condição essencial para o equilíbrio no âmbito da "sociedade dos indivíduos" como bem definiu o já citado sociólogo alemão, Norbert Elias.

É também um tempo de incontrolável e incessante inventividade humana, onde tudo parece ser feito para a rápida obsolescência moral e técnica. Haverá lugar para um bem que traz consigo o sentido da durabilidade e da permanência?

Talvez o desafio seja o contínuo avanço tecnológico do nosso setor, por uma via que leve ao pleno domínio da forma dos bens feitos em pedra, criando a percepção de que a rocha alcançou "fluidez" e "maleabilidade" no sentido figurado; moldando cortes, recortes, acabamentos e tantas outras formas, fazendo parecer que a pedra se libertou da sua rigidez e dureza em um simulacro de liquefação; um efeito perceptivo em um tempo em que a percepção pode valer mais e ser mais crível, que o fato real.

Não só isto, a própria pedra se reinventa pela força da tecnologia, assumindo outras formas não menos importantes de aproveitamento, ou de "valor de uso". No Brasil, que tem um setor agrícola dos mais desenvolvidos no mundo, poderemos contribuir para uma nova revolução verde, baseada na utilização "*in natura*" de pó de rocha para remineralização e fertilização de solo. Experimentos da Embrapa – Empresa Brasileira de Pesquisa Agropecuária, já permitiram comprovar a eficiência e a eficácia desse novo produto, potencializado pela ação de agentes biológicos para captura das substâncias contidas nas rochas.

Essa nova via tecnológica trará no futuro breve a possibilidade da formação de "*clusters* agrícolas" nas áreas de influência dos arranjos produtivos, ao mesmo tempo em que significará uma revolucionária solução ambiental para os rejeitos sólidos da nossa indústria.

Outra frente tecnológica a ser trabalhada será a inserção do nosso setor na complexa dimensão da denominada "Indústria 4.0". Estamos em estágio inicial de entendimentos com o SENAI nacional e com a ABDI – Agência Brasileira de Desenvolvimento Industrial, para definição da adequada estratégia a ser implementada.

De modo que, se faz sentido a reflexão aqui formulada, podemos congratular-nos com o Global Stone Congress, o congresso internacional que promove o encontro de inteligências científicas, realizado pela primeira vez no Brasil em 2005 no estado do Espírito Santo e subsequentemente realizado na Itália, na Espanha, em Portugal e na Turquia, e agora retorna ao Brasil para acontecer na bela cidade de Ilhéus, na Bahia, berço da nação brasileira.

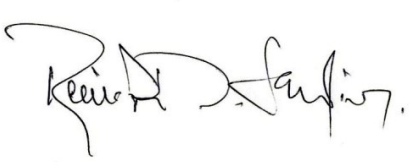
Sendo assim, a ciência e a técnica, somadas ao espírito empreendedor dos empresários do setor, são a resposta aos desafios do futuro das rochas ornamentais e de revestimento, permitindo projetar que experimentaremos uma "nova idade da pedra" na arquitetura mundial!

O Global Stone Congress está validado, definitivamente validado, justificando todos os esforços empreendidos e todos os apoios recebidos, em particular àqueles concedidos pela Secretaria de Desenvolvimento Econômico, através da CBPM - Companhia Baiana de Pesquisa Mineral, e à Prefeitura do Município de Ilhéus, reiterando aos seus respectivos dirigentes os nossos agradecimentos e dívida de gratidão.

Por fim, agradeço a presença de todos os que responderam ao nosso convite, às autoridades aqui presentes. Destaco também o apoio institucional da Federação das Indústrias do Estado da Bahia, agradeço aos amigos do setor, aos estudiosos, pesquisadores e cientistas de várias partes do mundo que aqui se fazem presentes e por fim, e de modo muito especial, à parceria dos integrantes do CETEM e aos empresários e dirigentes institucionais do setor, a todos os companheiros da ABIROCHAS, conselheiros, consultores e colaboradores, sem os quais não haveria sido possível realizar esse grande evento.

Obrigado a todos e sucesso ao **Global Stone Congress!**

Ilhéus, Bahia, 26 de abril de 2018



Reinaldo Dantas Sampaio
Presidente da ABIROCHAS
Associação Brasileira da Indústria de Rochas Ornamentais

# ARCHITECTURE TECHNICAL SESSION

Sodalite (Somibrás Company). Photo: Nuria F. Castro (2018)

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL
April 26-29, 2018
CONNECTING MINDS IN THE WORLD OF STONE

# Lessinia Stone (Italy): a candidate for "Global Heritage Stone Resource" designation

**Piero Primavori**

**Synopsis**

Lessinia Stone is the commercial name of a pinkish limestone, upper Cretaceous in age, that crops out in the Lessinia territory, Pre-Alps, Veneto region, N Italy. Historically known as Prun Stone, it is a stone worked from the earliest Cimbrian settlements. In the Lessinia territory this stone, in its singular slab formation, extraordinarily regular and easy to work, has favored the definition of building and composition rules that have left an unmistakable mark on the architectural language (vernacular architecture). Its unlimited fields of application have made it one of the most versatile stones in the local - and recently worldwide – panorama of the dimension stones. In the light of its relevant geological and technical properties, the growing commercial diffusion, and the role this stone has played in the local traditions, culture, history and architecture, the author proposes the candidature of the Lessinia Stone for the recognition as a Global Heritage Stone Resource.

**Keywords**

Lessinia, Prun, vernacular, lastame

## Introduction

Lessinia is a territory where anonymous stonecutters, masons and farmers have for centuries built entire houses, stables, barns, roofs, dividing walls, yards, public spaces, and anything else necessary for their life, using exclusively one type of stone - the Lessinia Stone - formerly known as Prun Stone.

Such territorial elements have developed a specific, unique and original constructive language, and represent today genial and creative testimonials of vernacular architecture, which has waited even longer for recognition, to the point that its survival is at stake.

The note intends to draw the attention on this quite peculiar dimensional stone, which has heavily influenced the architecture, culture, traditions and landscape of a large geographic area, and which has been recently re-discovered, and successfully applied worldwide, even with examples of important buildings by renowned and famous architects.

The main aim of the note is to propose the Lessinia Stone as a candidate for "Global Heritage Stone Resource" designation, an international recognition aiming to increase professional and community awareness of natural stone and cultural heritage and to enhance international co-operation for the research and documentation of natural stone resources.

## Global Heritage Stone Resource : the concept

The "Global Heritage Stone Resource" designation (GHSR) is a designation which has been created as the first international geological (as opposed to technical/mechanical) standard associated with dimension stone. It was first mooted within IAEG (the International Association of Engineering Geology and the Environment) Commission 10 – Building Stones and Ornamental Rocks (C-10) in late 2007, subsequently implemented and developed by the Heritage Stone Task Group (HSTG) until 2016. During the IUGS Council meeting at the 35$^{th}$ IGC-2016 in Cape Town, the HSTG has been upgraded to Subcommission, the Heritage Stone

Resource Subcommission (HSS). HSS is nowadays one of the two Subcommissions of the "International Commission on Geoheritage", being the other one the Heritage Sites and Collections Subcommission (HSCS).

Among the goals of HSS, the following should be emphasized:

- to facilitate formal designation of dimension stones that have achieved widespread recognition in human culture,
- to promote the adoption and use of this heritage stone designation by international and national authorities,
- to increase professional and community awareness of natural stone and cultural heritage,
- and to enhance international co-operation for the research and documentation of natural stone resources.

Potentially eligible dimension stones are required to fulfill most of the following attributes:

- Historic use for a period of at least 50 years.
- Wide-ranging geographic application.
- Utilisation in significant public or industrial projects.
- Common recognition as a cultural icon, potentially including association with national identity or a significant individual contribution to architecture.
- Ongoing availability of material for quarrying.

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## Geography and essential geology

Lessinia is a large geographic area divided between the provinces of Verona (which includes the vastest part of it), Vicenza and Trento, Northern Italy (Fig. 1). It is formed by a degrading plateau towards the Po plain (the longest Italian river), of trapezial shape, furrowed by five valleys: Valpolicella, Valpantena, Val Squaranto, Val d'Illasi and Val d' Alpone, all of them quite famous not only for stone but also for wine and wineries.

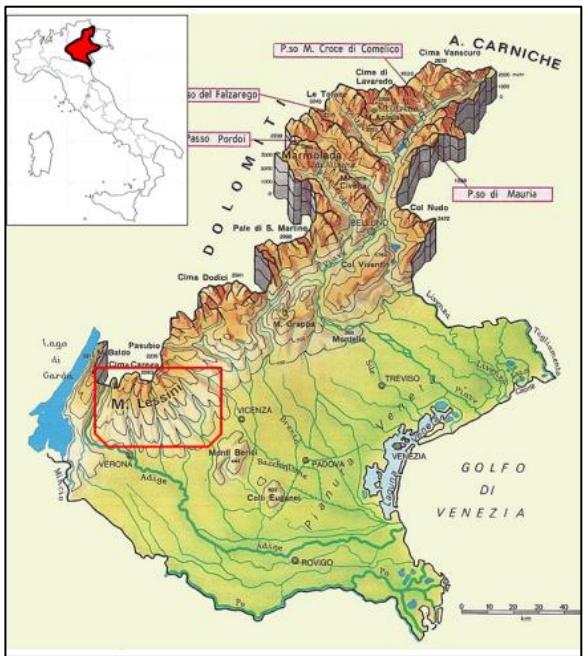


Fig. 1 Location of Lessinia geographic area

The plateau, southward spurs of the Pre-Alps chain, consists of sedimentary rocks of organogenic origin - almost entirely limestones and dolomites - and is dominated to the North by a circle of peaks exceeding 1,500 metres in height (Corno d'Aquiglio, Mt. Castelberto, Mt. Sparavieri, Castel Malera and Mt. Zevola). The plateau is crossed by numerous faults usually running straight from North to South, and slopes gently southwards with an inclination of 5-8 degrees. It is flanked to the west by the Val Lagarina (one of the largest valleys in Italy) and, to the East, by the Chiampo valley, where wide extensions of volcanic material (basalt and tuffs) occur (Chiampo valley is another Italian cluster area for dimension stone production). Lessinia Stone is a pink, more rarely whitish, fossiliferous, micritic limestone / marly limestone, belonging to the basal level of the Scaglia Rossa Veneta formation. It contains extremely important and rare macrofossils, such as vertebras, shark's teeth, remnants of turtles, together with ammonites, echinodermata and rudists, incredible samples of which are exhibited at the Paleontological and Prehistoric Museum of Sant'Anna di Alfaedo.

The famous courses of Prun Stone belong to the middle-lower part of the formation. It is a pack of regular layers, separated by thin layers of clay. The facies is often nodular and reminds one of the Red Ammonitic, where the most famous Rosso Verona "marble" (Verona Red) comes from.

## Lessinia Stone production

Lessinia Stone is the commercial name used to define the stone extracted from a specific part of the Scaglia Rossa Veneta formation. This stone, historically and traditionally referred to as Prun Stone (from the important village of Prun), has been quarried for centuries in the higher Negrar Valley, near the ancient towns of Prun, Fane and Torbe. It extends over an area of approximately 100 $km^2$, where fourteen quarries are currently in operation, together with a significant number of processing plants and artisanal laboratories.

It currently represents the second most important dimension stone quarried in the Verona province, after the most famous "Rosso Verona" ("Verona Red").

One of the most peculiar aspects of Lessinia Stone is represented by its sedimentary sequence; the basal levels of the Scaglia Rossa Veneta formation consist of an extremely regular succession of horizontal strata that vary in thickness from 3 cm to 40 cm. The composition is limestone-marly and the total thickness useful for productive purposes is only 7-8 m. Each stratum in the stratigraphy has been given a specific dialectal name on the basis of its practical application in the construction and building sector (an amazing Table with all these names could be here reported but it would be too long for an Extended Abstract). Hence, there are strata used exclusively for lintels, steps, gables, piers, shelves, window-sills etc. Each stratum has been used only for a specific purpose ! These layers of stone - 72 or 73, depending on the different authors - are separated by a veil of clay that make them easy to detach; this ease of detachment is the technical feature which has entirely determined not only the quarrying and processing techniques, but also the specific application of the stone. The curious (local) name given to the whole production, irrespective of the thickness of the strata extracted, was (and still is) "*lastame*" (not to be confused with lastrame, an Italian term to define a generic production of slabs). As per knowledge of the author, the Lessinia Stone represents probably the only case where such a detailed subdivision in the stratigraphy has totally driven the application of the stone.

The first quarries were set up underground, and they are still observable today in the landscape; the rigorous logic of functionality and optimization of the production are clearly reflected in the impressive geometry and architecture of such quarries (Fig. 2).

Fig. 2 Historical underground quarries in Prun

Due to its easy splittability the production cycle is organized to extract directly the slab from the deposit; the first step is to use a diamond disk to cut the slabs to a desired size (similar to cutting brownies in a pan), depending on the requirements of each single project. Next, a pneumatic hammer, or a fork-lift, are used to remove the slab.

## Lessinia Stone application

Since the Iron Age Lessinia Stone has been used in the construction of the castellars on the Lessinian ridges: the external walls of the village, the pavements and the roofs of the huts, were all built with slabs of stone. Its high versatility meant it could not only be limited to rural uses and, in Roman times, it found a variety of new uses: pavements, trusses, keystones, columns, monuments, balconies, and fountains. Particularly, in the Roman period and the Renaissance the stone adorned religious architectural masterpieces, such as St. Mark's Basilica in Venice, the Baptistery of Parma and the Basilica of San Zeno in Verona. Over the last twenty years, it has definitely acquired an international reputation, having being selected by renowned architects, and used in important and symbolic building, such as the Jewish Cymbalista Sinagogue in Tel Aviv (Israel) (Fig 3-4), also winner of an important international architectural award.

Fig. 3 - 4 Jewish Cymbalista Sinagogue, Tel Aviv (Israel). Mario Botta Architect project

## Conclusions

The originally called Prun Stone - nowadays Lessinia Stone – is here proposed as a candidate to the designation of Global Heritage Stone Resource. The proposal is justified not only by the intrinsic geological, technical and application features of the stone, but also by a set of peculiar aspects, amongst which the following deserve to be mentioned:

- the presence of a Regional Natural Reserve of Lessinia, instituted in 1990, covering 10,000 hectars with interesting geological, archaeological and ethnographic occurrences;
- the typical, and unique, rural vernacular architecture;
- the presence of a Paleontological and Prehistoric Museum (Sant'Anna di Alfaedo), with its numerous scientific evidences strictly related to the Lessinia Stone;
- the occurrence of an internationally reputed Fair (the Verona MARMO+MACC Fair).

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## About the authors

Piero Primavori, Free-lance, Dimension Stone International Consultant

*PSC*- Primavori Stone Consulting, Via Ressi, 19 c/o Crespi, 20125 Milano, Italy. Pieprima@gmail.com.

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# Marble Museum of Vila Viçosa, Portugal A mirror of geological and mining heritage

**Ruben Varela Martins, Joaquim Luís Lopes, Luís Brito da Luz, David Germano, José Patrício.**

**Synopsis**

Raquel de Castro Marble's Museum was built in an old quarry of ornamental marble located in one of the entrances of Vila Viçosa, Alto Alentejo – Portugal. It's a space intented to preserve all the knowledge acquired over decades of exploitation and processing of the Worldwide know stone, regionally called "White Gold".

The importance of this industry to the region's economy has profoundly affected the lives of its people and is always strongly linked to the natural stone sector.

The contents arranged logically and sequentially, frame the visitor in the most varied aspects, from the geological, historical, technological, environmental and social framework.

All the themes are approached in a scientific and practical way, making the museum an area of knowledge and culture constituting a portrait where the populations and industrialists of the region can be reviewed.

**Keywords**

Marble, Portugal, Museum, Estremoz marble.

## Introduction

The old quarry of Gradinha, at the gates of Vila Viçosa, had been deactivated and abandoned for many years, with several environmental impacts and safety risks for the population of the village. The city council of Vila Viçosa acquired this space, projecting it and reactivating it, in a museological way.

The proximity to an urban center (Fig. 1) and the fact that it has an old open pit exploitation with well development, typical of the extraction units of the region, heap with mine waste and all the support structures, has made this space an exceptional place for the installation of a museum dedicated to the marble.

At present, the Museum of Marble has a huge and rich collection of around three hundred pieces, a number that is increasing thanks to the donations and generosity of industrialists and individuals, as well as the support of institutions, where pontificates the University of Évora.

The project that is now underway represents a new museological trend, aiming at improving the quality of exposure, with a redistribution and labeling of the pieces in a logical way and the improvement of scientific and technological information related to all the geological, industrial, anthropological and environmental patrimony.

## A trip by the Museum

A 500 $m^2$ covered pavilion is divided into coherently arranged thematic areas, leading the visitor through the different fields of knowledge related to marble. The geological setting of the Estremoz Anticlinal represents the beginning of the journey by the marble industry as ornamental rock.

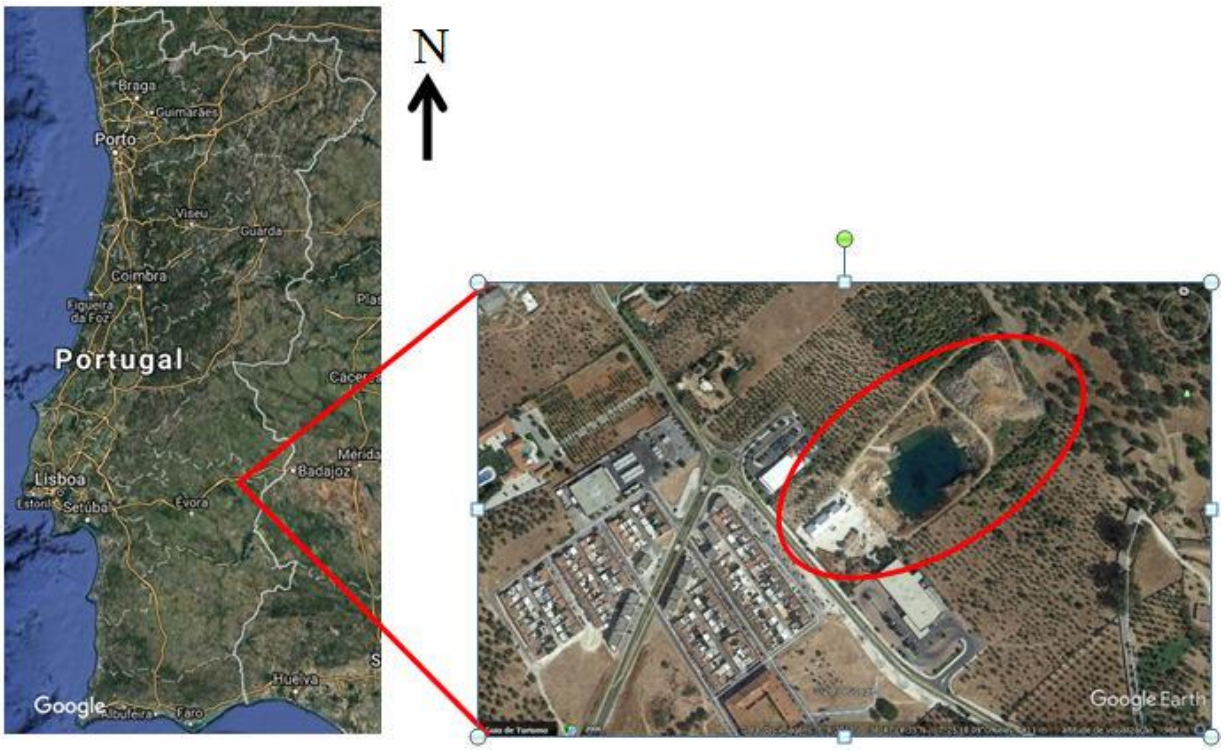


Fig. 1 Geographical location of the Vila Viçosa Marble Museum. Google Hearth image. No scale. 38º47'18,62´´N; 7º25´25,16´´O.

The museum´sintroduction is done with two polished slabs in open book, where visitors can realize that, what is observable in the typical veins of different colors, faithfully represents the geological phenomena occurred regionally (Lopes & Martins, 2014, 2015).

Following is the History and Ethnography sector. The importance of Portuguese marble dates back to the Roman period, and traces of exploitation of this period have been discovered. After centuries of intermittent exploitation, the modern phase of exploitation began in the early twentieth century. In this section we highlight the rich testimony of workers of the quarries, many of them perpetuated in verse.

This section will also constitute an imperceptible "bridge" for the next, more technological section. In the section dedicated to the extraction of marble, the centerpiece is a marble quarry model, 3.00 m long and 1.16 m wide, at 1:50 scale consisting of an open and an underground module, designed in 2008, by the Department of Geosciences of the University of Évora and improved in 2016.

Gradually it has been completing with equipment's involved in the quarry cycle works at scale 1:50, created by the Engineer José Patrício, previously modeling in Solid Works and then realized in 3D printerMakerbot and filament PLA, faithfully respecting all the details.

This exhibitor also includes an interactive screen where the visitor can select an operation, such as cutting with diamond wire, dismantling, removal, etc., allowing the viewing of a film and lighting a led in the model indicating the respective operation. For this purpose, the software was developed by the students of the Masters in Mechatronics of the University of Évora.

At the top of the model is a mural of 3.00 m in length and 0.40 m in height, painted by the artist Maria de Fátima Compõete. The piece is completed with a panel of 3.00 m x 1.50 m, explaining the operations performed in open and underground extraction units, carried out by students of the Master in Geological Engineering of the University of Évora (Fig. 2).

Fig.2 Assembly phase of the model and detail of the underground exploitationand drilling in open pit.

Following the logical circuit of the museum, after the extraction of the marble blocks, one enters the section dedicated to the transformation (marble processing). Here an image of the techniques used in ornamental rock processing is given.

The local artists' sector is especially dedicated to the artists of Estremoz's Anticlinal who work in marble and have artistic work done with this type of stone. It is a space to pay homage to the sculptors of the Municipalities of Estremoz, Borba and Vila Viçosa, people deeply knowledgeable with the marble who perform fantastic works of great cultural interest, revealing great mastery and sensitivity (Ruben et al. 2012; 2016).

In the sector dedicated to the environment, the aim is to make known the important role that quarries assume in the dynamics of local biodiversity, demystifying preconceived ideas that the impact of these spaces is negative from any perspective. Despite the impacts caused by the extractive activity during the active life of a marble quarry, especially at the level of the landscape, geomorphology and ecosystems, several studies indicate that the end of the extraction and consequent deactivation of a quarry will bring new opportunities for wildlife, and may even increase the diversity of fauna and flora (see Lucas *et al*., 2011; Germano, 2013).

The open area has a high potential space, not only of a museological nature, but also perfectly adapted to other leisure and cultural activities, such as musical concerts, theater plays, as happened in the past and possible sculpture contests. The exterior area of the Museum has four distinct zones: 1 - an olive grove with about 2300 $m^2$, adapted for a picnic area; 2 - exhibition area with 1200 $m^2$ for the exhibition of large equipment used in the extraction of marble, where he pontificates an Ingersoll Rand compressor manufactured in 1917 and used till 1954 in marble quarries. It is a rare and invaluable piece donated to the Museum by the company, Sociedade Luso Belga de Mármores, S.A.; 3 - a cavity from which the marble was extracted, has a perimeter of 350 m and usually has a water accumulation of approximately 52135 $m^3$ by interception of a surface aquifer and runoff of rainwater, giving a scenario of great beauty and tranquility (Fig. 3). The heap is an artificial element consisting of marble without ornamental quality is about 20 m high and an approximate area of 6400 $m^2$. It represents a fantastic element to finish a visit to the Marble Museum, since it constitutes a viewpoint from where one can observe the quarry and if one glimpses to the North, one of the extractive cores of the Borba Municipality, to the South Vila Viçosa and to the Northeast part of the Tapada Real and the Alentejo flat land.

Fig.3 General view of the quarry and museum building. Photo taken on top of the heap.

## Acknowledgments

This study was co-financed by the European Union through the ICT project (UID/GEO/04683/2013) with reference POCI-01-0145-FEDER-007690; E-TechStone POCI-01-0247-FEDER-017882 and is a contribution for the UNESCO IGCP-637.

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## About the authors

Ruben Varela Martins, PhD Geological Engineering, University of Évora, Escola de Ciências e Tecnologia, Departamento de Geociências, rubenvm@uevora.pt

Joaquim Luís Galego Lopes, PhD - University of Évora, Escola de Ciências e Tecnologia, Departamento de Geociências, ICT – Instituto de Ciências da Terra, FCT, Portugal, lopes@uevora.pt

Luís Brito da Luz, Master - MARBRITO – Indústrias Reunidas de Mármores Lda, lmnbbl@marbrito.com

David Germano, Master - CIBIO – Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade de Évora, david.lc.germano@gmail.com

José Manuel Duarte Gomes Patrício, Mechanical Engineer, jmpatricio.5@gmail.com

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# Stone materials and old buildings: how observations can help to preserve the past for the future

**Antônio Gilberto Costa**

**Synopsis**

Through the observation of a set of cultural heritage monuments built in stone, stone can be seen to have important ornamental or coating applications. From macroscopic descriptions realized in these monuments, a great variety and different intensities of alteration processes can be observed, mainly when comparisons are made between monuments located in large and small urban centers. These alterations and degradations, in part conditioned by the mineralogical composition and the structures present in these stone materials, are strongly influenced by the conditions of the environment. In general, the set of alterations and degradations observed are those related to the decomposition of the minerals that make up these rocks. Based on these in-situ investigations, diagnostics can be produced on the degree of degradation of stone materials and recommendations for their conservation.

**Keywords**

stone, monuments, degradation, conservation.

## Introduction

As a consequence of the presence of man, stone materials have been used more and more frequently and with some level of processing. In the first instance, these materials most likely had utility only as shelter or refuge. Later they were employed in the manufacture of various utensils, such as weapons for hunting and fishing, as well as for other daily activities. They were also widely used for the production of ornaments and as a source for the production of pigments with which pictorial representations were produced, recording scenes from the daily life of prehistoric man.

From these uses initially in their raw state, modern *Homo sapiens sapiens* has visualized other possibilities and advantages of applications for stone materials and since then their descendants have not only come to understand its diversity, explained by the differentiations, transformations, alterations and deteriorations, they also learned to identify their potentialities, due to their characteristics, and improved the techniques for their extraction and processing. These technological advances allowed a great expansion of the applications of these materials.

Among this set of applications, we are interested in those used in historical buildings, which have the important role of recording the history of Man at specific times.

## The stone materials in historical buildings in the world

Stone materials and examples of their applications in built monuments are many. While the former reflect local geodiversities, the latter represent an important part of the world's cultural heritage.

In antiquity, and as part of the group of builders and materials, the Egyptians were notable for building colossal monuments utilising primarily sedimentary rocks such as limestones and sandstones, , but also igneous rocks, such as Aswan granite. The Greeks immortalized themselves with the buildings of their temples and with their famous statuary art, involving the use of marbles, which are metamorphic rocks. The Romans discovered the advantages in the utilisation of of volcanic rocks in the production of mortars and cement, which led to the construction of the immense domes in its cultural buildings, for example the Pantheon in Rome. But the Romans' use of marbles, like those of Carrara, was not limited to the territory of the Roman Empire, crossing borders with its utilisation until modern times.

Considering the last two thousand years of history, other notable examples can be mentioned, such as those involving the application of granites, for example in Portuguese monuments in cities such as Viseu and Évora, of prasinites and serpentinites, such as those present in various constructions of Piedmont in the north of Italy (Fig. 1), and of conglomerates like those used in ancient cities of Turkey, such as Aspendos. Sicilian monuments built with the use of basalts and the red and orange sandstones and schists of ancient cities in Germany, such as the church of Santa Anna, in Annaberg-Buchholz, Saxony, are part of this set of examples. It is important to highlight the use of intra-formational conglomerate breccia, such as that of the Serra da Arrabida, Portugal, applied to carved pieces, floors and portals in religious monuments, such as Setúbal, Portugal, or Rio de Janeiro, Brazil. Other types of breccias or conglomerates with clasts of limestones with several colorations, in green matrix by the presence of chlorite or serpentine and from different parts of the Italian Alps and Greece have also been applied to numerous religious monuments and palaces in various parts of the world.

Fig. 1 The church of prasinite. In the Benedictine Abbey called Sacra di San Michele de la Chiusa, located near Turin, are applied metabasic rocks associated with ophiolytic sequences of the western Alps.

Materials, such as schists and slates, as well as other marbles, limestones, calcarenites and sandstones of monuments in Bogota, Colombia, Zagrebb, in Croatia, Prague, in the Czech Republic, Lisbon, in Portugal and Paris, in France may also be mentioned.

## The stone material of historical buildings in Brazil

In Brazil, considering only the period of 500 years, counting from the arrival of the Portuguese, a good part of its set of cultural properties, was built in stone and constitutes the greatest expression of its identity. In these constructions, several Brazilian stone materials were used, which reflect their geodiversity, as well as materials from other parts of the world. European natural stones, such as marble and limestone, were used as building material for historically important buildings and monuments, mainly in the most important cities of the north and northeast regions of Brazil (Zenaide 2007; Costa 2009).

In other regions local materials such as quartzites, schists, steatites and granitic rocks, gneissic or not, were more commonly used. Quartzites, always with some mica content and minerals rich in iron, and because of its chromatic variations, have been widely used for the production of structural elements, such as columns and wedges, that make connections between walls, or connecting walls and roofs and still as structuring elements of doors and windows. They were also used for the production of ornamental elements, such as church frontispieces and floor coverings.

Schists were used, especially in constructions in Minas Gerais towns, both in the production of structural elements such as bases, corners, pillars and foundations and in the creation of ornaments. Featuring different compositions, such rocks – which almost always occur interlayered with other ones such as quartzite – display coloration ranging from hues of gray to green to blue. In such schists occur in varying amounts, minerals such as sericite, chlorite, muscovite, biotite, epidote, carbonates, garnets, kyanite, chloritoid, graphite and metal oxides, which partly explain their chromatic variations.

Steatite was employed because of the ease with which it can be worked, essentially in the sculptural art and in the production of ornamental elements. Characterized by the presence of talc, steatite may contain other minerals such as serpentine, chlorite, carbonate, amphiboles, oxides like hematite and magnetite, and sulfites like pyrite, all in broadly variable amounts. In such rocks, talc content will be a decisive factor in their coloration. The higher its talc content the clearer and softer the stone type will be, which is generally known as a talc stone. In such cases, the rock can display different hues of green, blue and gray. When compared to other rocks, texture patterns containing talc crystals, chlorite and carbonate contribute to low absorption and porosity for steatites.

Among the granitic rocks used, gneiss predominated, and more rarely are examples of the application of *sensu strictu* granites. The gneisses, often with whitish gray coloration, migmatitic or not, present banding consisting of parts with different thicknesses and mineralogical contents. Due to these differentiated contents, clear bands were identified and constituted essentially by felsic minerals, such as feldspars and quartz, as well as dark bands formed by mafic minerals represented by: biotite, garnets, amphiboles, such as hornblende or pyroxene (hypersthene). Under the influence of this distribution of minerals, planar structures or foliations, more or less developed, that can be very penetrative have

been identified, mainly when these rocks were submitted to the performance of mylonitization processes.

## How observations in the present can help to conserve and preserve the past for the future

Awareness of the increased damage to stone materials on historic monuments and the danger of irrecoverable loss of this heritage have resulted in major worldwide efforts for the sustainable preservation of these monuments. Accurate damage diagnosis with the comprehensive characterization, interpretation and evaluation of these stone damages represents the basis for the adoption of effective and cost-effective conservation measures.

A methodological approach to be taken to evaluate such damage should combine *in situ* research and laboratory studies. With this approach the mapping of monuments is presented as a nondestructive procedure established for the *in situ* studies on damages caused to stones and can be applied to all types of stone and to all types of monuments built with stone. In addition, a wide range of analytical procedures and weathering simulation tests contribute to the diagnosis of modern damage to ancient monuments built in stone.

With these *in-situ* investigations we can identify the lithological types, researching and mapping the various forms of degradations of the stone materials as proposed by Fitzner (2002). If it is possible to collect samples, we can carry out analyzes, including those of microscopic petrography. Based on these investigations involving long-term observations and through photographic monitoring we can evaluate the state of degradation, we can produce maps of damages and propose solutions with information on necessity or urgency to adopt measures in the area of conservation of monuments. The adoption of these procedures involving a preventive conservation in the present will contribute to the preservation of this built heritage and its memories (Costa 2016) for future generations.

## Acknowledgments

Our thanks to LABTECRochas-UFMG for analytical facilities and financial support.

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## About the author

Antônio Gilberto Costa, Dr. Prof. Titular

University of Minas Gerais, Department of Geology, Av. Antônio Carlos, 6627, Belo Horizonte, 31.270-901, Brazil. ag.costa@uol.com.br

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# How long can salt last hosted in a rock?

**Zenaide Carvalho G. Silva, Carlos Galhano**

**Synopsis**

Six igneous rocks whose composition varies from under-saturated syenite, monzo-syenite, granite and gabbroic anorthosite were subjected to salt fog atmosphere during seven cycles of 10 days each, as described by Silva & Cruz (2012) in samples with polished and honed finishing. During the total experience salt crystals (NaCl) of varied shapes were formed on the surfaces, mainly observed on the polished samples. Mass loss in all rocks were recorded along the cycles. Ten years later, those samples which were stored in a closed container displayed salt crystals either as very fine grains along fractures and contouring mineral grains or larger ones, very well defined cubic crystals, exhibiting features of the gradual growth along the past 10 years. The variation in mass loss of those samples were determined and they fall on the average values determined during the seven cycles, for both types of finishing, polished and honed. These observations raised the question of the time that salt can last in a rock and the progressive alteration and damage that it can cause in the rock, as in many instances are observed in rock plates along time when they are exposed to coastal atmosphere.

**Keywords**

rock alteration, salt fog, time, damage.

## Introduction

A wide variety of rock types, mostly of igneous origin have been under study at Nova University laboratories where simulation of aggressive atmospheres was artificially prepared. The intent was to follow changes in color, texture, mass loss and eventual differences in technologic properties that could interfere with rock behaviour in construction and buildings. Among these aggressive atmospheres, salt fog was possibly the one mostly studied, partially considering that Portugal has a long coast, highly populated and the large variety of granites and limestones contributes to have these rocks as elected materials for use in the construction industry in the area.

Experimental work was carried out on different sets of rocks, varying from oversaturated granites to under-saturated syenites and gabbros, from compact microcrystalline to oolitic limestones, in which porosity, texture and mineral composition were important parameters to be accounted for most changes observed. Salt fog atmosphere was one of the most frequent and explored techniques due to the necessity to test some Portuguese rocks widely used in the construction industry and placed on buildings on the sea side. Observations throughout areas near the coast where modern architecture promoted the use of rocks with different surface finishing enabled an interesting response regarding alteration differences on the same rock type on places of different surface finishing, whether honed, polished, hammered or flamed (Silva et al., 2013).

This research could be considered as an extension of the one carried out during one year on six specific rocks, each one having some special feature, either textural,

compositional or origin. The original research results were published (Silva & Cruz, 2013). Time correspondent to these results refers to one year (2003-2004), but samples which underwent salt fog exposition, intense washing and draining, dryness and porosity evaluation were kept during one decade and after that time, salt crystals appeared on the surface of some samples, mostly visible on polished surfaces. Now the question is, how long can a rock host salt in its interior and what could that mean in terms of internal changes, weight loss and other characteristics?

## Observations, previous and recent data

Rocks under experiment are identified as: Blue Bahia “Granite” (BB), a sodalite syenite; Belfast “Granite” (BG), a granophyric monzonite; Amazonite Granite (AG), a Rb bearing K-feldspar granite; Baltic Brown Granite (BBG), a rapakivi textured granite; Imperial Brown “Granite” (IBG), a rapakivi textured monzo-syenite and Labrador Blue “Granite” (LBG), a gabbroic anorthosite.

For each rock two finishing were tested: polished and honed. Open porosity of these rocks varied from 0.13% to 0.82%. The mass loss (in grams) for each cycle, in a total of seven cycles during the one year of experiment under salt fog atmosphere was more pronounced in samples having a honed finishing, suggesting that polished surfaces are somewhat more protected from fluid penetration in the rock. There was not a direct correspondence of mass loss with open porosity, indicating that other parameters like mineral composition and texture also play their role on the alteration process.

Tab. 1 reports some parameters as open porosity, total and average mass loss for the seven cycles experienced previously and the mass loss after ten years of rest for the same samples. These values were obtained after observing the samples, the exposed salt crystals on their surfaces, most evident on polished samples and repeating the previous procedure as weighing the samples before and after they were washed and dried. The two most distinct features observed on those samples were: i. the maintenance of the trend in mass loss variation, more accentuated on honed than on polished samples and ii. the shape of the new salt crystals.

Figs. 1 and 2 show some of the observed recent crystals. Although the distribution along fractures were common on the previous experiments, the crystals shapes are different. In the previous ones, cubic and hopper crystals were observed, as contrasted to cubic crystals exhibiting patterns of growth along time, in the new ones. Minor, smaller crystals were spread in the polished surfaces and these differences in size and shape can be accounted for different rates and conditions of growth, and a different path of fluid from the interior to the surface of the samples, as discussed by other authors as Arnold & Kueng (1985), Arnold & Zehnder (1985), Silva & Simão (2009).

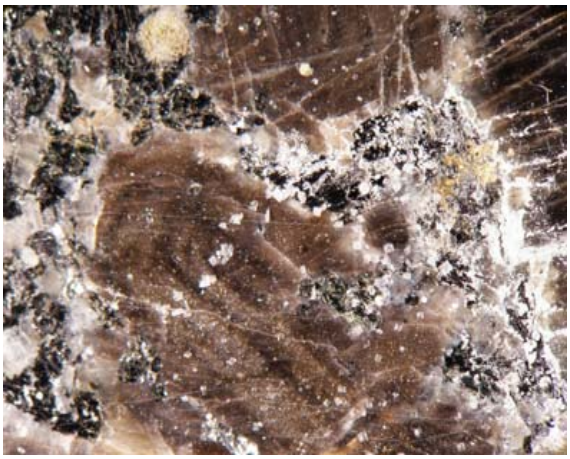

Fig. 1. Halite crystals on the polished surface of Imperial Brown Granite. Small crystals with average size of 1mm on feldspar surface and on surrounding grains.

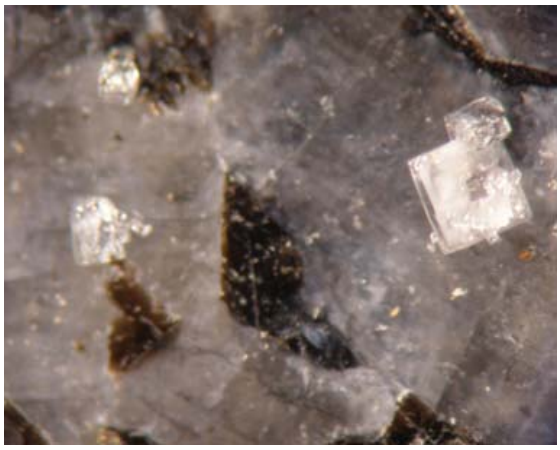

Fig. 2. Halite crystals deposited on the polished surface of Labrador Brown Granite after 10 years rest. The largest crystal is 5mm. long in diameter.

Tab. 1. Data on the six studied lithologies: BB (Sodalitic syenite); BG (Monzonite); AG (Granite); BBG (Rapakivi granite); IBG (Monzo-syenite); LBG (Gabbro-Anorthosite). P- polished; H- honed.

| | Open Porosity (%) | Finishing | Total mass loss (gr) | Average mass loss, 7 cycles | Open porosity After 10 years (%) | Mass loss after 10 years (gr) |
|---|---|---|---|---|---|---|
| BB | 0,31 | P | 0,1923 | 0,0294 | 0,443 | 0,0311 |
| | | H | 0,2456 | 0,0351 | 0,495 | 0,0279 |
| BG | 0,57 | P | 0,2121 | 0,0303 | 0,451 | 0,0277 |
| | | H | 0,2281 | 0,0326 | 0,506 | 0,0301 |
| AG | 0,45 | P | 0,116 | 0,0159 | 0,717 | 0,0365 |
| | | H | 0,1333 | 0,0191 | 0,728 | 0,0264 |
| BBG | 0,54 | P | 0,2089 | 0,0298 | 0,676 | 0,0271 |
| | | H | 0,2822 | 0,0403 | 0,484 | 0,0689 |
| IBG | 0,82 | P | 0,1716 | 0,0245 | 0,917 | 0,0489 |
| | | H | 0,1992 | 0,0284 | 0,884 | 0,0562 |
| LBG | 0,13 | P | 0,0399 | 0,0571 | 0,178 | 0,0578 |
| | | H | 0,0494 | 0,0705 | 0,231 | 0,0296 |

## Conclusions

The unexpected formation of new crystals on the rock surfaces after 10 years of experience by exposing 6 special rocks to salt fog atmospheres and following their alteration on mass by loss after each cycle of exposition raised an important question on how long can a rock host salt, even after being washed and dried many times.

Buildings having rock plates on their façades in constructions along the coast, where saline atmosphere and moist are common alteration agents, show signs of oxidation and leaching of iron from minerals, as well as removing of crystals from the rock.

Although many different rocks have been under experiments for the two last decades, this type of observation as discussed here had never been raised before. As such, the observations just reported opens space for monitoring situations of progressive damage in rocks, sometimes very fast, depending on how far the building is from the sea, how porous is the rock, its texture, mineralogy and surface finishing.

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### About the authors

Zenaide Carvalho Gonçalves da Silva

GeoBioTec, Dpartamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
e-mail: zcs@fct.unl.pt

Carlos Galhano

GeoBioTec, Dpartamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
e-mail: acag@fct.unl.pt

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# Chemical mobility of major elements during lixiviation experiments, in magmatic ornamental stones from Portugal

**Joaquim Simão, Nuno Leal, Carlos Galhano**

**Synopsis**

Six Portuguese magmatic ornamental stones were submitted to Soxhlet experiments during 10000 hours (approximately 416 days) in order to evaluate how the rain water affects the rock behavior as a dimension stone. Macroscopic alterations were observed in the rock fragments and chemical analysis of leaching water solutions revealed how major elements were mobilized from rock-forming minerals allowing to compare weathering susceptibilities between different natural stones.

**Keywords**

Soxhlet experiment, granite, leaching, natural stone, dimension stone.

## Introduction

Water is the main solvent present at Earth surface, thus playing a determinant role in the alteration of rocks. Rain is a major agent for such changes, and their intensity strongly depends upon the available quantity of water that drains through rocks. During the last decades, due to their granted durability and inalterability, silicate ornamental stones, often referred as “granites”, have been more exploited than ever. However, when used as exterior claddings, they are subject to the action of weathering agents. In order to simulate the effect of atmospheric water action on rocks, a Soxhlet extractor has been used, during a total time of 10000 hours. Experiments of the same kind have been performed by Simão (2003), Simão (2003a), Simão & Silva (2003), Galembeck *et al.* (2009), Costa *et al*. (2010) and Oliveira (2017),to evaluate the alterability of silicate ornamental stones, trying to find relationships between similar stones with different origins, and to help in the correct choose of applications for such materials. They also allow the identification of the way factors like mineralogy, texture, original state of degradation, climate condition and atmospheric pollutants contribute to mineral instability, and thus may change the physical characteristics and mechanical properties of rocks. When such features are known and considered by producers, architects, civil engineers and constructors, a correct choice for application can be achieved, with a good performance, both in terms of durability and safety. So, it is most useful that ornamental stone transformation industry gets information on the limitations that some kinds of exploited stone materials may exhibit as a result of the presence of minerals that will become unstable on specific environmental conditions.

## Petrography

Six “granites” have been selected for the present study, named after their origin location regions: the Monção (MnGr), the Vila Real (VRGr), the Castelo de Vide (CVGr) and the Monforte (MfGr) granites, the Odivelas gabbro (OdGb) and the Monchique Nepheline Syenite (MoNS).

MnGr is a porphyritic, medium- to coarse-grain, leucocratic, biotitic, pinkish (due to microperthitic microcline phenocrysts) calco-alcaline granite. VRGr is a two micas (mainly muscovite), sometimes porphyritic, medium- to coarse-grain, leucocratic, yellowish (due to strong alteration) granite. CVGr is a two micas (mainly biotite), porphyritic (microcline phenocrysts), medium- to coarse-grain, white granite. MfGr is an homogeneous medium-grain, leucocratic, reddish pink coloured (abundant pinkish feldspar) granite, with biotite and horneblende. OdGb is an homogeneous medium-grain, melanocratic, olivine gabbro, with greyish plagioclase and black pyroxene crystals. MoSN is a greyish, medium- to coarse-grain, leucocratic nepheline syenite, with prominent elongated tabular K-feldspar crystals and (sometimes well-developed) reddish brown nepheline crystals.

## Methodology

The Soxhlet extractor is used to simulate the action of atmospheric precipitation, in order to promote rocks and/or minerals leaching during a certain period of time. Water is initially distilled, and then evaporated and condensed, and finally it will circulate through the sample. This experiment will accelerate the natural alteration process and has been used in several types of rocks. The methodology is described by Aires-Barros (1991) & Simão (2003), according to these authors, the experiment simulates higher-temperature (60°) and more acidic rain than natural ones, humid atmosphere, hydrostatic level fluctuation, percolation through the porous rock-system and leaching and reprecipitation of materials. The studied rocks have been subjected to the action of a Soxhlet extractor, in which previously fragmented samples (about 25g each) suffer draining processes during 10 successive cycles, 1000 hours each. At the end of each cycle, percolation water has been analysed, so Si, Al, Fe, Mg, Ca, Na and K chemical mobility can be evaluated. Then, new, fresh, distilled water was added to the rock-system.

## Results

Major changes were found for OdGb and MoSN. At the end of the experiment, homogeneous, black, gabbro fragments exhibited reddish-brown patches, mainly composed by residual Fe-oxides, as a result of olivine and pyroxene alteration. By its turn, MoNS nepheline crystals turned from reddish-brown to light-yellow colour, with intense alveolization and disaggregation; pyroxene crystals got reddish-brown colouration and K-feldspar became lighter relative to the original colour. In granites, changes were less marked, mainly consisting in the alteration of feldspar and biotite on CVGr and VRGr. Here (VRGr), the enhancement of the original colour is the result of continuous degradation of biotite, with the resulting dissolution and leaching of Fe-oxides, and their precipitation on feldspar, which became altered. MnGr and MfGr were less altered, reflecting stronger resistance to the experiment conditions.

At the end of each cycle, water coming from the leaching of each rock-type was analysed by Atomic Absorption Spectrophotometry, and the results can be shown as charts (Fig. 1), in which Si, Al, Fe, Mg, Ca, Na, and K (recalculated as oxides), accumulated and absolute variations are expressed as ratios between each end-of-cycle and original values. These values reflect the ease of dissolution of each analysed element. Due to dissolution of

nepheline and feldspar, Na and K that more change show in MoNS, and Al values are due to nepheline dissolution. In OdGb, K, Na and Si are the most prominent elements in terms of change; although Si leaching tends to be slow, destruction of olivine and pyroxene crystals, as well as plagioclase leaching lead to significant values for the element. These effects in olivine grains were recorded in a more intense way by Simão (1996), Simão & Silva (1999) and Silva & Simão (1995). In granites, Na was the more mobilized element, due to feldspar leaching, followed by Si, and then by K, Mg and Ca. In all samples, Fe exists in very low amounts in solution, staying as residual deposit in the rocks, after oxidation and precipitation.

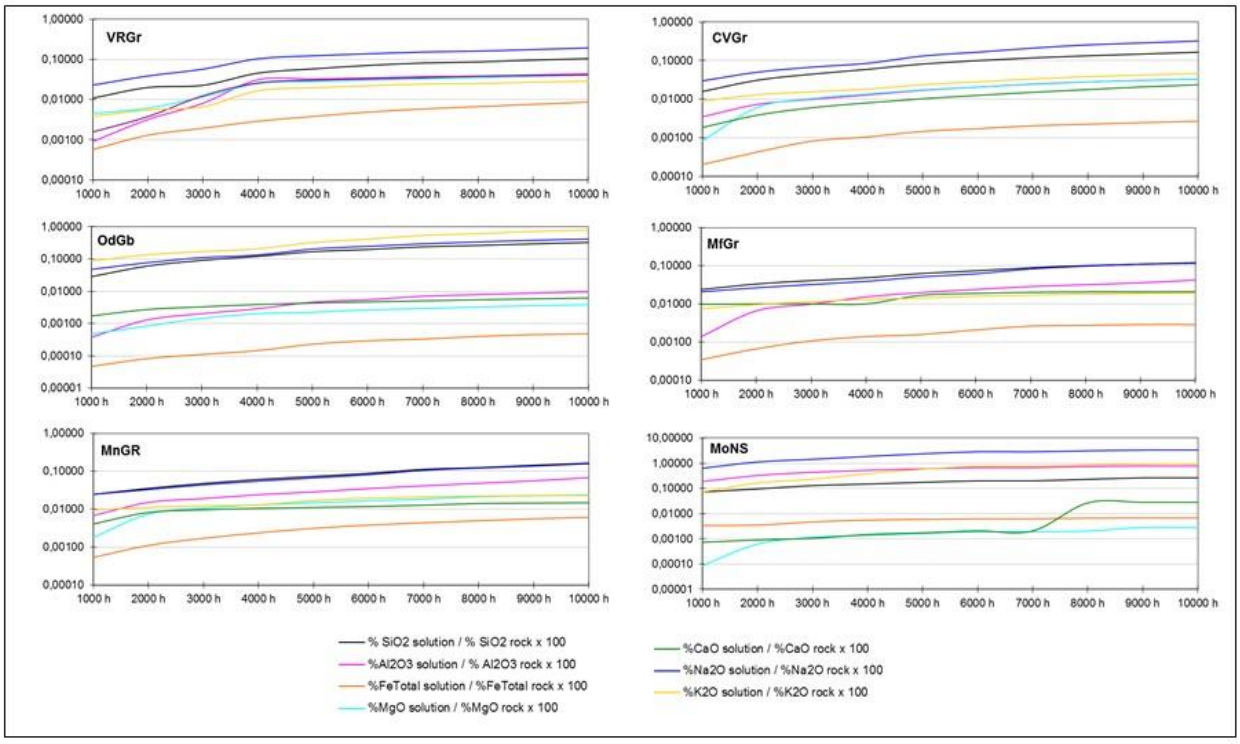


Fig. 1 Accumulated variation for Si, Al, Fe, Mg, Ca, Na and K (major elements oxides) in the cycles of the Soxhlet experiment waters.

## Conclusions

Alteration and alterability studies evaluated and compared the different rock-types behaviour when exposed to the action of conditions similar to atmospheric precipitation, and allowed the prediction of their behaviour in real natural conditions. Among the studied rocks, MoNS and OdGb include minerals with a high susceptibility to alteration, respectively nepheline and olivine, thus suffering more damages than granites, which gave a better response. In granites, it is possible to distinguish two main different behaviours: MnGr and MfGr are highly-resistant rocks, while CVGr and VRGr are less resistant. Apparently CVGr seems like a solid rock, but when exposed to disequilibrium conditions shows changes that decline its behaviour as an ornamental stone. VRGr is a rock that suffered significant meteoric alteration that diminished its response capacity and prejudiced its behaviour when exposed to new aggressive environments. This kind of alteration studies show that even apparently solid rocks may develop fast degradation patterns, when submitted to environments with specific characteristics. These changes are reflected in loose of quality,

both in aesthetic terms and physical-chemical behaviour, and thus this kind of studies must act as an indicator of the rock quality, being critical its inclusion in the characterization and recommendation (or not) of each ornamental stone, for a determined application.

## Acknowledgements

This work was supported by the investigation center GeoBioTec (Project UID/GEO/04035/2013), by the Project INOVSTONE 4.0 - Advanced Technologies and Software to the Natural Stones (Portugal 2020: LISBOA-01-0247-FEDER-024535, POCI-01-0247-FEDER-024535) coordinated by ACPMR - Associação Cluster Portugal Mineral Resources), DCT/FCT/UNL and FCT project CTM/10067/1998-PRAXIS XXI, PRODEP III, DGUA, Ferbritas, JMM, Granisintra, Mármores Longarito, Granitos de Maceira and Sienave.

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## About the author(s)

Joaquim Simão, Professor; Nuno Leal, Professor; Carlos Galhano, Professor.

University Nova de Lisboa, Department of Earth Sciences and GeoBioTec, Campus de Caparica, Almada 2829-516, Portugal. jars@fct.unl.pt; n.leal@fct.unl.pt; acag@fct.unl.pt.

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# Geochemistry and mineralogy to industry: from stone degradation to BIM

**José Mirão, Luís Dias, Inês Cardoso, Pedro Barrulas, Patricia Moita, António Candeias**

**Synopsis**

Mineralogy and geochemistry techniques are essential tools to understand building rocks degradation processes and to predict their future performance. These tasks are essential to reinforce Stone as a major building material that transmits values as tradition and glamour but also it is an easy maintenance material.For diagnosis and prognosis of stone behaviour, chemical and mineralogical composition must be understood together. This implies the use of multianalytical approaches comprising of complementary techniques like X-ray fluorescence spectrometry (XRF), Inductively coupled plasma mass spectrometry (ICP-MS), X-ray diffraction (XRD), micro-RAMAN and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS). Some case studies are presented. The role of geochemistry and mineralogy to understand the degradation of the stone and the influence in physical characteristics such as colour is underlined. The future consequences in the forthcoming use of Building Information Modelling (BIM) is referred as an opportunity and a threat.

**Keywords**

Mineralogy, Geochemistry, Degradation, Colour, BIM.

## Introduction

Building rocks as any rock is a natural material where the chemical elements are organized in different mineralogical phases. Therefore, their aesthetic characteristics, weathering behaviour and the possible uses in architectural structures are not independent of the chemical and mineralogical composition. Moreover, mechanical and physical properties of commercial stones are mainly outcomes of their composition modulated by fabric features.

Only a multi-analytical approach can provide all the information that is required to predict future performance of the natural stone or to obtain the best practices and products. The complexity of the processes demands specific equipment for its characterisation that includes X-ray fluorescence (XRF) or Inductively coupled plasma mass spectrometry (ICP-MS) for bulk chemical composition, X-ray diffraction (XRD), micro-RAMAN or Thermal Analysis for mineralogical composition and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS).

The HERCULES Laboratory (HERança CULtural, Estudos e Salvaguarda / Cultural Heritage Studies and Safeguard) is a research infrastructure from University of Évora, Portugal, devoted to the study and valorisation of cultural heritage and endogenous natural resources, focusing on the integration of physical and material sciences methodologies and tools in interdisciplinary approaches. In the last years the HERCULES Laboratory is developing intense research in the chemical and mineralogical characterization of stone materials and as well in the modelling of its degradation processes.

In order to underline the importance of geochemistry and mineralogy in the study of building rocks, several case studies are briefly discussed. The process of stone degradation at the UNESCO world heritage Alcobaça monastery shows the importance of environmental factors and of previous conservation actions. The production of natural analogue materials can protect and eventually, consolidate ancient stone employed in important heritage buildings. Recently, stone research at HERCULES Lab is focused in the discoloration of economically important marbles and lime stones and in the implementation of BIM (Building Information Modelling) in building stone industry.

## Stone degradation

The weathering of the oolitic limestone in the Cloister of "Hospedaria" of Monastery of Santa Maria of Alcobaça (Portugal) induced an important conservation action in 2010/2011. The present loss of cohesion (Fig. 1) stimulates the interest in the efficiency study of the previous treatment.

Fig. 1 Monastery of Santa Maria of Alcobaça (Portugal), left and loss of cohesion in the limestone in Cloister of "Hospedaria", right.

Non-treated, treated lime stones and efflorescences were sampled during the execution of the INOVSTONE research project (Cardoso et al, 2016). The presence of soluble salts was also confirmed by SEM-EDS and X-ray diffraction (XRD). Halite, sylvite and aptitalite was identified. The application of limewater results in the precipitation of calcium carbonate, less compact than the oolitic limestone. Traces of the consolidation treatment with ethyl silicate were detected due to the presence small particles composed of silicon, which have a different morphology compared with the small grains of quartz from the natural mineralogical composition of the limestone.

## Marble and limestone colour

Colour characteristics are major arguments that drive the decision making of architects and the worth of an ornamental stone. Therefore, research is being carried out to understand how the colour of each limestone and marble is naturally achieved, the

mechanism of colour alteration and discoloration and strategies for its mitigation (Dias et al., 2017)

The initial works were conducted in white, green and pink marble samples from Estremoz region. The colour was measured with a spectrophotometer Data Color CheckII Plus. The XRF data shows a pure calcium carbonate in the case of the white marble and several minor elements in the green and pink marble. The compositional mapping by SEM-EDS (Fig. 2) reinforce these results. It must be underlined that manganese enrichment was not identified in the pink marble by these techniques.

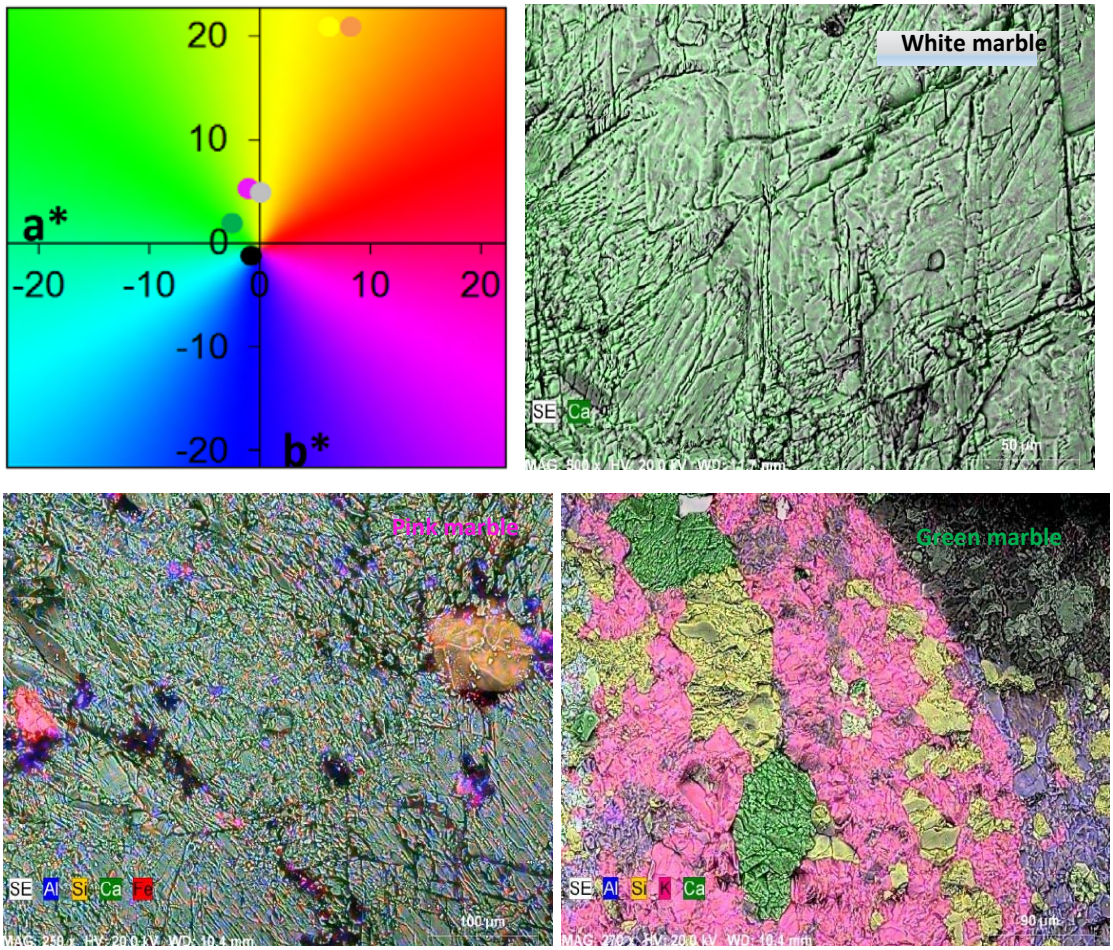


Fig. 2 Colour of the white, pink and green marbles and the compositional mapping by SEM. EDS in each sample.

## Building Information Modelling (BIM)

Building Information Modelling refers to all the information and its management covering the entire cycle of the buildings, from the project to its demolishing. The BIM implementation is guaranteed by the public decision of some European and North American governments. The 3D building information models will support all the major decision concerning the building. This means that the traditional procurement models will shift to "BIM procurement" (Silva, 2017) during the building design stage. Therefore, the existence of compatible stone BIM objects is essential for the survival of the stone industry. These objects must incorporate the seven dimensions of BIM and models for future stone maintenance must be created.

## Acknowledgments

This work was supported by European Union [project INOVSTONE4.0, E-Techstone and grant numbers POCI-01-0247-FEDER-003457, ALT20-03-0145-FEDER-000017, FCOMP-01-202-FEDER-013854]. Luís Dias and Inês Cardoso acknowledges Fundação para a Ciência e Tecnologia by the grants SFRH/BD/111498/2015 and SFRH/BD/99965/2014co-funded by European Social Fund (ESF) and MEC national funds. Hercules Laboratory is supported by Fundação para a Ciência e Tecnologia by the grants UID/Multi/04449/2013-POCI-01-0145-FEDER-007649

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### About the authors

José Mirão, Dr.

Sciences and Technology School, University of Évora, HERCULES Laboratory, Apartado 94, 7000 Évora, Portugal, jmirao@uevora.pt

Luís Dias

Sciences and Technology School, University of Évora, HERCULES Laboratory, Évora, Portugal, luisdias1234@gmail.com

Inês Cardoso

Sciences and Technology School, Évora, University of Évora, HERCULES Laboratory, Portugal, ineslemoscardoso@gmail.com

Pedro Barrulas, Dr.

Sciences and Technology School, University of Évora, HERCULES Laboratory, Évora, Portugal, pbarrulas@uevora.pt

Patricia Moita, Dr.

Sciences and Technology School, University of Évora, HERCULES Laboratory, Évora, Portugal, pmoita@uevora.pt

António Candeias, Dr

Sciences and Technology School, University of Évora, HERCULES Laboratory, Évora, Portugal, candeias@uevora.pt

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# Physical and petrographical characteristics of roofing slate litho types

**Víctor Cárdenes Van den Eynde**

**Synopsis**

Roofing slates are a group of natural stones of metamorphic origin. As the name suggests, these rocks are used for roofing, being the most important natural stones used for this purpose. The main property of these rocks is the occurrence of a continuous and plane cleavage, induced by low-grade metamorphism of pelitic sediments. This cleavage allows the rock to be split into thin and uniform shingles. There are four rocks that meet this definition: shale, slate s.s., phyllite and mica-schist. These rocks can also be separated by color: black, green and red. The color is the result of the mineralogy and the environmental conditions during the period when the primal sediment was deposited.

From a technical point of view, the mechanical and physical characteristics of roofing slates are defined by the petrography. This article reviews the petrographic characteristics of roofing slate lithotypes.

**Keywords**

Roofing slate, lithotype, phyllite, argillite, mica-schist

## Introduction

Roofing slates are a group of stones used in building since historical times (Cárdenes *et al.*, 2014). These stones have been profusely used in the historic architecture of many European countries, especially Germany, France and the United Kingdom. Today, Spain is the world's leading producer, followed by China and Brazil (Cárdenes *et al.*, 2014).

A roofing slate is any metamorphic rock displaying a continuous and penetrative cleavage enough to allow a homogeneous split for producing thin, flat and durable shingles. There are four main group of stones that can potentially be used for this purpose: low-grade slates (argillites), slates s.s., phyllites and mica schists. Other stones have been used for roofing, such as ultraphyllonites (Valentino, 2014), highly deformed lutites (Cárdenes *et al.*, 2015) or even sandstones (Hughes, 2003). However, these stones are always used in a very local context.

This article gives an overview of the petrographic characteristics of the roofing slate lithotypes described in the international classification for roofing slates (Cárdenes, 2016). The petrography affects several physical and technical properties: such as mineralogy, fissility, thickness, trimming, water absorption and flexural strength.

### Mineralogy

Since roofing slates come from the metamorphism of pelitic sediments, their composition is rather homogeneous for all the lithotypes. Main minerals are quartz, mica and chlorites, with secondary minerals depending on the lithotype (Cárdenes *et al.*, 2014). Mineralogy establishes the color (Cárdenes, 2016) of the roofing slate, and also the potential weathering. There are two groups of minerals potentially alterable, iron sulphides and carbonates. The alteration of iron sulphides produce oxidation, probably the main technical problem nowadays, and the alteration of carbonates, gypsification (Cárdenes *et al.*, 2012).

### Fissility

This is an essential property for a roofing slate. The rock must be able to split into flat, homogeneous shingles. These planes usually develop during the metamorphism ($S_1$), although some roofing slates are split by the sedimentation planes ($S_0$). The operation of splitting the shingles is done manually by specialized hewers, using a hammer and a chisel. For more than one hundred years, there have been attempts to mechanize this work (Dale, 1914), but the resulting product has never completely met industry requirements.

### Thickness

The minimum thickness of the shingles into which a slate can be exfoliated is one of the factors that define the quality. Smooth, fine-grained slates can be split into shingles with a thickness as little as 3 mm, while mica-schists are usually split into shingles of no less than 8–10 mm. The thickness is defined also by the market requirements. Very thin roofing slate shingles might not be appropriate for roofing, since they can be damaged by hail (Jenkins, 2008).

### Trimming

Trimming refers to the process of giving shape to the roofing slate shingles once they are split. This is performed during the fabrication process, to give shingles a standardized shape, and during the installation of the roof, when the slater has to adjust the shape of some shingles for endings, like valleys, hips or intersections (Menéndez-Seigas, 2007).

### Water absorption

Water absorption is defined as the percentage of its weight that a roofing slate absorbs during a standardized test. This test is found in the two main roofing slate standards, ASTM C121 and EN 12326 (Cárdenes *et al.*, 2016). This property is directly linked to durability and freeze-thaw resistance.

### Flexural strength

This is the response of the roofing slate shingle to a three-point flexural test, which gives the Modulus of Rupture, which depends in turn on the thickness of the shingle. The MoR is the highest stress borne by the shingle at the moment of its rupture (Cárdenes *et al.*, 2016) and is greatly influenced by the brittleness and crystallinity of the rock.

## Roofing slate lithotypes

Each of the roofing slate lithotypes defined in (Cárdenes, 2016) has its own petrographic characteristics, which define the physical properties of the resulting roofing slate shingles :

### Shale

Also known as argillite (O' Brien & Slatt, 1990) or low-grade slate (Cárdenes, 2016), these rocks are characterized by the incipient development of their slaty cleavage. About 10% of the estimated wordwide production of this rock is used as roofing slate, and it comes mostly from Brazil. Its cleavage is penetrative enough to allow splitting, but not enough to allow a good trimming on the roof, so the slater might have trouble during installation. The pore system is relatively high for this rock, and hence its water absorption is the highest among the four lithotypes, with values generally over 0.8%. This is due to the relative low crystallinity of the fabric of the rock (Table 1). The crystal growth associated with an increase

in crystallinity tends to fill in the pore system, reducing water absorption but increasing stiffness (Cárdenes *et al.*, 2016). There is no or very poor development of $S_1$ planes, splitting being usually carried out along the remaining $S_0$ sedimentary planes. The miscroscopic fabric is usually lepidoblastic (Fig. 1A).

### Slate

About 85% of world production of roofing slates are indeed slates. The intrinsic characteristics of this rock (fine grain, development of cleavage) make it perfect for roofing. However, other technical criteria need to be met in order to have an exploitable quarry (Cárdenes *et al.*, 2014). Regarding physical properties, slate's bending strength is generally the highest among the roofing slate group, in some cases reaching values as high as 80 MPa (Table 1). Trimming is considered to be perfect, especially in the black fine-grained slates from Central Europe and Spain. These slates can usually be split into shingles that are very few millimeters thick, keeping a smooth surface. The petrographic fabric ranges from lepidoblastic to porphyro-lepidoblastic (Fig. 1C).

### Phyllite

Phyllite represents the next stage in terms of increasing grade of metamorphism. This rock is not as abundant as the previous two, accounting for an estimated 2–3% of world production. The main outcrops are located in Argentina, Spain and the United States (Cárdenes *et al.*, 2014). From a physical point of view, the main characteristic is low water absorption. Other properties are very similar to those of slate, although this rock is more rigid, since it has a higher degree of crystallinity. The microscopic fabric is porphyroblastic (Fig. 1E). In some cases, the only way to distinguish it from slate is through microscopic examination. The occurrence of biotite marks the boundary between slate and phyllite.

### Mica-schist

This is the last rock in the metamorphic range that can be used as roofing slate. The shingles usually have rough surfaces, as a result of an increase in mineral size, which hinders the split operation. Today, most of the world's production (which accounts for 2–3% of roofing slate) comes from Scandinavia, although there are some outcrops of uncertain quality in India and China. Due to the coarse cleavage, the shingles are rather thick, with thicknesses usually greater than 8 millimeters. Because of this, the building structure has to support more weight than with other roofing slates. The values for mica-schist's bending strength are usually high, due to the thickness, since this value is calculated taking into account the total thickness of the shingle (Cárdenes *et al.*, 2016). The petrographic fabric is granoblastic-nematoblastic (Fig. 1G).

Table 1. Physical properties for the roofing slate lithotypes. These values are approximate for each lithotype and may vary greatly depending on the local quarry. The thickness column corresponds to the minimum for that type that is sold on the market.

| Lithotype | Fissility | Thickness | Trimming | Water absorption | Flexural strength |
|---|---|---|---|---|---|
| Shale | Medium-high | >5 mm | Poor | >0.8% | 40 MPa |
| Slate | High | >3 mm | Good | >0.6% | 80MPa |
| Phyllite | High | >4 mm | Medium | >0.4% | 60 MPa |
| Mica-schist | Medium-low | >8 mm | Poor | >0.3% | 60 MPa |

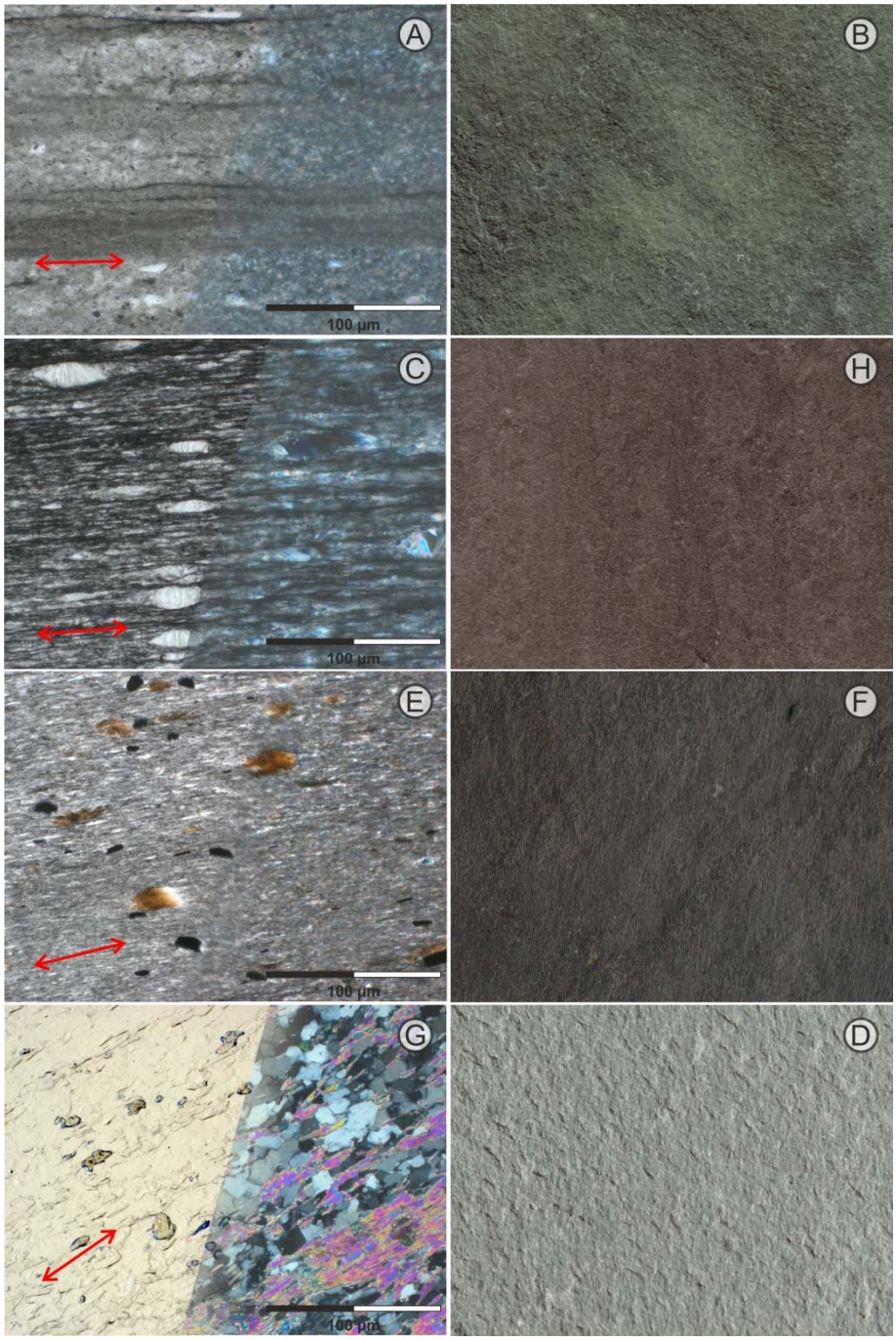


Fig. 1 Petrographic (left column) and hand specimen images (right column) of the lithotypes of roofing slates. In the left column, the right part of the picture uses crossed polarizers. The red line marks the direction of the cleavage.

## Conclusion

The petrography of roofing slates is closely linked to their physical properties as construction materials. The greater the degree of metamorphism, the more difficult the split operations, but the water absorption decreases, which improves the durability of the shingle. These and other properties can be deduced from petrographic analysis. Thus, it is necessary to incorporate petrographic description into test results; otherwise the information provided by these tests is liable to be misunderstood.

## Acknowledgements

The author would like to express his gratitude for the IEF Marie Curie Grant 623082 TOMOSLATE from the European Research Council (ERC) and for the support given by the International Geoscience Programme project IUGS-UNESCO IGCP-637. Thanks also to language editor Deirdre Casey for her review of the manuscript.

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## About the author

Víctor Cárdenes Van den Eynde

University of Oviedo, Department of Geology. Address: Jesús Arias de Velasco s/n, 33005, Oviedo, Asturias, Spain. Email: víctor@valdeorras.com

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Imperial Blue quartzite characterization purposing the removal of stains in natura

**Juliano Tessinari Zagôto, Rogério Danieletto Teixeira, Bruno do Vale Miotto, Bárbara Gonçalves Rocha, Heloíse Saick de Paula**

**Synopsis**

The blue quartzite of the *Serra do Espinhaço*, Central South Region of Bahia is marketed under different commercial names, such as: "*Azul Imperial*", "*Azul Boquira*" and "*Azul Macaúbas*". The bluish color, which generates the exotic features to the rock, comes from the minerals rich in boron, mainly the dumortierite. This ornamental stone has high market value and, currently, has a great demand for this type of rock, mainly for export. However, in some portions of this stone pit, there are stain spots of yellowish to reddish tons that cause the final price of the benefited rock (slabs) to lose up to 40% of its market value. Thus, the purpose of this work aims to characterize this lithology in order to identify the minerals that cause the stains and provide a chemical treatment capable of returning the market value to the rock. For this purpose, characterization tests were used, such as: petrographic description of rock samples, X-ray fluorescence (FRX) and X-ray diffraction (XRD). Analyzes showed a presence of minerals containing Iron (Fe), Aluminum (Al) and Titanium (Ti), possible causes of such changes in rock coloration.

**Keywords**

Ornamental stones: Technological characterization; Quartzite; Removal; Stains.

## Introduction

Ornamental stones according to the standards of ABNT – Brazilian Association of Technical Standards (2013), ornamental rocks constitute material natural stone used in internal and external claddings, structures, architectural composition, decoration, furniture and funerary art. The chromatic pattern is the main attribute considered for the commercial qualification of an ornamental rock and commercially the main ornamental rock groups are the granites and marbles.

Imperial Blue Quartzite is considered as a valuable ornamental rock. Dumortierite and kyanite, the most abundant color-causing minerals in its composition, they are mostly concentrated along millimeter-wide. (Evangelista and Filho, 2012). Near Imperial Blue Quartzite occurence, there are other lithology outcraps with the same yellowish to reddish-brown spots occurrence, which low the value of this kind of ornamental rock in the market. So the main goal of this research is identify the minerals and find out ways to remove the spots of the surface of the rock.

## Materials and Methods

The research carried out, from the point of view of its nature, can be classified as applied, because it aims to find out a methodology for the removal of spots in the imperial blue quartzite, from a demand of a rock company of the city of Nova Venécia / ES.

The approach to the proposed problem was quantitative, since the methanesulphonic acid in the rock in question over a period of 216 hours. From the point of view of their objectives, this was an explanatory type of research, since was intended to identify and relate methanesulfonic acid ($CH_3SO_3H$ - 7 – 10%) to exposure time. As for the technical procedures used, it was experimental research, because the variables were analyzed as time

of exposure (Gil, 1994). The tests were carried out by the laboratories of the Mineral Technology Center (CETEM/NRES - Cachoeiro de Itapemirim - ES) and Institute of Technological Research (IPT - São Paulo - SP). After the characterization test, one sample (size 10cmx10cm, fig.5) with stains was used to methanesulfonic acid reaction cycles as in Table 1.

Table 1 – React cycles methanesulfonic acid (7-10%) on the rock sample.

| CYCLE | TIME (h) | EXPERIMENTAL CONDITIONS* |
|---|---|---|
| I | 24 | uncovered |
| II | 48 | covered |
| III | 120 | covered |
| IV | 144 | uncovered |
| V | 216 | covered |

***Experimental Conditions:** In the uncovered condition, methanesulfonic acid was applied on surface of the sample and left exposed to the environment. **Covered condition reproduced conditions similar to those used in industry in this kind of case.** For this, the sample was covered with plastic.

## Results and Discussion

### 3.1. Petrographic Description

Macroscopic petrographic analysis described the rock as a blue quartzite with a thin equigranular textural and fine / medium grain, with grains of up to 1 mm. Also presented as minerals secondary brownish oxides in brownish and with clear evidence of percolation, sometimes intra-stratum and sometimes out of order the foliation. Mineralogical composition of the rock can be observed in the Table 2.

Table 2 - Mineralogical composition of the rock.

| MINERALOGICAL COMPOSITION | PERCENTAGE (%) |
|---|---|
| Quartz | 75 |
| Kyanite | 15 |
| Muscovite | 7 |
| Dumortierite | 3 |

Microscopic petrographic analysis classified the rock as muscovite kyanite quartzite (Best, 2003). The most important minerals for this work are described microscopically below:

- Dumortierite: very strong pleochroism between shades ranging from deep blue to colorless, lamellar habit with poorly developed cleavage planes. (Figures 1 and 2).

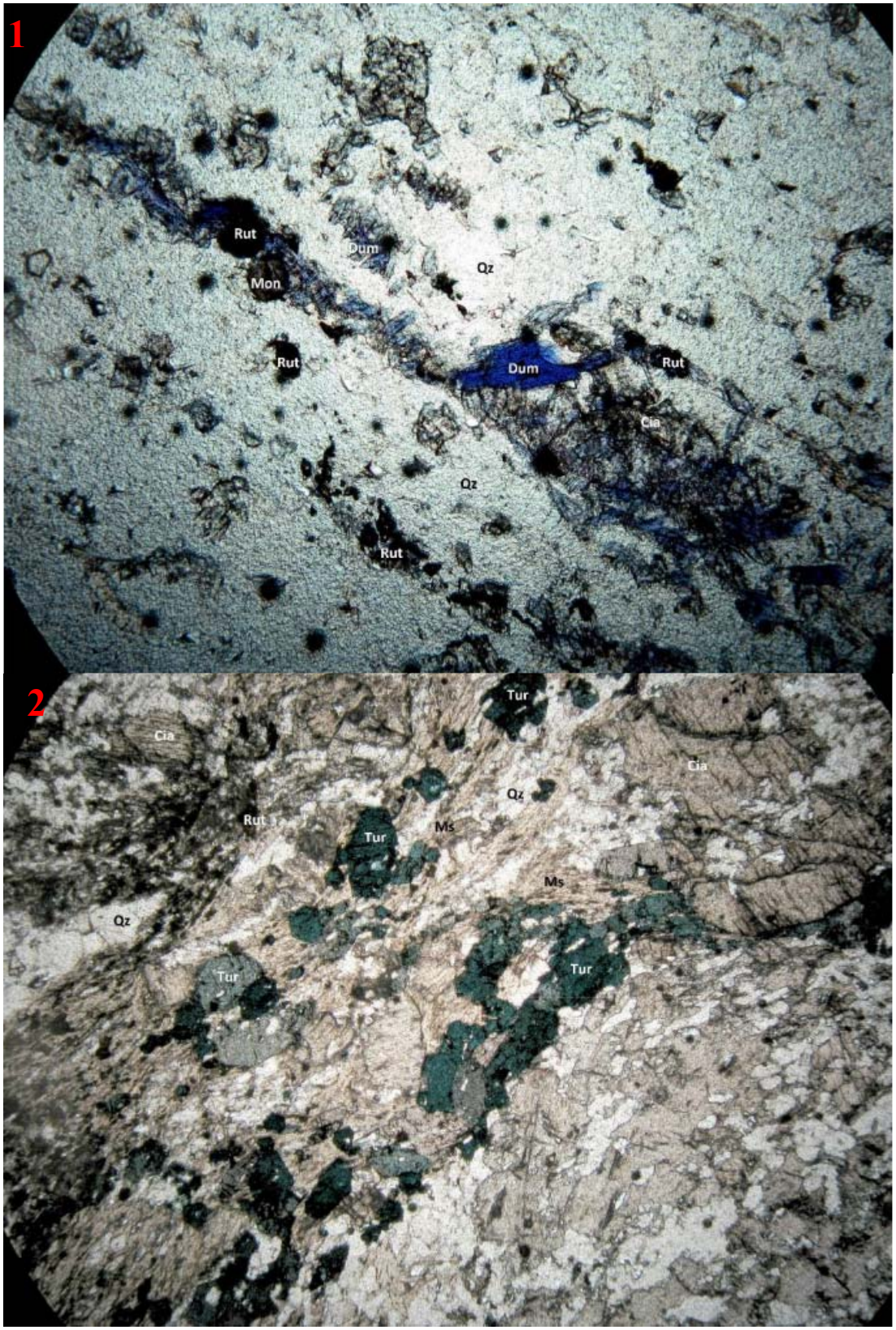


Fig. 1 and 2 - Photomicrography of the sample in light natural and plane polarized light at 10x magnification, respectively. Dum = dumortierita; Tur = tourmaline; Cia = kyanite; Rut = rutile; Qz = quartz; Ms = muscovite; Mon = monazite.

- Rutile: micrometric xenomorphic crystals occur exclusively in hydrothermal vowels composing the association described above. (Figure 3).

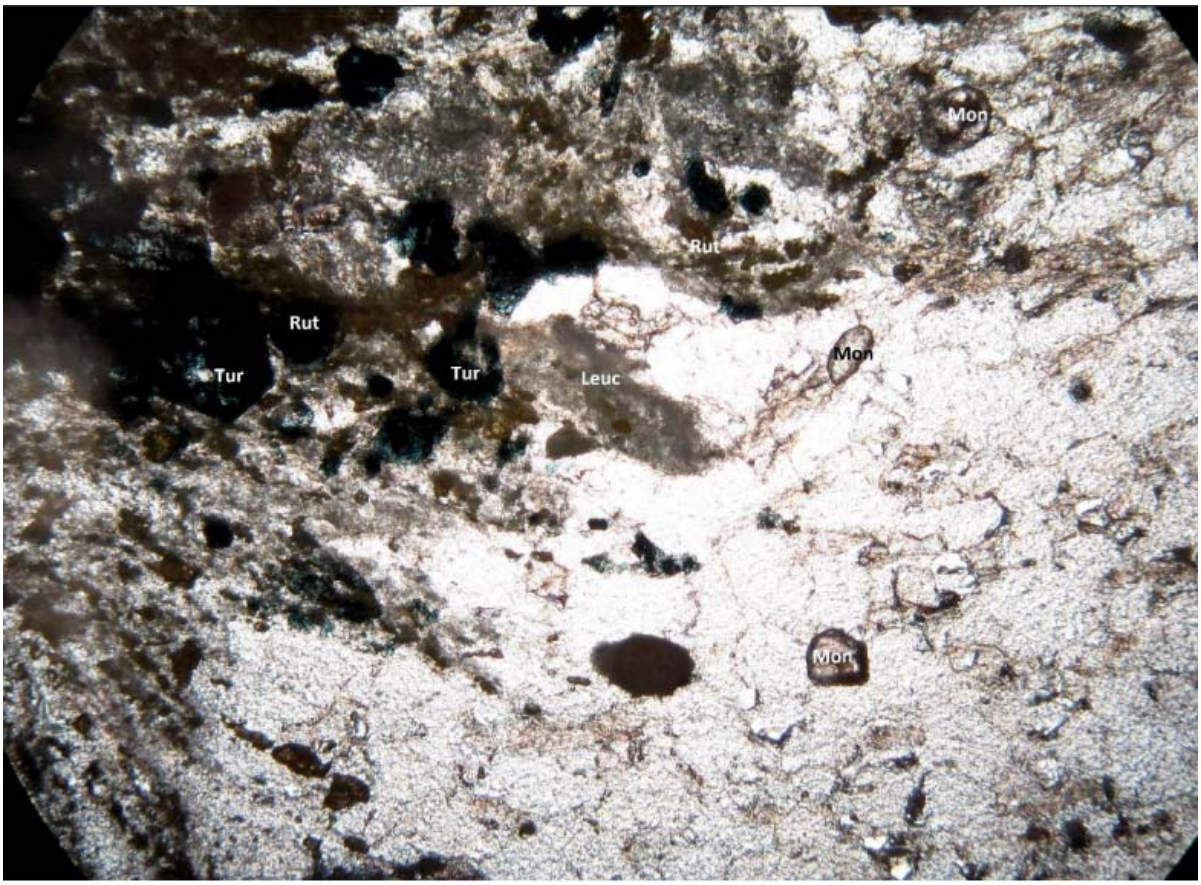


Fig. 3. Photomicrography of the Imperial Blue quartzite showing the contact between a hydrothermal venule with the quartzite matrix. Note the presence of rutile-associated tourmaline, monazite and muscovite. Tur = tourmaline; Rut = rutile; Qz = quartz; Mon = monazite; Leuc = leucoxênio.

### 3.2. X-Ray Fluorescence (XRF)

Results of the chemical analysis of X-ray fluorescence (XRF), performed through the AXIOS Panalytical model spectrometer, can be observed in the Table 3.

Table 3. Chemical X-ray fluorescence analysis (XRF).

| CHEMICAL COMPOSITION | $Al_2O_3$ | $SiO_2$ | $P_2O_5$ | $K_2O$ | $TiO_2$ | $Fe_2O_3$ | PPC |
|---|---|---|---|---|---|---|---|
| PERCENTAGE (%) | 7.0 | 90.5 | 0.15 | 0.78 | 0.32 | 0.20 | 0.60 |

High percentage of $SiO_2$ occurs because it is a quartzite and that the Fe and Ti present in the composition of the rock are the main responsible for yellowish to reddish-brown spots in Imperial Blue Quartzite.

### 3.3. Reaction Cycles of Methanesulfonic Acid (7 - 10%)

The applications of methanesulphonic acid in the spotted rock attempted to reproduce in the laboratory the procedures performed in the ornamental stone industry. It is an unprecedented work, in addition to the difficulty of finding references in the area, the methodology of covering or not the sample followed a determined by the researchers. The effects of acid action on the rock can be observed in Figure 5.

(a) (b)

Fig. 5. Comparative photos of the action of methanesulfonic acid on the imperial blue quartzite surface.

Figure 5a shows the previously stained rock before the application of methanesulfonic acid. After 16 hours of the action of methanesulfonic acid as cycles under experimental conditions (uncovered and covered), it is possible to observe a visual decrease in the intensity of the spotting (Figure 5b). Besides, it can be seen that the acid etching resulted in bleaching of the spots, but not in the total removal of the spots. It is noted that other tests are ongoing to improve stain removal results.

## Conclusions

The alteration of the minerals releases Ti and Fe ions that generate products of reddish-brown coloration, which, viewed under a microscope, resemble leucoxene, which are those responsible for the spots found in the imperial blue quartzite.

Methanesulfonic acid demonstrated potential to remove stains on rock studied.

## Acknowledgments

The authors gratefully acknowledge the Federal Institute of Espírito Santo (Ifes) - Campus Nova Venécia, Graniti Indústria Comércio e Exportação LTDA, BASF and CNPq.

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## About the authors

ZAGÔTO, J.T.[1]

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. tessinari@ifes.edu.br.

TEIXEIRA, R.D.[2]

Federal Institute of Espírito Santo, Environment Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. danieletto@ifes.edu.br.

MIOTTO, B.V.[3]

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. bruno.miotto@ifes.edu.br.

ROCHA, B.G.[4]

Federal University of Vale do Jequitinhonha e Mucuri, Mining Department, BR-122, Janaúba - MG, 39440-000, Brazil. barbara.rocha@ufvjm.edu.br.

DE PAULA, H.S.[5]

Federal Institute of Espírito Santo, Mining Student, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. helosaick@hotmail.com.

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# National inventory of historical quarries associated with the construction of the Spanish architectural heritage

**Enrique Álvarez Areces, José Manuel Baltuille Martín, Jorge Fernández Suárez, Javier Martínez-Martínez**

**Synopsis**

Spain has a rich architectural heritage, being recognised as the second country in the world with the largest declared World Heritage Sites that includes 44 protected monuments. This built heritage needs plans for its study and conservation. In this sense, the characterization of building stones and the localization of the historical quarries becomes essential in order to establish adequate measures of preventive conservation. Moreover, this kind of studies contributes to increase the knowledge of monuments as well as the relationship between building materials and the physical natural environment. Currently, the Geological Survey of Spain (Instituto Geológico y Minero de España, IGME) is developing the Project: *National Inventory of Historical Quarries associated to the Architectural Heritage.* The first part of this extensive project has been developed on the Extremadura Region (West Spain), 492 historical buildings have been studied and 440 historical quarries have been located. The examined area represents 8.2% of the total surface of the country. The sequent action programmed inside this global project will be developed in the immediate future and will be focused on the localization of the historical quarries of the Andalusia Region. Andalusia represents 17.3% of the total surface of Spain. It means that for the upcoming years, the 25% of the historical quarries of Spain will be located . The whole obtained data set will be stored in a database and in a geographic information system.

**Keywords**

Historical quarries, architectural heritage, natural stones, inventory, Spain

## Introduction and background

Spain counts on a numerous Architectural Heritage because of all the different cultures which have inhabited the Iberian Peninsula. From prehistory to the contemporary Kingdom of Spain, the territory was influenced by many cultures throughout its history: Celties, Phoenicians, Romans, Arabs, Jews, Christians, etc. This fusion of cultures remains in the conservation of a built historical heritage through a large variety of architectural styles and built heritage declared as an Asset of Cultural Interest, a National Monument or a World Heritage Site, being the second country after Italy with the largest number of testimonies included in the list of the World Heritage Sites, which amount to a total of 44 examples.

In order to conserve this Heritage, it is necessary to accomplish a work of analysis and evaluation. In this sense, Geology, through the study and characterization of rocks and materials used in architectural construction, allows the identification and interpretation of the processes of degradation suffered and the study of pathologies (Esbert et al. 1997) and damages as well as the suggestion of the adequate measures of protection.

Being aware of the importance of the study of construction materials, the Geological Survey of Spain (Instituto Geológico y Minero de España, IGME) has lead the Project *National Inventory of Historical Quarries associated with the Architectural Heritage* (INCHaPA, acronym from project title in Spanish) since 2014 with the aim to localize the historical

quarries and characterize the stone materials used in construction. The localization of quarries allows to obtain samples of the original rock to be used in future works on the architectural heritage. Furthermore, it offers data for the study of the building, its construction process, the planning of works and the relationship with the physical surrounding, which constitutes an essential information to get to know the construction of historical buildings (Fig.1).

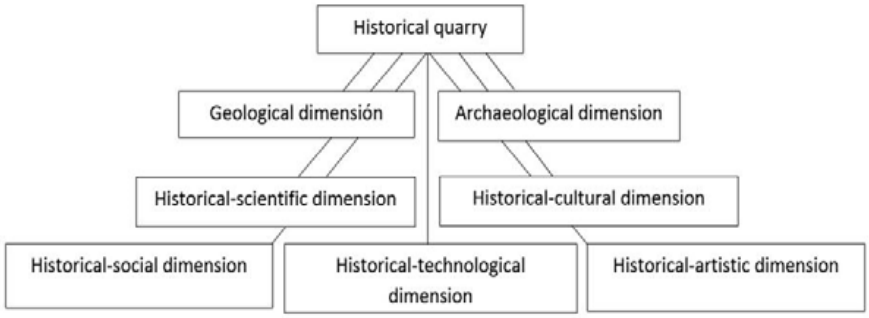


Fig. 1 The localization of historical quarries shows information in different areas of knowledge and the relationship between the building and the quarry offers very useful data for the analysis of the built heritage.

## Methodology for the localization of historical quarries

The localization of historical quarries implies a necessary methodology of work, which consists of a research on documentary sources (historic, architectural, geological, etc.), processing work (aerial pictures, elaboration of technical records), laboratory work (petrographic studies, characterization tests and geochemical analysis) and field survey (sample collections of building-quarry, cartography and quarry characterization) (Fig.2). Once the quarry has been localized, it is necessary to accomplish the assessing studies to evaluate those samples which, derived from their importance, must be protected, estimating their influence on the built historical heritage, the peculiarity of the exploited resource, the number and conservation state of the tool marks, as well as other additional parameters, and all that with the final aim of establishing a specific authority of protection for these spaces.

## Database and INCHaPA Geographic Information System

The data set is included in a database that stores heritage, geological and technological information, as well as a geographic information system where the extraction marks, the exploitation areas and quarries are georeferenced. These two instruments will be technically very useful for professionals on the natural stone sector and the preservation of architectural heritage; and scientifically for researchers of other scientific disciplines (Baltuille et al. 2015).

## Discussion and results

For the development of our Project *National Inventory of Historical Quarries associated with the Architectural Heritage* (INCHaPA), we selected the Autonomous Community of

Extremadura which is located at the Southeast of the Iberian Peninsula with an extension of 41,634 square kilometres, which corresponds to 8.2% of the national Spanish surface. Within this context, it was accomplished the study of a total of 492 historical building catalogued as an Asset of Cultural Interest and/or Defence Architectural Heritage. 440 historical quarries were localized, 211 of them in the province of Cáceres and the other 229 in the province of Badajoz (Tab.1).

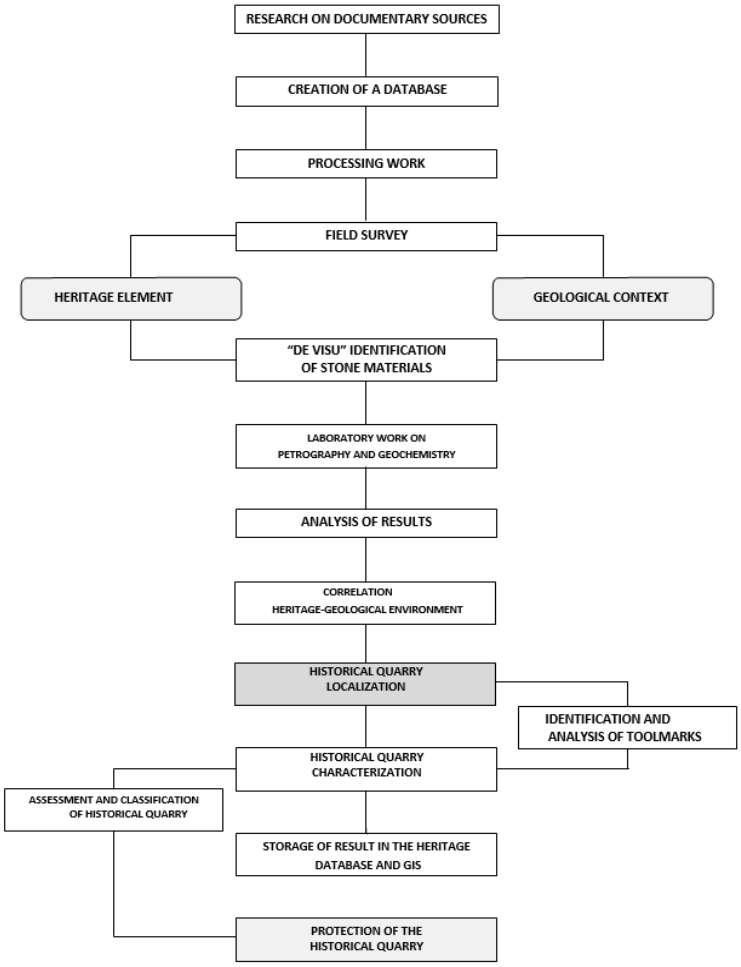


Fig. 2 Methodological diagram for the localization of Historical Quarries associated with the Architectural Heritage.

Most quarries localized correspond to wide areas of granite exploitation where tool marks for the extraction of blocks and all kinds of imprints related to the extraction activity have been identified and georeferenced. Georeferencing of these marks allows the delimitation of extraction areas and thus, gaining further knowledge for the planning of works in the historical quarry. With of this body of information, in subsequent phases of the project, it will be possible to define the territorial influence of certain stone production areas in the past and, therefore, being able to understand the construction of historical buildings in the region through the means of communication and the vectors of flow concerning the transportation of stone (Álvarez Areces et al. 2017).

Table 1. Synthesis of the results of the Inventory of Historical Quarries in Extremadura

| Province | Extension ($Km^2$) | Monuments (units) | Number quarries | Lithologies |
|---|---|---|---|---|
| Cáceres | 19,868 | 252 | 211 | Granite, quartzite, grauvaque, slate, limestone |
| Badajoz | 21,766 | 242 | 229 | Granite, quarzite, grauvaque, sandstone, limestone, marble |
| Total | 41,634 | 492 | 440 | |

Note: Data obtained from the Project INCHaPA, IGME (2017).

Fig. 3 Cathedral of Plasencia (Cáceres) and historical quarry "Virgen del Puerto" in Plasencia (Cáceres).

In the future, it will be accomplished the studies in the Autonomous Community of Andalusia, located at the South of Spain with an extension of 87,268 square kilometres, which represent 17.3% of the total extension of the country.

## Conclusions

The *National Inventory of Historical Quarries associated with the Architectural Heritage* (INCHaPA Project) developed by the Geological Survey of Spain (Instituto Geológico y Minero de España, IGME) is focused on the location and study of the historical quarries associated with the Spanish architectural heritage, as well as the petrographic characterization of the building rocks. Spain is one of the countries with the largest number of historic and architectural heritage built, and consequently, this project will be carried out sequentially. The first step of this global project has been developed on the Extremadura Region (West Spain), locating and studying a total of 440 historical quarries. The sequent action programmed inside the INCHaPA project will be developed in the immediate future and will be focused on the localization of the historical quarries of the Andalusia Region. At the end of this second step, almost 25% of the Spanish territory will have been studied.

## Acknowledgments

The authors are grateful to the project IGCP-637 for the financial support to participate in the Global Stone Congress 2018 with this contribution.

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## About the authors

Enrique Álvarez Areces, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Ríos Rosas, St. 23, Madrid 28007, Spain. e.alvarez@igme.es.

José Manuel Baltuille Martín, MSc

Geological Survey of Spain (IGME), Geological Resources Department, Ríos Rosas, St. 23, Madrid 28007, Spain. jm.baltuille@igme.es. Unit of Natural Stone and Monumental Heritage.

Jorge Fernández Suárez, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Matemático Pedrayes, St. 25, Oviedo (Asturias), 33005, Spain. j.fernandez@igme.es.

Javier Martínez Martínez, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Ríos Rosas, St. 23, Madrid 28007, Spain. javier.martinez@igme.es.

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# Historic natural stone: a new market opportunity in the field of heritage restoration and new construction

**Jorge Fernández Suárez, José Manuel Baltuille Martín, Enrique Álvarez Areces, Javier Martínez-Martínez**

**Synopsis**

The development in recent years by the Geological Survey of Spain (Instituto Geológico y Minero de España - IGME) of the National Inventory of Historical Quarries associated with Architectural Heritage (*Inventario Nacional de Canteras Históricas asociadas al Patrimonio Arquitectónico - INCHaPA*), offers new possibilities for the advance of extractive activities in the natural stone sector. Being able to offer the original material in the restoration works of the wide and varied architectural heritage of the Spanish territory, assumes the reduction of future problems in the natural development of the building. But aside from this destination of the material, this inventory of historical quarries allows us to improve our knowledge and including the possibility of future exploitation of totally unknown historical sites. In this way an important market in natural stone is opened, focused on the production of a material to which, in addition to the quality and functionality, a historical component differentiable from the rest is added.

**Keywords**

Historical quarries, Historical Natural Stone, Spain, Architectural heritage.

## Introduction

The production of natural stone in Spain has been one of the sectors that has been most affected by the global economic problems suffered in recent years (Fig. 1). The decline has been constant since 2008, although prospects indicate that this fall has bottomed out and remains stable. But it is during economic situations that new opportunities for the development of industries, market expansion and the search for new aims can arise.

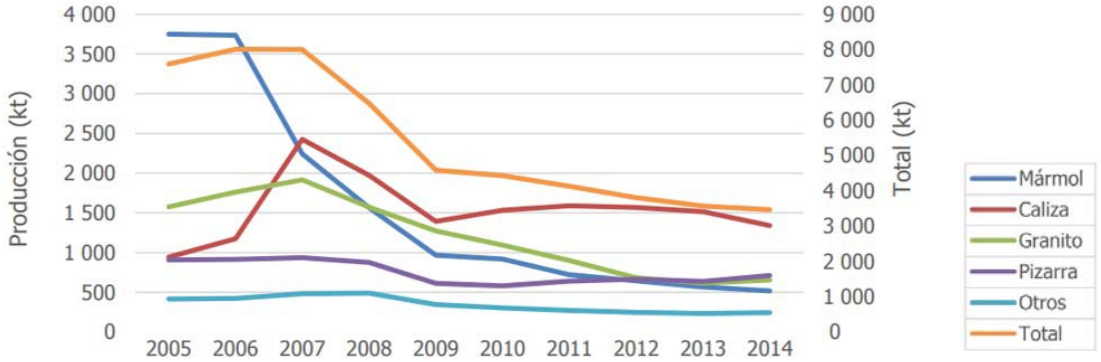


Fig. 1 Evolution of the production of different types of natural stone in Spain. Period 2005-2014. Source: *Panorama Minero*. *Instituto Geológico y Minero de España*.

Taking advantage of the recognized experience in the field of ornamental rocks of IGME, and that most of the studies that were carried out on stone and architectural heritage focused, mainly, on topics related to the pathologies of the stone. It was decided to develop its own line of research, differentiated from those of other centers and teams: "the Natural Stone as an essential element of the monumental heritage and location, characterization

and preservation of historical quarries and extractive areas used in the construction of the national architectural heritage". The main objective is to locate and characterize the historical quarries associated with the construction of architectural heritage; to subsequently preserve and value them, which may entail, among other actions, the exploitation of them. In 2014 IGME started a national project, the National Inventory of Historical Quarries associated with Architectural Heritage (*Inventario Nacional de Canteras Históricas asociadas al Patrimonio Arquitectónico - INCHaPA*), in collaboration with the autonomous communities.

## The National Inventory of Historical Quarries associated with Architectural Heritage (INCHAPA) as a basis for identifying new natural stone

The National Inventory of Historical Quarries associated with Architectural Heritage (INCHaPA) is an ambitious project that systematically aims to cover the national territory in the medium term. Including with this, apart from the necessary collaboration of the Autonomous Communities, with entities and research organizations, universities, associations, etc., thus being able to obtain a systematic cartography of historic quarries at a national level, and whose data of patrimonial, geological and Historical data are loaded into a database associated with a GIS. Regardless of its use for tourism or ethnographic purposes, one of the objectives of this project is the improvement of the rocks used in historical buildings.

Fig. 2 Left: Marble block from the Macael quarries, exploited from Roman times. Right: Gneis from the quarries of Aceuchal (Badajoz), used only at the end of the 18th century.

Throughout the centuries a great number of civilizations have left their mark on the territory that now includes Spain in the form of numerous buildings that constitute the rich architectural heritage of this country. This required the exploitation of natural stone deposits, some of which have continued to provide building materials over the centuries (Fig. 2, right).

The quarries of Macael (Almería), Alconera (Badajoz), Coto Pinoso (Alicante) or Tortosa (Tarragona) are well known worldwide. These quarries have supplied material for the construction of a large number of monuments and are still in use today.

Table 2. Some examples of historical natural stones of Spain.

| Historic Quarry | Province | Stone | Operating period |
|---|---|---|---|
| Macael | Almería | Marble | Roman -Today |
| Alconera | Badajoz | Marble | Roman -Today |
| Coto Pinoso | Alicante | Marble | Roman -Today |
| Tortosa | Tarragona | Marble | Roman -Today |
| La Tablada | Badajoz | Granite | Roman - Medieval |
| El Medol | Tarragona | Limestone | Roman |
| Cartagena | Murcia | Limestone | Roman |
| Cueva de la Campsa | Almería | Limestone | Arab |
| San Cristobal | Cadiz | Limestone | Medieval |
| Aceuchal | Badajoz | Gneis | Medieval |
| Hontoria | Burgos | Limestone | Medieval |
| Boñar | León | Dolomite | Medieval |

Other quarries, in spite of being known and having played an important role in the past, are not exploited at present many of them are consideres as archaeological sites. This is the case of the Roman quarries of El Medol (Tarragona), Cartagena (Múrcia) or the quarries of the Caliphate period in Almería.

However, there are a large number of historic quarries that were not known, established in unexploited deposits or exploited in pre-industrial times, which have emerged during this study and which constitute the majority of the quarries that make up the rich mineral heritage of natural stone of Spain. An example of this type of exploitation is the quarry of Aceuchal (Badajoz), used at a specific moment at the end of the 18th century, and not exploited since then (Fig. 2, left).

For the moment, in addition to the quarries and historical exploitation areas located in a timely manner in other studies, the best known area is in Extremadura, the autonomous community of Spain, which offers important materials for future use under the name of historical stone.

## Historical quarries, a new business opportunity in the world of natural stone

First of all, it is important to preserve for the future the vestiges of historical exploitation located in relation to the architectural heritage of Spain. To preserve these extractive areas, IGME proposes, to the competent administrations, the need to create a specific legal protective structure for them. Its specificity is based on the fact that, when there is a need to intervene in the heritage property and use the original rock, and this is not located only in the quarry area, this material can be extracted from it, defining protection perimeters for the preservation of historical extractive brands.

But outside these protected areas, with concrete feasibility studies carried out by professionals from different fields of research, the exploitation of natural stone could be carried out, obtaining materials that could be considered as "Historical Natural Stone", having been materials previously used in the construction of Spanish heritage. This term is similar to others previously used, such as "vernacular stones", "strategic stones", "sourcing stones", "Global Heritage Stone" or "heritage stone". This partial and controlled reopening of historical quarries is something that has been claimed in other countries for years, as in England with the BRITPITS and the English Strategic Stone Study or even at European level with the Global Heritage Stone Group.

Both the well-known quarries not exploited and the unknown quarries constitute an important opportunity to use material for replacements in buildings that have been built with them in the past; for future constructions that will integrate harmoniously in the historic nuclei of Spanish cities and towns without losing homogeneity or historical criteria, also avoiding incompatibilities with the original material, sometimes caused by substitutions with foreign material; or in future constructions that want to be supplied with materials with the addition of historical tradition (Tab 1).

From the point of view of geology, these studies are aimed at locating the identical facies within the granitic massif or the concrete seam within a sedimentary formation. Through comparative petrographic and geochemical studies between the rocks that constitute the heritage and those of the outcrops, a correlation can be established and define exploitation areas that do not endanger the deposits exploited in the past.

## Conclusions

The study of historical quarries associated with heritage is today an essential element for the better knowledge of architectural and monumental heritage works. To your interest, from the constructive point of view (facilitating rehabilitation with the original material), technology (extraction tools and methodologies), ethnological and socio-economic (the quarries as historical poles of social-regional development), we must add the opportunity offered by the exploitation and commercialization of the "Historical Natural Stone".

The need to create a legal structure to protect the vestiges of historical exploitation, while pointing out the areas with the greatest possibility of industrial exploitation in areas that do not affect historic sites, can be covered with the realization of specific studies and detailed, once introduced by a series of multidisciplinary criteria.

The future establishment of a differentiating stamp that attests to the historical importance that this natural stone has had in the history of the construction in this country, would be a great advance in the impetus that this new product can offer to an increasingly homogeneous and demanding market of differentiating elements that provide added value.

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## About the authors

Jorge Fernández Suárez, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Matemático Pedrayes 25, Oviedo 33005, Spain. j.fernandez@igme.es. Geologist.

José Manuel Baltuille Martín, MSc

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Ríos Rosas 23, Madrid 28007, Spain. jm.baltuille@igme.es. Geologist.

Enrique Álvarez Areces, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Ríos Rosas 23, Madrid 28007, Spain. e.alvarez@igme.es. Geologist.

Javier Martínez Martínez, PhD

Geological Survey of Spain (IGME), Geological Resources Department, Unit of Natural Stone and Monumental Heritage, Ríos Rosas 23, Madrid 28007, Spain. javier.martinez@igme.es. Geologist.

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# Portuguese marbles in history of architecture: new perspectives

**Carlos Filipe, Armando Quintas**

**Synopsis**

In this presentation, we seek to disseminate a study in the field of Social and Human Sciences on the Heritage and History of the Marble Industry (PHIM), whit news approaches on the use of marbles in the identified architectural elements, in cities and towns of Portugal, in particular at Alentejo province.

The paper is divided into two parts: firstly, is about the objectives of the project and their methodologies used throughout the research and the reasons that led to the study of the relationship between the Marbles of Estremoz and the urban architecture buildings from the 16th century. The second reason, are rehearsing some parallels with applications abroad from the internalization of this economic activity, identifying destinations for the export of Portuguese marble.

**Keywords**

Marble, Portugal, Alentejo, History, Architecture

## Introduction

The study about marble has been developed since 2012, at the Center of Studies – CECHAP, by a group of researchers in the fields of History, Archaeology and Digital Humanities, whit the scientific coordination of the research academic centers of Universidade de Évora, Faculdade de Letras of Universidade de Lisboa, the Universidade Nova de Lisboa and ISCTE-Instituto Universitário de Lisboa.

The goals of the project are the study of the ornamental stone industry, in particular the marble of Estremoz Anticline, through history, industrial archaeology, the processes of technical and technological evolution, social issues and the economic relation whit the territory, including the counties of Borba, Estremoz and Vila Viçosa. The research project has also sought to establish the relationship between the natural resource and the evolution of architecture and urbanism.

It is in the context of this research, which seemed pertinent to us, to make known the progress of this study, seeking to highlight the importance of the application of this natural resource, paying particular attention to aesthetic concepts and the artistic tendency, by typologies and uses in architecture. [1]

We sought to establish chronological targets and specific areas of research for the execution of this project. The first phase of the study took place between 2012 and 2015, cover the chronological period from 1850 to 1986. It allowed to identify and gather, through a database, many unpublished sources in archives, bibliographic documents and other in public and private libraries of Portugal, about industrial licensing of divers activity linked whit marble industry like quarries, factory's and others industrial unit's, for the 19th and 20th centuries. Preferential areas where established, such as legislation, the evolution of techniques and technologies used in extraction and landscape changes caused by the intensity of new explorations in the geography of the Anticline.

## The uses of Portuguese marbles in architecture and heritage

As far as fieldwork is concerned, the space of the marble industry was crossed and visited, and between quarries and transformation units we tried to identify the evidence of technological evolution in the field of industrial archaeology. At the same time, a set of oral history, whit interviews of the various actors (engineers, industrialists, trade unionists, quarry masters, masonry workers and other technicians).

The second phase of PHIM project began in 2017, whit new areas of study: Art History and Roman Archaeology, distributed by speciality teams, each chronological period. It is in this context that Art History, conducting a systematized research and inventory of sources for the sixteenth and nineteenth centuries, contemplating the Renaissance, Mannerism, Baroco and Classicism periods, whit a collection of testimonies of the use of marble in architecture and urbanism in the region of Alentejo.

Today it is possible to determine the economic moments of greater dynamism in the marble sector, between the 16th and 20th centuries, confirmed by the diversity of orders and the availability of the endogenous resource.

Whit this presentation, we also sought to frame the process of late industrial development of this activity in Portugal [2] and their influence in the internationalization of the Portuguese marble at the beginning of the twentieth century. Their trade had some meaning in supplying the urban expansion of cities in important markets like Brazil and United States of America. [3]

For this productive growth, as not indifferent, in the nineteenth century, the presence of Portuguese marbles at the Universal Exhibitions like London and Paris, where, from 1851, they would be appreciated and raised the interest of use then in domestic furniture and also in decorative elements inside houses. It was, whit this reality that several quarrymen become, at the same time, businessmen in the extraction, processing and exportation of marbles. To this scenario would add in the early of twentieth century, the large foreign investments in the sector, destined to supply the orders based in the news architectural trends. [4]

Finally, whit regard the outputs of the project, it was possible so far to gather in a database the treated information, making it available to the community in general, through the project portal available at: ( http://phim.cechap.com/en/project ), complemented whit a cultural itinerary and smart-phone application, both about marble, such as, a publication about this thematic, published and available for download at the site of the project. [5]

## Acknowledgments

The authors are grateful for the support provided by the Alentejo regional directorate of culture (Direcção Regional da Cultura do Alentejo), the researcher center CIDEHUS of Évora University and CECHAP Association.

The present research is supported by the CIDEHUS project – UID/HIS/00057/2013-POCI-01-0145-FEDER-00770/2; by the PhD Program: Heritas - Heritage Studies [Refª. PD/00297/2013] and by CECHAP project: PHIM – Heritage and History of Marble Industry.

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## About the authors

Carlos Filipe

Member of CIDEHUS-University of Évora; Member of CLEPUL – University of Lisbon | CECHAP

Largo D. João IV, nº 40-A, 7160-254 Vila Viçosa (Portugal)

carlosfilipe2.cechap@gmail.com

Armando Quintas

Phd Student in History at Évora University, Member of CIDEHUS-University of Évora | CECHAP

Largo D. João IV, nº 40-A, 7160-254 Vila Viçosa (Portugal)

aquintas.cechap@gmail.com

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# Thermal and ultrasonic properties of Estremoz marbles, Portugal

**Tiago Alves, Johanna Menningen, Ruben Martins, Luís Lopes, António Correia, Siegfried Siegesmund, Luis Sousa**

**Synopsis**

Thermal and ultrasonic properties are non-destructive methods used to determine dimension stones anisotropy. Both methods are very simply to operate and give results quickly, nevertheless in particular rocks of visible textural anisotropy such as the Estremoz Marbles, a special care must be taken when doing the cubic samples to test. In fact to get better results one of the cube face must be parallel to the foliation plane (*XY*), so the others are perpendicular and one them must be cut along the stretching direction (*XZ*), consequently the third face of the cube (*YZ*) will be perpendicular to the others (also to the local fold axis when it is present).

An ultrasonic standardization will enable the determination of possible structural defects, such as discontinuities, which may exist within marketable blocks, noticeable for instance, when speeds are lower than typical for marbles observed. The thermal properties are particularly important when processes related with heating and cooling of buildings must be considered.

It's know that dimensions stones processing efficiency, as well as aesthetical characteristics, could be improve if the stones anisotropy are considered. Combine these two parameters an expedite procedure could guide stone manufacturer to obtain better results from the quarry to the final products.

**Keywords**

Thermal properties, ultrasonic properties, dimension stone, Estremoz marble

## Ultrasonic measurement

The ultrasonic test is based on measuring the time that a high frequency wave takes to cross a body. For this end, two diametrically opposed points are defined, where one is placed a transducer which will convert one electric pulse into one ultrasonic wave and another, a receiver transducer that reconverts the waveform back into an electrical signal. The monitoring in a central unit of the apparatus, allows to determine the speed propagation of the wave, allowing a physical characterization of the body to the sample.

This test intend to determine a standard speed for various types of marble, as well as for the different directions related to calcite preferred orientation.

Since marble is an essentially monomineralic rock, this standardization will enable the determination of possible structural defects, such as discontinuities, which may exist within marketable blocks, noticeable for instance, when speeds are lower than typical for marbles observed.

The ultrasonic test were performed on 6,5 cm edge cubes and for each sample of marble, ultrasonic velocity measurements were performed dried at room temperature, oven dried at 60 °C and water saturated, in the Geoscience Centre of the University Göttingen.

The records were obtained using a Fluke 192 and USG30 Generator, Scopemeter 60 MHz 500 MS / s, a Light House 2000 - SM program, UPG emitter transducer, 250 kHz and

UPE-T receiver transducer. The frequency used was of 250 kHz, obtaining the direct measurement of the P-waves velocity (Vp).

In spite of some marbles have the same hue, they were collected in different places in the Estremoz Anticline, and there may be differences from a structural and mineralogical point of view. However, for the sake of discretion, the different chromatic types of marbles were grouped into seven major families: White, White with Veins, Cream with Veins, Pink, Tiger Skin, Ruivina and Marinela. Tab. 1 shows the average values of the velocities (km/s) obtained by each chromatic type.

Table 1 Marble ultrasound average velocity (km/s). In each of the three measurement conditions, lowest and higher values are underlined.

| | Dried at Room | | | Dried at 60º C | | | Water saturated | | |
|---|---|---|---|---|---|---|---|---|---|
| | X | Y | Z | X | Y | Z | X | Y | Z |
| White | 4,525 | 4,530 | 4,066 | 4,446 | 4,300 | 4,152 | 5,327 | 5,333 | 5,214 |
| White with veins | 4,744 | 4,969 | 4,433 | 4,711 | 4,935 | 4,110 | 5,437 | 5,567 | 5,047 |
| Cream with veins | 4,742 | 4,874 | 4,422 | 4,669 | 4,792 | 4,326 | 5,879 | 5,849 | 5,326 |
| Pink | 4,619 | 4,605 | 4,444 | 4,665 | 4,971 | 4,447 | 5,768 | 5,763 | 5,598 |
| Tiger Skin | 4,536 | 4,988 | 4,551 | 4,427 | 5,067 | 4,463 | 5,510 | 5,650 | 5,266 |
| Ruivina | 4,604 | 4,981 | 4,375 | 4,500 | 4,945 | 4,236 | 5,697 | 5,872 | 5,458 |
| Marinela | 5,427 | 6,165 | 5,274 | 5,721 | 6,280 | 5,365 | 5,826 | 6,400 | 5,365 |

## Thermal properties

Thermal conductivity, thermal diffusivity, and specific heat were measured rock samples of this study in the University of Évora Geosciences Department Mechanical Tests Laboratory with an ISOMET 2104 Heat Transfer Analyser (Fig. 1) which allows measuring the three properties simultaneously. The thermal probe used to make the measurements has a range between 2.00 and 6.00 W/mK. The average values for the thermal conductivity, the thermal diffusivity, and the specific heat of samples were obtained by placing the probe in the six polished faces of the 8 cm edge cubes tested (not the same used in the ultrasonic tests, but these 8 cm edge cubes will be tested as soon as possible in the Geoscience Centre of the University Göttingen). Opposite faces were named A and A'; B and B'; C and C´. The calculated average values as well as the standard deviations are presented in Table 2.

Thermal conductivity (in W/mK) is a thermal property that quantifies the ability of a rock to allow heat to go through it; it has to do with stationary heat flow and the higher its value the better heat flows through a rock. Thermal diffusivity (in $m^2/s$) reflects the ability of a rock to absorb and release heat; it has to do with non-stationary heat flow and the higher its value the better heat is absorbed or released from it. Specific heat ($J/m^3K$) represents the amount of heat a rock can accumulate and the higher its value the bigger the amount of heat it can accumulate. In general terms, thermal conductivity depends on open porosity, bulk density, mineralogy, anisotropy and size of the crystals, pressure, and temperature. Thermal diffusivity (α) depends on the thermal conductivity (K), the bulk density (ρ), and the specific heat capacity (C) of the rock (Amaral et al., 2013).


Fig. 1 Heat Transfer Analyser ISOMET 2104. The measuring probe is the black device on top of the rock sample.

Table 2 Values of the thermophysical properties measured on opposites faces (A, A'; B, B´and C, C') of cubic marble samples with the ISOMET 2104 using a surface probe (range between 2.00 and 6.00 W/mK). TC - Thermal conductivity; TD -Thermal diffusivity; VHC - Volumetric heat capacity. N - Number of measurements per sample.

| | | TC [W/mK] | | TD [$\times 10^{-6}$ $m^2/s$] | | VHC [$J/m^3K$] | |
|---|---|---|---|---|---|---|---|
| | | Mean | ± s,d | Mean | ± s,d | Mean | ± s,d |
| White marble, N=5 | **A** | **2,786** | 0,021 | 2,280 | 0,056 | **1,224** | 0,026 |
| | **A'** | 2,694 | 0,046 | 2,262 | 0,079 | 1,194 | 0,034 |
| | **B** | 2,704 | 0,033 | 2,262 | 0,036 | 1,198 | 0,012 |
| | **B'** | 2,744 | 0,027 | 2,268 | 0,046 | 1,212 | 0,035 |
| | **C** | 2,746 | 0,044 | 2,278 | 0,079 | 1,206 | 0,038 |
| | **C'** | 2,738 | 0,056 | **2,284** | 0,049 | 1,196 | 0,029 |
| Pink marble, N=6 | **A** | 2,662 | 0,026 | 2,238 | 0,035 | 1,198 | 0,031 |
| | **A'** | 2,644 | 0,050 | 2,234 | 0,069 | 1,187 | 0,027 |
| | **B** | **2,676** | 0,037 | **2,278** | 0,031 | 1,182 | 0,018 |
| | **B'** | 2,598 | 0,113 | 2,186 | 0,069 | 1,198 | 0,032 |
| | **C** | 2,632 | 0,055 | 2,206 | 0,051 | **1,200** | 0,027 |
| | **C'** | 2,638 | 0,062 | 2,200 | 0,055 | 1,198 | 0,030 |
| Cream marble, N=6 | **A** | **2,982** | 0,150 | **2,342** | 0,078 | 1,263 | 0,041 |
| | **A'** | 2,918 | 0,099 | 2,240 | 0,114 | 1,268 | 0,062 |
| | **B** | 2,972 | 0,057 | 2,286 | 0,022 | 1,292 | 0,029 |
| | **B'** | 2,962 | 0,070 | 2,228 | 0,144 | **1,332** | 0,063 |
| | **C** | 2,938 | 0,120 | 2,284 | 0,085 | 1,282 | 0,027 |
| | **C'** | 2,936 | 0,059 | 2,284 | 0,068 | 1,278 | 0,041 |

## Discussion and conclusions

Köhler (1991), created an interesting classification where it relates degrees of structural alteration of the marble caused by weathering and velocities of the compression waves.By

establishing a comparison between the values of the ultrasonic velocities obtained in the tests carried out on the different chromatic marble types of the Estremoz Anticlinal and the classification suggested by Köhler, it is observed that even the velocities found in the plane against foliation (Z-axis) reveal a marble that fits in the second highest grade of the classification (rock in good condition), showing the high quality of these Portuguese Marbles.

In terms of the thermal measurements, it is possible to say that rocks can be classified (in a qualitative way) as good or bad by measuring the thermal conductivity. These data must be completed, at least with bulk density and the open porosity data. Even though the thermal properties values vary little amongst the rock samples, there is a tendence for the pink marble, shows lower values, what doesn't happens reggarding the ultrasonic properties.

## Acknowledgments

This study was co-financed by the European Union through the ICT project (UID/GEO/04683/2013) with reference POCI-01-0145-FEDER-007690; BRO-CQ ALT20-03-0247-FEDER-017659and E-TechStone POCI-01-0247-FEDER-017882 and CRUP through "Ações Integradas Luso-Alemãs, Projeto: A-50/16"

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## About the authors:

Tiago Alves, Master. Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: rubenvm@uevora.pt

Johanna Menningen, Master. Geoscience Centre, University Göttingen, Goldschmidtstrasse 3, 37077. Göttingen, Germany. E-mail:johanna.menningen@uni-goettingen.de

Ruben Martins, Prof.Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: rubenvm@uevora.pt

Luís Lopes, Prof. Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: lopes@uevora.pt. ICT (Instituto de Ciências da Terra, Portugal; Earth SciencesInstitute, FCT) and Associação Cluster Portugal Mineral Resources

António Correia, Prof.Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: rubenvm@uevora.pt

Siegfried Siegesmund, Prof. Geoscience Centre, University Göttingen, Goldschmidtstrasse 3, 37077. Göttingen, Germany. E-mail: ssieges@gwdg.de

Luis Sousa, Prof. Universidade de Trás-os-Montes e Alto Douro, Departamento de Geologia, Portugal. E-mail: lsousa@utad.pt

# Biodeterioration of the Lioz of the facade of the Real Gabinete Português de Leitura

**Bárbara Santana Tasca, Maria Inês Sarquis, Roberto Carlos Ribeiro**

**Synopsis**

The Real Gabinete Português de Leitura, located in downtown Rio de Janeiro, stands out, among other reasons, for its neo manueline style architecture, built in lioz (microcrystalline limestone). Unfortunately, the monument is undergoing the action of different physical, chemical and biological agents that result in several changes in its structure. The strong microbiological colonization results in the biodeterioration of the constituent rock from the release of acids by microorganisms. To understand the action of these, collections were made in several points of the facade of the monument where the presence of microbiological colonies was observed macroscopically. After plaque growth, isolates and a microscopic visualization were made to identify fungi from two different species: Aspergillus flavus that has the capacity to grow in different nutrient sources, and Aspergillus awamori that is capable of producing citric acid. From the obtained results it is concluded that the identified fungi cause biodeterioration of the rocks present being the possible responsible, mainly, for the alterations in the coloration.

**Keywords**

Royal Portuguese Reading Office, biodeterioration, Aspergillus.

## Introduction

On May 14, 1837, a meeting in Rio de Janeiro with 43 Portuguese emigrants came up with the idea of building a library with the objective of improving the knowledge of its members. Thus appears the Real Gabinete Português de Leitura, that only in 1906 received the title of "Real" given by King D. Carlos.

The Real Gabinete Português de Leitura is recognized for its many characteristics. Its activities include its numerous bibliographical collections, with about 350 thousand works, composed of different examples, among them rare works such as the princeps edition of Os Lusíadas (1572), who belonged to the Society of Jesus, and for the architecture of his building whose project was done by the Portuguese architect Rafael da Silva Castro.

Fig. 1 Royal facade Portuguese reading cabinet

Located in downtown Rio de Janeiro (Brazil), the monument is built in lioz (microcrystalline limestone) and undergoing the action of different physical, chemical and biological agents that cause cracks, staining, colorimetric alteration and strong microbiological colonization, among others, that lead to the degradation of the constituent rock.

Fig. 2 Stones Alterations.

This colonization results in biodeterioration, which is any undesirable change, produced by normal activities of living organisms on materials of economic, cultural or historical importance (modified from Hueck, 1965), being a problem that affects several monuments due to the production of acids, originating of the microorganisms that end up degrading the rock, and the change in coloration caused by these beings. The study of the action of microorganisms on the rocks of monuments is of paramount importance in order to understand the event and protect the cultural and historical heritage, which is the objective of this work.

## Methodology

The collection was performed at points where intense microbiological growth was observed. Plates containing Dextrose Agar (BDA) medium, suitable for fungal growth, and sterile swab were used for this. The collection is done by smearing the swab at the chosen spot and transferring this material to the plate containing the culture medium.

Fig. 3 Collection points where microbiological growth is macroscopically visualized

The plates were kept in a 30° oven for 5 days for microbial growth. After this first growth, the different morph types present in each plate were identified visually to initiate the process of isolation of the species. Isolation was done in tubes containing Malt Extract medium, which is suitable for the growth of yeasts and molds, and in plates with BDA medium for the fungi, as already explained. After isolation, the techniques of blade culture and inoculum point were used, both being used to better visualize the structures of the colonies and to facilitate a later identification of the species.

## Results and discussion

Through macroscopic and microscopic visualization, it was possible to identify fungi belonging to the genus *Aspergillus*. From this recognition, two distinct species, *Aspergillus awamori* and *Aspergillus flavus*, were identified.

Fig. 4 *Aspergillus awamori* e *Aspergillus flavus*, respectively.

Aspergillus flavus is a saprophytic fungus with the ability to grow in different nutrient sources. It can be found in cotton, corn seeds and nuts being a problem for farmers who need to avoid their growth in food. In addition, this is a pathogenic fungus, that is, it is capable of producing infectious diseases in its host due to the release of aflatoxin which is a toxic substance. Aspergillus awamori is able to produce citric acid and, like Aspergillus flavus, can be found in seeds, fruits, soils and plants.

## Conclusion

From the results obtained it is concluded that the identified fungi are the possible responsible for the biodeterioration of the rocks present. It is possible that these fungi have been brought by the wind since during reproduction; these release spores that are dispersed through the air until they find a new substrate to begin the formation of a new colony. When these fungi are younger, they are yellowish green and when older they change their color to dark green, a factor that can be visualized macroscopically.

## Acknowledgments

To CNPq for the financial support; To CETEM, for the infrastructure; to the laboratory staff of the Filamentous Fungus Collection of the Oswaldo Cruz Institute; and to all those involved in the preparation of this work

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## About the authors

Barbara Nunes Santana Tasca, Biology student

Centre for Mineral Technology - CETEM. Av. Pedro Calmon, 900, Ilha do Fundão, 21941-908, Rio de Janeiro – RJ.

Maria Inês Sarquis, Biologist, D.Sc.

Fundação Oswaldo Cruz, Laboratório de Coleção de Fungos Filamentosos, Av. Brasil, 4365, Rio de Janeiro – RJ.

Roberto Carlos Ribeiro, Chemical Eng., D.Sc.

Centre for Mineral Technology - CETEM. Av. Pedro Calmon, 900, Ilha do Fundão, 21941-908, Rio de Janeiro – RJ.

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# Characterization of the Portuguese rocks of Copacabana boardwalk

**Roberto Carlos Ribeiro, Rosana Coppedê Silva, Gabriela Lacerda, Daniel Silva Barbutti and Patrícia Figueiredo**

**Synopsis**

The boardwalk of Copacabana, by Roberto Burle Marx, is a work in Portuguese stone that incorporates the traditional figure of the waves, next to the beach of Copacabana. The technological knowledge of the rocks and their alterations will favor the activities of their restoration. The objective of the work is to characterize these Portuguese stones and identify their alterations. The stones were collected in 10 points of the beach, subjecting them to petrographic analysis, physical indexes, x-ray fluorescence, x-ray diffraction and scanning electron microscopy. The problems observed in the samples were thinning by abrasion of the upper parts, lichen growth, detachments and chromatic alteration. Petrographically, the white rocks are microcrystalline limestone (~ 40% CaO) and the black rocks are basalts (~ 50% SiO2). The values of water absorption (~ 0.1%) and porosity (0.8%) are considered adequate for these rocks. However, in some specific points (regions with greater circulation of people and stage set-ups); there are changes in these values to 1.5% and 3.0%, since they were worn out. It is concluded that the rocks used are microcrystalline limestone and basalt; and in some stretches there are constructive, misuse and poor conservation issues. Some rocks showed color changes and their physical indexes.

**Keywords**

Copacabana boardwalk, dimension stone alterability, dimension stone characterization.

## Introduction

The Portuguese sidewalk (HENRIQUES et al., 2009) is the established name of a particular type of paving of sidewalks and of public spaces in general. This type of tour is widely used in countries with a set of cultural identities of the Portuguese language, such as Angola, Brazil, Cape Verde, Guinea-Bissau, Macau, Mozambique, Portugal, Sao Tome and Principe, and Timor-Leste. The cobblestone in Portuguese stone was introduced in Rio de Janeiro in the administration of the mayor Pereira Passos, in the beginning of the 20th century, integrating the set of urban measures promoted by the City Hall. The boardwalk of Copacabana (REY PÉREZ, 2010), by Roberto Burle Marx, was executed in the early 1970s, being the greatest example of an applied work of art in the world. Designed as a continuous panel in urban scale that can be seen in large sections, pedestrians can enjoy a variety of designs and compositions (CALS, 1995).

The rocks, used in great part of the monuments, are affected by the processes of chemical and physical weathering (FRASCÁ, 2003) that act depending on the climatic conditions of the region. Therefore, alterations and degradations can result from the performance of this weathering (AGAPIOU *et al*., 2015). However, the action of man is another element that has been accelerating and causing this process. In a highly urban environment like the city of Rio de Janeiro, the anthropic action has great influence in the processes of alteration of the rocks. With this, it becomes of great importance the technological knowledge of these rocks and their alterations to carry out adequate restorations.

## Objective

The objective of the work is to characterize the boardwalk and to do a description of the alterations.

## Experimental

White and black stones in 10-point were evaluated as indicated in Fig. 1 during the years of 2013 to 2015. The collection points were: Francisco Otaviano st. (1), Forte de Copacabana (2), Rainha Elizabeth Av. (3), Barão de Ipanema st. (4), Posto 5 de Salva Vidas (5), Santa Clara st. (6), Hotel Copacabana Palace (7), Ronald de Carvalho st. (8), Princesa Isabel Av. (9) e Forte do Leme (10).


Fig. 1 Sampling Points. (Google Earth, 2017).

### Technological Characterization

The stones were characterized by X-ray fluorescence, X-ray diffraction, petrographic analysis, scanning electron microscopy (MEV) and verification of physical indices (ABNT NBR 15845: 2010).

### Alterations description

To determine the changes in rocks, a photographic record and comparison with the patterns of changes described by ICOMOS were used.

## Results and Discussion

### Technological Characterization

Petrographic analysis (Fig. 2) indicated that the white Portuguese stone is a metamorphic, light colour rock with compact structure, microcrystalline texture, fine granulation, with 40% calcite, presence of dolomite, quartz, muscovite and albite. The rock is classified as microcrystalline limestone. The black stone is an igneous rock, menalocratic, with fine granulation, presents anortite, albite, andesine, labradorite, diopside and magnesite.

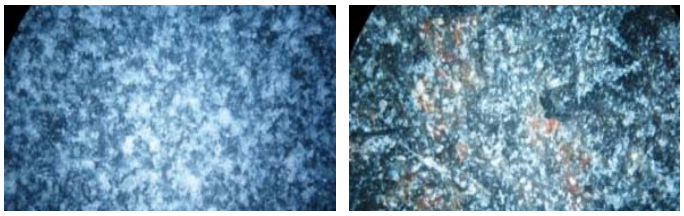

Fig.2: Photomicrographs with polarized light, Portuguese white and black stones.

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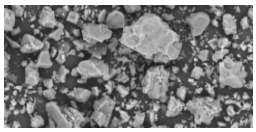
The X-ray diffraction of the white stone identified that the most abundant mineral is calcite, followed by dolomite, quartz and muscovite. Feldspars (albite and microcline) also occur in small amounts. The black Portuguese stone identified the peaks of anortite, albite, andesine and augite. The scanning electron microscopy (MEV) (Fig. 3 and Fig. 4) of the samples indicates the uniform distribution of the minerals and the confirmation of the minerals identified in the XRD.



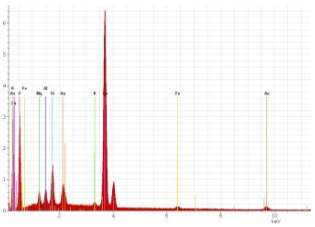
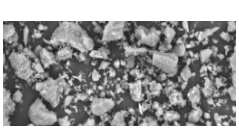


Fig. 3 Portuguese microcrystalline limestone – MEV-EDS.



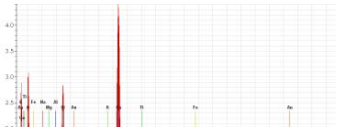


Fig. 4: Portuguese black basalt – MEV-EDS.

Table 1 presents the results of the chemical composition of the Portuguese stones, with 40% calcium and 40% calcination loss for the white stones, confirming that it is calcite. The black stones present 50% silica, 15% alumina, iron content of approximately 12%, sodium content of 4% and manganese of 0.20%, configuring the composition of the basalt identified in the mineralogical analysis.

Table 1. Chemical composition (%) of Portuguese's stones.

| ***Points*** | ***1*** | ***2*** | ***3*** | ***4*** | ***5*** | ***6*** | ***7*** | ***8*** | ***9*** | ***10*** |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 12.30 | 51.30 | 12.50 | 49.90 | 10.50 | 49.80 | 18.10 | 48.20 | 13.40 | 50.20 |
| CaO | 40.20 | 7.60 | 41.80 | 7.30 | 43.60 | 6.60 | 32.6 | 9.10 | 42.50 | 8.00 |
| $Fe_2O_3$ | 1.10 | 11.50 | 0.80 | 13.40 | 1.00 | 12.90 | 1.40 | 12.50 | 1.10 | 11.70 |
| $K_2O$ | 0.40 | 1.50 | 0.40 | 1.17 | 0.30 | 1.10 | 0.70 | 1.20 | 0.40 | 1.30 |
| MgO | 5.30 | 2.90 | 4.10 | 3.00 | 4.10 | 2.90 | 7.50 | 3.10 | 3.70 | 2.70 |
| $a_2O$ | 0.10 | 4.10 | 0.20 | 4.10 | 0.10 | 3.70 | 0.40 | 3.90 | 0.20 | 4.00 |
| $Al_2O_3$ | 3.02 | 15.20 | 2.30 | 15.0 | 2.00 | 15.6 | 3.90 | 14.90 | 2.30 | 15.50 |
| MnO | 0.05 | 0.10 | 0.04 | 0.20 | 0.04 | 0.20 | 0.06 | 0.20 | 0.06 | 0.20 |
| PF | 37.30 | 1.80 | 37.60 | 1.90 | 38.10 | 2.90 | 35.00 | 2.80 | 36.10 | 2.10 |

(1) White Posto 5, (2) Black Posto 5, (3) White Forte, (4) Black Forte, (5) White S. Clara st., (6) Black S. Clara st., (7) White Copa Palace, (8) Black Copa Palace, (9) White F. Otaviano st., (10) Black F. Otaviano st.

In relation to the values of porosity and water absorption, the white and black rocks had, on average, 0.8% and 0.1%. However, in some specific points (Ronald Carvalho, Copacabana Palace and Princesa Isabel), these values increase to 3.0% for porosity and 1.5% for water absorption.

### Alterations description

It was found that the stones are unchanged in boardwalk. However, in some sections, Fig. 5, where there is assembly and disassembly of stages for shows (Ronald Carvalho st., Copacabana Palace and Princesa Isabel Av.), there are problems of detachment and inadequate repositioning. At some points, spotting is caused by ferrous oxidation.

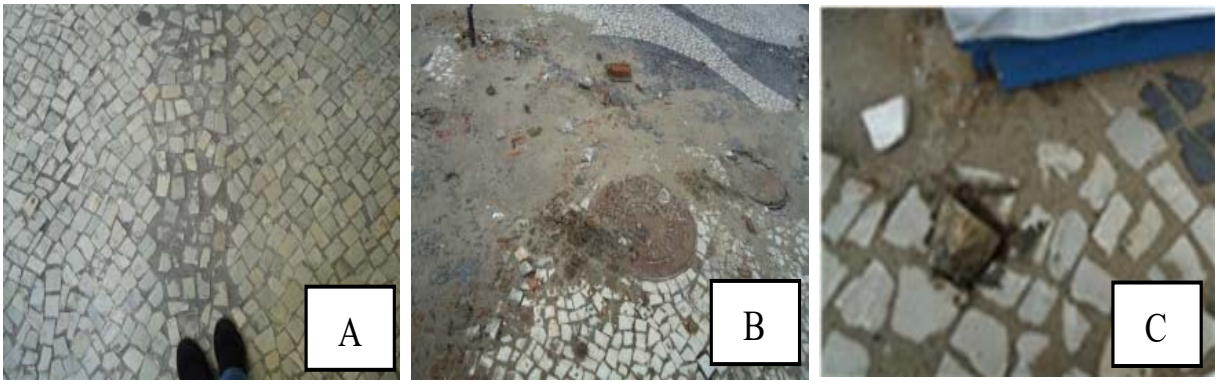



Fig. 5 A - Bad intervention, B - detachment and C - staining.

## Conclusions

The Copacabana boardwalk is historical heritage-listed. The rocks that make up the Portuguese stone pavement are microcrystalline limestone (white stone) and basalt (black stone) and the main alterations in the rock are changes of porosity and water absorption, spotting and loosening in places of greater circulation and events.

## Acknowledgments

CNPq and the National Artistic and Historical Heritage Institute – IPHAN

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## About the authors

Roberto Carlos da Conceição Ribeiro, Chemical Engineer, D.Sc.

Centro de Tecnologia Mineral – CETEM, Av. Pedro Calmon, 900, C.P. 21941908, Ilha da Cidade Universitária, Rio de Janeiro, RJ, Brasil, rcarlos@cetem.gov.br

Rosana Elisa Coppedê Silva, Geóloga, D.Sc. - Freelancer, rosanacoppede@gmail.com

Gabriela Fernandes Lacerda, Chemical Engineer student.

Centro de Tecnologia Mineral – CETEM, Av. Pedro Calmon, 900, C.P. 21941908, Ilha da Cidade Universitária, Rio de Janeiro, RJ, Brasil, glacerda@cetem.gov.br

Daniel Silva Barbutti, Industrial Chemistry student.

Centro de Tecnologia Mineral – CETEM, Av. Pedro Calmon, 900, C.P. 21941908, Ilha da Cidade Universitária, Rio de Janeiro, RJ, Brasil, dbarbutti@cetem.gov.br

Patrícia Marques Ferreira de Figueiredo, Chemical Engineer, M.Sc.

Centro de Tecnologia Mineral – CETEM, Av. Pedro Calmon, 900, C.P. 21941908, Ilha da Cidade Universitária, Rio de Janeiro, RJ, Brasil, patriciam@cetem.gov.br

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# Studies related to the deteriorations in stones of Mestre Valentim´s Fountain

**Roberto Carlos da Conceição Ribeiro, Patrícia Marques Ferreira de Figueiredo, Daniel Silva Barbutti**

**Synopsis**

Mestre Valentim's fountain, originally built with the purpose of water sourcing, became an important historical patrimony for Brazil, being portrayed by famous artists such as Jean-Baptiste Debret.In 1938, the fountain was registred as cultural heritage by the National Historical and Artistic Heritage Institute (IPHAN), and in 1990, it was subjected to excavation and restoration works. The fountain was built in gneiss and lioz limestone, with lead plates and mortar connecting the gneiss blocks. Currently, deteriorations in the fountain stones can be observed such as light stains in several points, as well as some aesthetic modifications caused by inadequate restorations. X-ray fluorescence (XRF) analyses infer that light stains may have been caused by the formation of an insoluble salt as a result of the association of lead from the plates and mortar with other elements still unknown.Colorimetric evaluations have shown differences in chromatic trends between original gneiss and replacement parts, as well as between lioz limestone parts and restored areas. These results attest to the importance of greater technological support in restoration and conservation works.

**Keywords**

Mestre Valentim, Colorimetry, Gneiss, Lioz Limestone, Conservation and Restoration.

## Introduction

Nowadays, fountains are usually associated with aesthetic elements. However, they were originally used as water supply sources. One example is the fountain designed by Carlos Mardel and installed in 1747 in the area formerly known as Terreiro do Paço (now Praça XV de Novembro), in downtown Rio de Janeiro, Brazil(DUARTE, 2008; ARQGUIARIO, 2015). In 1789, due to the distance from the sea and as a substitute of this fountain, a new one was built, closer to the port, by the artist Valentim da Fonseca e Silva, better known as Mestre Valentim. The objective was to attend the demand from sailors and from thecity , transforming the place into the main entrance door for travelers that arrived by means of ships(IPHAN, 1938). At the end of the 19th century, the fountain lost its usefulness as a water source, but at the beginning of the 20th century it became an important monument, which is portrayed in Jean-Baptiste Debret's artistic production.In 1938, the fountain was registered as a cultural heritage by the National Historical and Artistic Heritage Institute (IPHAN), having its urban condition recovered in the 1990s, through a work of excavation and restoration that revealed the original staircase and berth (ARQGUIARIO, 2015).

The architecture of “Mestre Valentim's fountain” (Fig. 1), as it is commonly called, was inspired by Rococo, being built in gneiss and liozlimestone (TELLES, 2007). To connect the gneiss blocks and other blocks of the monument, Mestre Valentim used his talent in the manipulation of molten metals(BRUSADIN and QUITES, 2016),using lead plates and mortar.Currently, it is possible to observe deteriorations in the fountain stones, besidessome inadequate aesthetic modifications. Therefore, the objective of the present work is to study the deteriorations of the stones and their possible causes, as well as the results of the restorations in comparison with the original materials used in the construction of this important monument.

Fig. 1 Mestre Valentim's Fountain, located in Rio de Janeiro, Brazil.

## Methodology

Chemical analyses through X-ray fluorescence spectrometry (XRF) were carried out in areas where the stones had light staining and in a lead plate of the monument that was provided for study. For the lead plate, a bench top equipment of the brand Edax and model *Orbis* was used, and for the stains, the analyses were made *in situ* by means of a portable instrument of the brand Bruker and model*S1 Turbo SD*. In addition, a portable spectrophotometer of the brand BYK and model *Spectro-Guide Sphere Gloss* was used to evaluate the color and brightness of the original stones and of those used in the restorations as well as the stains mentioned above. The determination of colors is given in the CIELAB color space. To perform a colorimetric trend identification, the LAB values were converted to hexadecimal format and identified by a software of digital colors analysis. All analyses for the original stones (used as control) and for the altered or substitutes stones were performed in quadruplicates.

## Results and Discussion

### X-Ray Fluorescence

XRF analyzes were performed at three different points on the lead plate (Fig. 2a) and the results showed lead oxide (PbO) values between 77.8% and 88.9%, thus confirming that the major element found on the plate is lead. In addition, smaller levels of aluminum and silicon oxides ($Al_2O_3$ and $SiO_2$ respectively) were verified, as well as traces of other elements. The XRF analysis performed on the light stains (Fig. 2b) indicated levels of approximately 50% of lead (Pb), 38% of silicon (Si) and 8% of aluminum (Al), besides other elements. On the stones areas without stains, the values were around 7% of Pb, 60% of Si and 16% of Al, with traces of other elements. These results suggest that these stains may have originated from the association of the lead of the plates and mortar used to connect the blocks with other elements such as sulfur (from the pollution present in the environment of high urban movement), forming an insoluble salt of white coloration.

## Colorimetry

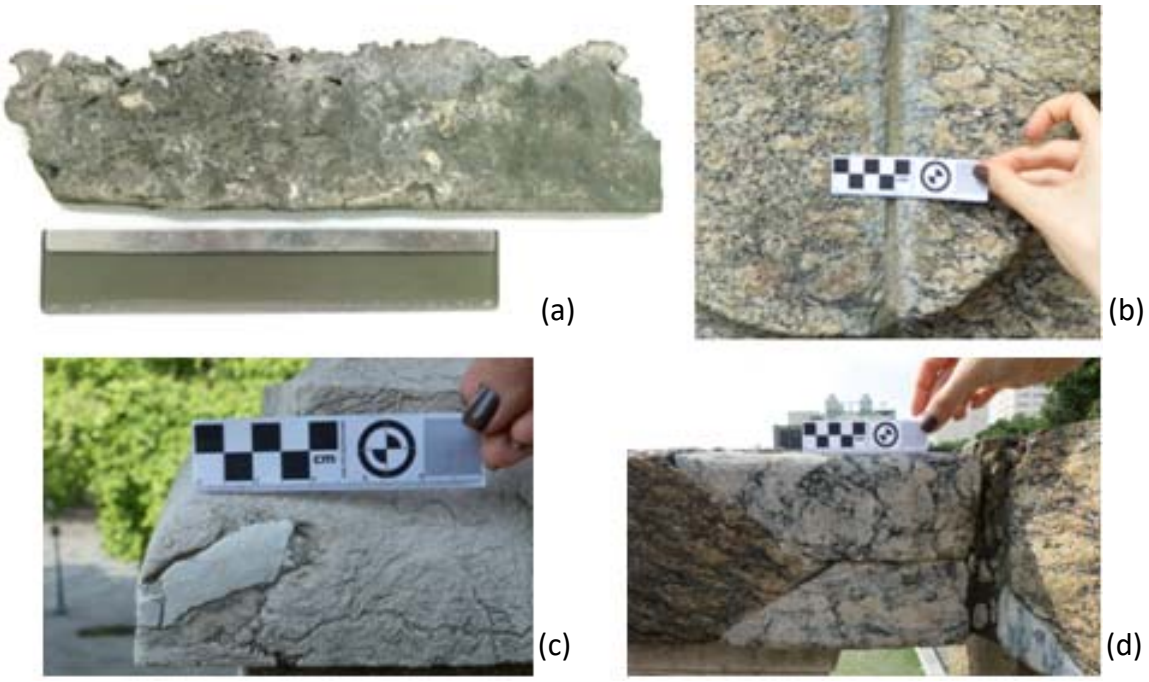


Fig. 2 (a) Lead plate; (b) Light staining on a gneiss block; (c) Lioz limestone area with restored part; (d) Substitute piece on a gnaisse block.

Looking at the stones with the naked eye, it is possible to easily distinguish the difference between the original gneiss stones and the substitute pieces, the latter with distinct color and better polished (Fig. 2d). In the same way, the restorations made in lioz limestone balustrade and torches (Fig 2c), although more similar (possibly due to the existing polishing), also present perceptible differences. Regarding the brightness, there was little increase in the most recent pieces, but no noticeable difference. The analyses showed that lioz limestone is light faded brown, slightly orange, but compatible with the stone in question. On the other hand, gneiss showed a tendency to brown, with a more intense orange. The substitute stones to the gneiss showed grey color slightly orange. Tab. 1summarizes examples of values obtained for some surfaces analyzed. It is important to note that this is a monochromatic trend and therefore there is no direct relationship between the obtained color and the color saw with the naked eye, since the stones are heterochromatic.

Table 1 LAB parameters for the analyzed samples.

| Samples | Restored Stone Parameters | | | | Standard Stone Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| | L* | a* | b* | G | L* | a* | b* | G |
| Substitute Gneiss (torch top) | 67.5 | 2.05 | 7.77 | 1.30 | 61.4 | 3.62 | 16.0 | 0.70 |
| Substitute Gneiss(torchbasis) | 72.1 | 1.99 | 9.29 | 1.10 | 61.4 | 3.62 | 16.0 | 0.70 |
| Substitute Gneiss(parapet) | 65.7 | 0.42 | 5.94 | 1.00 | 55.3 | 5.07 | 15.3 | 0.50 |
| Original Gneiss (external wall, light staining) | 56.8 | 0.22 | 4.83 | 0.50 | 57.4 | 1.43 | 12.9 | 0.80 |
| Lioz Limestone (torch) | 74.3 | 1.77 | 6.98 | 1.50 | 73.4 | 1.99 | 8.44 | 0.80 |
| Lioz Limestone (balaustrade) | 76.1 | 1.86 | 7.74 | 0.90 | 73.9 | 2.54 | 9.80 | 1.10 |

## Conclusion

From the results of XRF obtained, it was verified that the plate used in the connection of the gneiss blocks shows mainly lead in its composition. Moreover, such results suggest that this element, when associated with others still unknown, forms an insoluble salt of white coloration, which is probably responsible for the light stains on the fountain stones. The colorimetric evaluations have showed differences in the chromatic trends of the stones used in the restoration of the parts in gneiss. For lioz limestone parts, the differences are more subtle but still noticeable to the naked eye. These observations point to the importance of prior technological support for the conservation and restoration of historical monuments in order to minimize the likelihood of inadequate results.

## Acknowledgments

The authors would like to express their gratitude to Centre for Mineral Technology – CETEM for its infrastructure support, and to CNPq for its financial support.

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## About the authors

Roberto Carlos da Conceição Ribeiro, DSc.

Center for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. rcarlos@cetem.gov.br.

Patrícia Marques Ferreira de Figueiredo, MSc.

Center for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. patriciam@cetem.gov.br.

Daniel Silva Barbutti, Industrial Chemistry Student.

Center for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. dbarbutti@cetem.gov.br.

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April 26-29, 2018
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# Investigation of structural consolidation of the Candelária Church in Rio de Janeiro, Brazil

**Roberto Carlos Ribeiro, Patrícia de Figueiredo, Daniel Silva Barbutti, Sônia Santos**

**Synopsis**

The Nossa Senhora da Candelária church was created in the XVII century. Built in gneiss stone and mortar, the church is located in downtown Rio de Janeiro, and has suffered deteriorations in most of the stones due to the action of salt and sulfur, generating degradations in several areas. Based on this, the objective of the work was to verify the consolidation product used in the Candelaria's restoration, observing if the stones physical properties (porosity and absorption) were reestablished. Records of stone degradation in the church were carried out, FTIR of the consolidation product was characterized, fragments of stones were collected and tested with the product at dilutions of 5% and 10% to check porosity and water absorption. Colorimetric standards and gloss measurements were performed. The results indicated that the product has ester in its composition, and that the dilutions were able to react with the stones, generating no colorimetric changes. Moreover, the results also showed that the porosity decreases from 2.5 to 1% and that the water absorption decreases from 1 to 0.3%. It is concluded that the consolidation was effective and that stones physical properties were adjusted.

**Keywords**

Candelária, Dimension Stone, Conservation and Restoration.

## Introduction

The Nossa Senhora da Candelária church dates back to the 17th century. According to the Brotherhood of the Blessed Sacrament of Candelária, surveys carried out in Portugal confirmed the date of the parish's creation on August 18, 1634, showing that the history of the Church is confused with the history of the city itself. The church was reformed in 1710, and between 1775 and 1885 it was submitted to building works and expansion. Its facade is covered by two rocks typical of the region: leptinite and augen gneiss (ALMEIDA; PORTO JUNIOR, 2012).

Currently, the church is visited by tourists, besides being very popular for celebrations of masses, weddings and baptisms. Its monumentality is unquestionable, as well as the necessity of preservation of such patrimony, which impelled the present research work. It is located in Praça Pio X, in downtown Rio de Janeiro, Brazil, near Guanabara Bay (Fig. 1). In this region is located the historic, commercial and financial center of the city, being one of the regions with the highest traffic of vehicles and citizens.

The objective of this work is to verify the effectiveness of the church's facade stones and to verify if the physical indices are preserved.

## Methodology

The analyzed materials were fragments of Augen Gneiss that were detached from the church facade and a consolidation product provided by the restoration company. The product was characterized by infrared (IR) spectroscopy on a *Spectrum 400* model *Perkin Elmer* brand, and the length range evaluated was 4000 to 400 $cm^{-1}$.


Fig. 1 Candelária localization (Google Earth, 2017).

## Stone characterization

### *X-Ray Diffraction (XRD)*

According to Marques et. al (2008), Augen Gneisses are rocks with medium to coarse grain size, mainly composed by microcline and a fine matrix composed by plagioclase, biotite, quartz, garnet, opaques and microcline (lower quantities). To analyze the mineralogical composition of the gneiss fragments it was used the benchtop equipment Bruker-AXS D4 Endeavor.

### *Physical indexes*

The stones were evaluated according to the determination of the physical indexes, before and after the application of the agent of consolidation. This procedure aims to characterize the physical properties of the stone, determining the porosity and water absorption capacity of the material, based on ABNT NBR 15845-2.

### *Colorimetry*

The average staining was determined before and after application of the product. The analysis was performed using a portable spectrophotometer of the brand BYK and model *Spectro-Guide Sphere Gloss* for determination of values on axes a*, b* and L*.

The coloring results should be interpreted according to the spatial distribution of colors. It is verified that the materials have 3 values ranged in axes a*, b* and L*. Axis a* indicates the color variation of green (-a*) to red (+ a*), axis b* indicates the variation of color of blue (-b*) to yellow (+b*), and axis L* indicates the variation from white (100) to black (0).

## Results and discussion

### Characterization of the consolidation product

The FTIR spectrum of the product (Fig. 2) showed an elongated peak at 1733 $cm^{-1}$ and smaller peaks at 760, 852, 1024, 1160, 1175, 1242, 1382, 1449, 2952 and 2984 $cm^{-1}$. According to Cocca et al. (2004), these peaks confirm the presence of aliphatic C-H groups, C = O ester, C-O ester and C-C ethyl. Tab. 1 shows the assignments of the groups related to the peaks identified, based on the reference frequencies reported by Cocca et al. (2004).

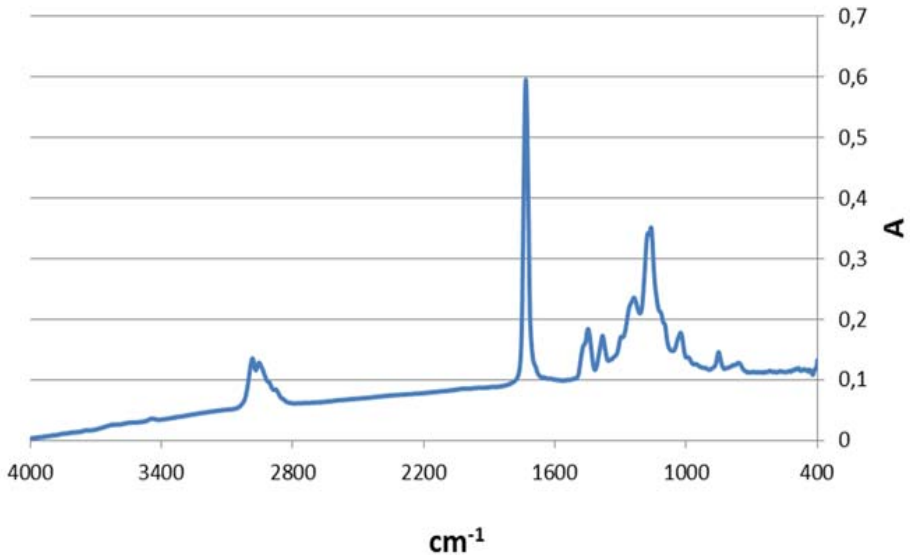


Fig. 2 FTIR chart of the consolidation agent.

Table 1 Reference wavelength values ($cm^{-1}$).

| Reference Frequency ($cm^{-1}$) | Frequency Found ($cm^{-1}$) | Attribution |
|---|---|---|
| 2988-2982 | 2984 | ν (C–H alifatic) |
| 2957-2952 | 2952 | ν (C–H alifatic) |
| 1731 | 1733 | ν (C=O éster) |
| 1453-1447 | 1449 | β (C–H alifatic) |
| 1383-1382 | 1382 | β (C–H alifatic) |
| 1251-1238 | 1242 | ν (C–O ester) |
| 1177-1174 | 1175 | δ (C–H alifatic) |
| 1160-1159 | 1160 | δ (C–H alifatic) |
| 1024 | 1024 | ν (C–C etil) |
| 852-846 | 852 | ν (C–C etil) |
| 760-754 | 760 | η (C–H alifatic) |

## Stone characterization results

### *X-Ray Diffraction (XRD)*

The mineralogical composition analysis indicated presence of quartz, plagioclase, K feldspar, mica and zircon. Such result is in agreement with the expected to gneiss stones according to the literature.

### *Physical indexes*

The stone removed from the church shows water absorption (1.00%) and porosity (2.50%), values above the values of a healthy stone, indicating possible alterations that this stone suffered during the time of exposure to the elements. After the consolidant application, the water absorption reduces to 0.30% and the porosity reduces to 1.00% in both dilutions, showing that the consolidation power and that the stones have their physical properties enhanced.

### *Colorimetry*

Tab. 2 presents the results of the colorimetric patterns of stones before and after the consolidation and it is verified that there is no significant change in the colorimetric and

brightness conditions. The values of * (red), b * (yellow) and L * (light) have shown no significant differences, indicating that the chromatic tendency remains the same.

Table 2 Colorimetric stone patterns before and after the application of the products.

| Parameters | Before | After | |
|---|---|---|---|
| a* | 0.66 | 0.87 | 0.29 |
| b* | 4.30 | 4.14 | 4.27 |
| L* | 72.90 | 71.67 | 72.61 |
| G | 1.39 | 1.20 | 1.50 |

## Conclusion

It was concluded that the consolidation was effective and necessary for stones that are in this accelerated degradation process level, without changes in colorimetric patterns and partially restoring the original physical properties.

## Acknowledgments

The authors would like to express their gratitude to Centre for Mineral Technology – CETEM for its infrastructure support, to CNPq for its financial support, to the Brotherhood of the Blessed Sacrament of Candelária, to IPHAN, and to Câmara Costa company.

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### About the authors

Roberto Carlos da Conceição Ribeiro, DSc.
Centre for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. rcarlos@cetem.gov.br.

Patrícia Marques Ferreira de Figueiredo, MSc.
Centre for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. patriciam@cetem.gov.br.

Daniel Silva Barbutti, Industrial Chemistry Student.
Centre for Mineral Technology (CETEM), Av. Pedro Calmon, 900 – Cidade Universitária, Rio de Janeiro, 21941-908, Brasil. dbarbutti@cetem.gov.br.

Sônia Santos, Architect
Brotherhood of the Blessed Sacrament of Candelária, Av. Rio Branco, 57 – Rio de Janeiro, Rio de Janeiro, 20090-901, Brasil.

GLOBALSTONE CONGRESS2018
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# Map of natural stones from Sardinia

**Nicola Careddu, Massimo Scanu, Paolo Desogus**

**Synopsis**

The poster shows a collection of natural stones quarried for ornamental purposes in Sardinia (Italy) over the last fifty years. Its user-friendly map has been graded to school students level and can be used as a reference in public libraries. There are no previous publications showing a similarly wide range of Sardinian stones. The poster offers scientific information about lithology, quarrying sites, dimension stone producing areas, quarries of historical and/or archaeological interest, historical trend in quarries output, technical properties, stone surface workability and a glossary.

**Keywords**

Dimension stone, Sardinia, geo-education, geoheritage, geotourism.

## Lithological framework

Because of its multi-geological events, the lithological Sardinian landscape has offered a remarkably wide range of options in terms of research evidence of decorative stones. Such stones have often satisfied a vast array of requirements, from color and workability, to other important characteristics such as hardness and durability.

The geological history of Sardinia covers almost all geological periods. More than half the surface of the island consists of Paleozoic rocks, for about 13,000 km$^2$, while the remaining 11,000 km$^2$ are home to the secondary, tertiary and quaternary formations.

With regard to their origin, igneous rocks prevail over sedimentary ones, which in turn take precedence over metamorphic ones.

## The design of the map

The concept of a map is based on an official list of Sardinian stone types that was compiled by Siotto and Ullu (1997). This list was then used by a lot informative media (especially websites); however, the image referring to the stone types included in the list were never released. As a result, the purpose for the poster has been to give readers a complete framework of the Sardinian natural stones by showing their colors, structure, and texture.

Moreover, despite their wide availability and variety, only few Sardinian stones types (especially granites) were known outside the Island during the 1900s (i.e. *Rosa Beta* and *Ghiandone Gallurese* have been used worldwide). None of the most influential publications (see references) reported images about, for instance, *Black Prestige* basalt, *Orani/Sarule granite*, *Grigio Sarrabus granite*, *Travertino di Ulassai* and *Alabastro di Narcao*.

Furthermore, the map aims to show all the eight *Dimension stone producing areas*, as referred in the Regional Plan of Mining Activities (Piano Regionale delle Attività Estrattive - P.R.A.E.) for the Autonomous Region of Sardinia. Each of these areas features quarries for

petrographically homogeneous rock types: granite (4), limestone (1), volcanic rocks (2, basalt and ignimbrites), metamorphic rocks (1, phyllites and schists). Before the publication of the map, a reference of only five of the eight dimension stone producing areas (granites and Orosei marble areas) was ever made by the scientific community in previous work.

Finally, the number of both active and non-active quarries has been updated, since some of the new publications were still mentioning data dating back to 1994!

## Description of the map

First of all, authors felt it was important to explain what an ornamental stone is. The definition was based on Primavori (2004): the term *decorative stone* is generically used to refer to all natural stones that can be used as decorative material, first of all for cladding and covering, but also as a structural role. The term *ornamental stone* is also used. The international industry term is *dimension stone*.

In order to make the map easier to read as much as possible, the first thing that we did was to provide the best image that we could produce of each stone, with detailed information about its range (commercial name, lithology, color, petrographic definition, quarrying sites).

To facilitate the reading, only the basic technical properties of the most marketed stones from Sardinia are given.

A new symbol (Fig. 1), which represents the quarrying activity, has been introduced herein for the first time. This symbol was inserted in the map for each municipality which has a quarrying activity for ornamental purposes.

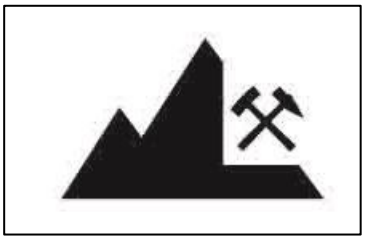

Fig. 1 Proposed symbol for dimension stone main quarrying areas.

Geoheritage was also considered whilst planning the map, and a list of quarries with historical and/or archaeological interest were provided during this phase. Tourists and excursionists can now use this map to visit the historical quarries (with the exception of the Monte Lapanu quarry, which is currently part of a military polygon) which are geo-referenced on the map as shown in Fig. 2.

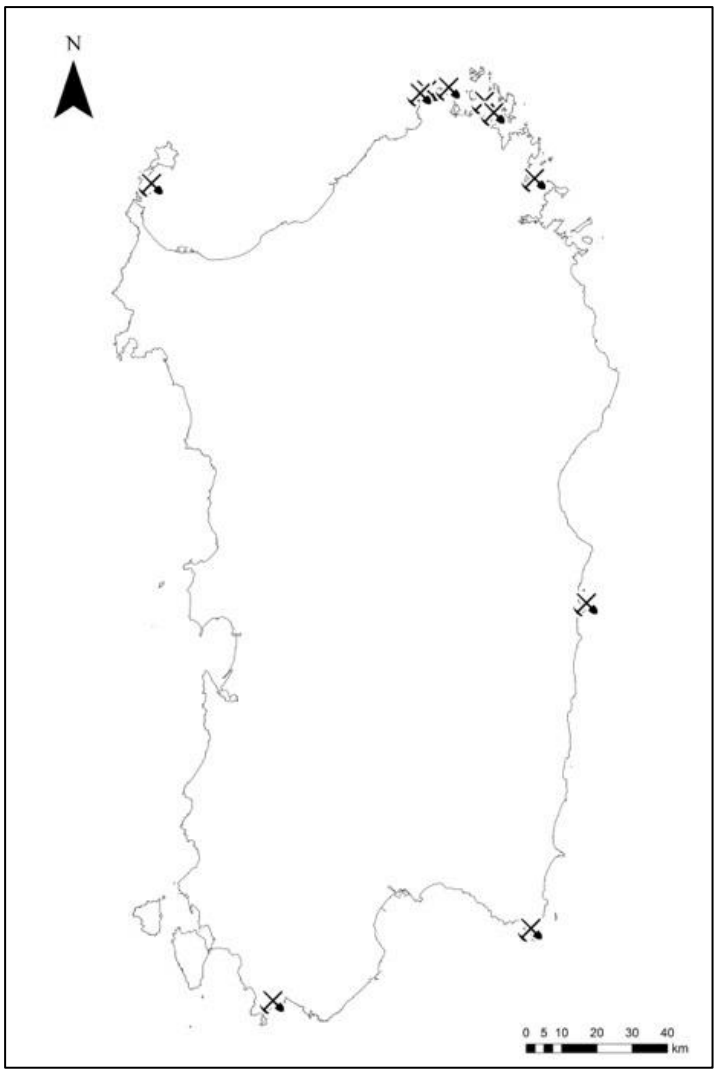


Fig. 2 Geolocation of Sardinian quarries of historical and archaeological interest.

A complete glossary of the mentioned stone types is provided at the end.

The map was published in 2015 with the support of the University of Cagliari, the Sardinian Mining Society and the website *minieredisardegna.it*.

## Acknowledgments

The authors wish to thank the operators for their help providing the samples used to make this poster.

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## About the authors

Nicola Careddu, senior researcher

University of Cagliari, Department of Civil, Environmental Engineering and Architecture (DICAAr). Address: via Marengo 2, 09123 Cagliari, Italy. E-mail: ncareddu@unica.it. Phone n.: +390706755561.

Massimo Scanu, webmaster of minieredisardegna.it

Address: via Nuoro 6, 09025 Sanluri, Italy. E-mail: massimo1312@gmail.com. Phone n.: +393281226241.

Paolo Desogus, environmental engineer

Address: via Cornalias 150, 09121 Cagliari, Italy. E-mail: ing.paolo.desogus@gmail.com. Phone n.: +393491559408.

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# Stereotomic design: the use of stone in contemporary architecture

**Andréa Régis, Carla Marzo**

**Synopsis**

In the last few years, digital fabrication and parametric design have started to be seen as a technological tendency in contemporary architecture. From these techniques, came the Digital Stereotomy, a rescue of the use of stone as a structural element of construction. While nowadays this rich material is being misused, some research in the field of stereotomy decided to try to combine traditional stone construction with new ways of production, like CNC's and robotic arms. This combination is starting to show amazing results, which are being exposed in exhibitions, prototyped and even constructed. This is an important tendency in architecture, which brings digital fabrication and parametric design closer to the cultural tradition, to the society and to the landscape of a specific site. In many parts of the globe, researchers are dedicating time and resources to develop and learn more about this new opportunity for the revival of stone usage in architecture, bringing back its importance to the construction process.

**Keywords**

architecture, parametric, digital, fabrication, stereotomy.

## Parametric architecture, digital fabrication and stereotomic design

Current experimentations reveal a tendency of contemporary architecture to use new technologies of creation and design, which are already in use in other fields, like car fabrication and international industries in general. This search for new ways of construction increased the development of what were called *digital fabrication* and *parametric architecture*. Digital fabrication can be understood as the act of using digital instruments, such as 3D printers, robots and CNC's (*Computer Numerical Control Machines*) to build something – from small design pieces to large buildings -, while parametric architecture is more commonly referred to as a conception technique rather than fabrication itself. The parametric way of design is defined by the fact that the project is, as the name says, based on parameters, which can be more easily modified and adapted when necessary, responding efficiently to what the architect or designer intends. In architecture, many important basic variables may be involved in a project in the form of parameters: temperature, ventilation, sun course, main views, physical or legal constraints. As so, it's possible to say that the use of parameters may help making a building respond intelligently to the architect's idea, using nothing more than coded mathematical logic created with the help of computer software, like Grasshopper (Rhinoceros) and Microsoft Visual Studio C++.

The biggest difference between a "traditional" design process and a parametric one rests entirely on the coding process that is used in the conception of the form. The traditional adopted process usually bases itself on the thought of imagining a form and a functional logic, using the machine essentially to represent the design, and more rarely, for spatial studies. On the other hand, Parametric architecture is based on the thinking process of humans (architects) evolving a final form from a logical conception, using machines as an excellent design tool with infinite mathematical possibilities. It helps professionals to create,

test, prototype, and prove if their points are working or not. This process is of much better used by people that have complete awareness of what their intentions are, inputting in the final form more clearly. This makes parametric architecture likely to be intelligent, responsive, sustainable and easily adaptable to many environments.

However, how does parametric architecture *really* work? If we put aside the code reading, which takes some time to learn, it's possible to say that it works, basically, as an association between inputted information and a final form. First, the computer reads a *data* (code), made by the architect or designer - that represents nothing more than his/her intention for the project -, and then the machine itself translates it into a form. For example, if on a site the predominant wind comes from the southeast, the architect puts this information as a parameter (in a coded language) and, if it's what the professional intends, the final form will take this information as a factor in the building's form. If the professional includes as much information as he/she wants, the building will be as close to the idealized efficiency as mathematically possible. Usually, digital fabrication and parametric architecture are used together, because both of them work with the same kind of technology: the computer logic. The results of this combination are usually constructed with materials like wood (easily cut by laser-cutters), plastic (a 3D printable material), or even steel and fabric. In already built parametric architectural projects, like in Zaha Hadid's, Calatrava's or Norman Foster's, it is common to see all these kinds of materials already in use.

A creation concept called Stereotomy, however, is improving the use of stone in these methods of fabrication. Stereotomic Design consists in a type of this mutual work between digital fabrication and parametric design, which uses essentially calcaric stones - normally called limestone - as a resource for constructing edifications or objects. Stereotomy can be defined as a traditional and historical process of using rocks in a construction by cutting them in to smaller pieces, which would be set up together to build a bigger structure. This was usually done in Ancient Rome and in Palestine. However, nowadays, it has attached to itself a new technological meaning, since it now counts with the help of robotic arms, routers, and others computational instruments that can facilitate the use of this kind of material and, consequently, increase it. Parameterization helps architects and designers to construct with stone, because it helps in processes of structural calculations, material necessities and construction process. Working with stone, also, shows more concern with the history and the traditional local construction techniques, with the communities and especially with the landscape that surrounds it.

## The use of stereotomy in contemporary architecture

### AAU Anastas | Stone matters, prototype 01 | Palestine, 2017

"*Palestine suffers of a misuse of stone as a structural material: while it was an abundant material used for structural purposes in the past, it is now used as a cladding material only and the know-how of stone building is disappearing*." This phrase starts the describing text available in the website from the architectural office AAU Anastas, from Palestine, about the project "*Stone matters, prototype 01*" (Fig. 1-LEFT), built in 2017, in the city of Jericho. AAU Anastas has a research department (SCALES) leading this research on stone construction techniques, working as partner of GSA (Geometrie Structure Architecture) ENSA Paris-

Malaquais. As the name suggests, the project was an experiment, which the results would be used as a feedback to help the construction of a much bigger stone vault. This other design would accommodate a group of artist called el-Atlal. It covers 60m² with just a constant 12cm depth of material, following the structural principles of minimal surfaces and interlocked stones. It uses 300 unique stone pieces, mutually supported. One of the major challenges was to find technical solutions and available machines close to the area of Jericho, where there were no labs or factories to turn the project into reality. The building process was divided into two parts. Firstly the pieces were design through a computational weaving process. Then they were moulded into individual parts and cut from blocks of local limestone with the help of a CNC saw machine. Secondly it was built a negative form from the final vault, with polystyrene blocks moulded by robotic hands doing a milling process (Fig. 1 -RIGHT). It would work as a support for the central stone pieces, which would guide the rest of the construction with the bases.

Fig. 1 LEFT: Stone Matters, prototype 01. The use of stereotomy – the process of cutting stones – to make contemporary architecture. Fig. 1 RIGHT: Stone Matters, prototype 01. Milling Styrofoam with a robotic arm, aiming to do a negative form of the vault's centre. (From: http://aauanastas.com/project/stone-matters/)

### New Fundamentals Research Group – Giuseppe Fallacara | Italy, 2017

New Fundamentals Research Group is a non-profit association in the city of Bari, Italy, dedicated on researching about the use of stone in contemporary construction. They develop prototypes and designs that integrate traditional material into vanguard technologies, creating completely new forms and architectures that show themselves to be innovative and still respectful of their landscape. Italy has always been a traditional user of stone as a structural material, so the current resurgence of its use shows a relation with the country's historical technologies of construction. They have been using CNC's, robotic arms and routers as tools to construct their models as their main methods of digital fabrication and parametric design. Using a variety of limestone as main resources, they use the technique of *stereotomy* to mould blocks into modular pieces that will create together a new object or architecture. Among so many works, it is possible to use as an example a very simple project as the one called "Alveare" (Fig. 2), from 2010. The design consists in creating a single piece that, when seated with other just like it, starts creating hexagonal shapes. The parametric condition allows this hexagon to be moulded at any size and shape that the machine handles to sculpt. This process enables multiple uses and makes it more practical.

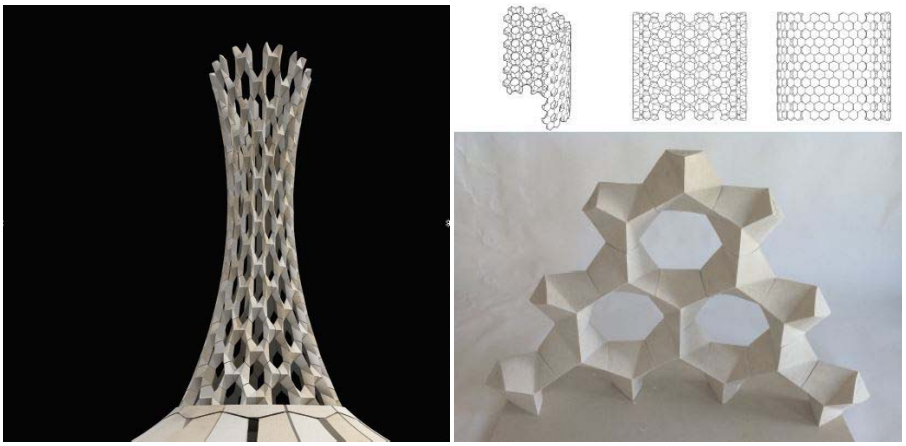

Fig. 2: “Alveare” project. Left, perspective of the final structure idealized by the group. The smaller modular piece, better seen in the picture at right, can be parametrically deformed and used to build infinite types of shapes. (From: FALLACARA, G. New Fundamentals of Natural Architecture, 2014)

## Conclusions | And the future?

It is easy to conclude that parametric design and digital fabrication are technologies that will influence Architecture massively in the next decades. Stereotomy seems to be an optimal alternative that associates future with tradition. Improving these techniques will allow professionals to gain better results and develop more efficient and sustainable constructions, respecting local communities, history and landscape.

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## About the authors

Andréa Silva Régis, graduation student from Federal University of Pernambuco (UFPE)

Federal University of Pernambuco (UFPE), Department of Architecture and Urbanism, CAC – Centre of Arts and Communication, Academico Helio Ramos Avenue, 50740-550, Cidade Universitária, Recife (PE), Brazil.

Carla Daniela Papariello Marzo, graduation student from Federal University of Pernambuco (UFPE)

Federal University of Pernambuco (UFPE), Department of Architecture and Urbanism, CAC – Centre of Arts and Communication, Academico Helio Ramos Avenue, 50740-550, Cidade Universitária, Recife (PE), Brazil.

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# Proposal of use of rock in architectural project in Recife

**Ana Karine de Souza; Luana Oliveira de Souza**

**Synopsis**

The disregard for the use of rocks in projects it is a reality in the present world of architecture. According to Professor Risale Neves (2012), there are very few architects who use rocks in their work and / or who have a little more in-depth knowledge about their types and characteristics. Thus, the present production allowed us to exercise the use of the stone as a structure and aesthetics, rethinking its support capacities, which, despite being exploited since many centuries ago, were left aside in the massive part of the current constructions.

**Keywords**

stone, project, church, Recife.

## Introduction

Rocks have been used in the construction of buildings since the beginning of the humanity, being present in the Egypt's pyramids, in the Roman aqueducts, in Greek temples, among many others. In those buildings, the rocks play a structural role and form part of the aesthetic and volumetric composition of the building. In addition, it is observed that many of the constructions made with this material still exist, as is the case of the Parthenon, which shows a great resistance of the rock material. But currently, the most common function attributed to rocks in Brazil is that of covering. It is seen, therefore, that the rock has a great structural, aesthetic and compositional potential for the architecture, but that this potential is not totally taken advantage of. What is proposed with this work is to use the rock in an architectural project, taking advantage of the potential that this material has, giving it not only the coating function, but also structural, compositional and conceptual.

In a city as full of memory as Recife, the churches are a spectacle apart. From various eras, they represent in physical form the history of faith of the people. The following work was guided by this religious charm, trying to understand what makes the churches such a special place from the exploration of architecture, which has the capacity to influence the spirit to feel connected not only with that space, but with the divine.

## Proposal

In order to choose the place where the project was hypothetically to be constructed, it was based on the idea that an ideal place for worship would be one with an abundance of green space and away from the busy routine of the city center. That said, the land chosen for the church proposal is located in the Apipucos neighborhood, Dr. Anauro Dornelas Câmara Street (Fig. 1 and Fig. 2). The area has the mentioned characteristics and is even more privileged by the landscape offered by the dam (Fig. 3).


Fig. 1 Location
Source: Google Images


Fig. 2 Location
Source: Google Images

Fig. 3 View of the terrain to the dam.
Source: Google Images

There are several ways to produce a church. Baroque and Gothic, for example, follow very proper styles of being, so the design process began by choosing what would be the architectural inspiration. Thus, coherently with the quest for a place of calm, the most logical path for the form would be the Modern one: cleanness, truth of materials and light in abundance.

To serve as a structure, a limestone rock proved to be a great choice: it is durable (Greek temples still standing today, they were built with blocks of marble and limestone - Fig. 4); is easy to find (the state of Ceará is a major extraction pole); The color of the stone, white / beige, inspires a peace and tranquility that is appropriate for the concept of place of worship explored in this activity.

Fig. 4 Peristyle Temple - foundation of limestone
Source: edukavita.blogspot

The walls would be composed of massive blocks of limestone, measuring 40 centimeter in height, 60 in width and 20 in depth. In an attempt to refer to the Pernambuco regionalism, it was sought in the cobogós, (an element that emerged in the city of Recife in the 1920s,) the source of inspiration. Knowing that the cobogó has as main quality the leaked elements, it was thought of an arrangement in which the blocks had a few inches of separation between them, allowing the entrance of air and threads of light, creating an interesting effect when drawing shadows in the entire space (Fig. 5)

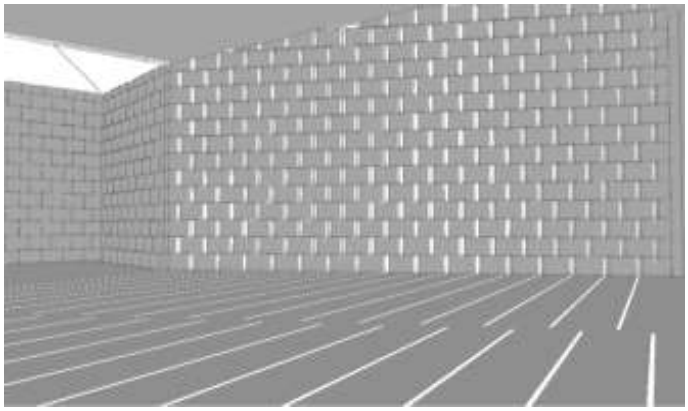

Fig. 5 Light entering through the cracks.
Source: Prepared by the authors

Regarding the level of polishing, it was thought to have the stone in its roughest state, with sawed finish. If nature is divine creation, we try to refer here as far as possible to the conception of the primitive, of the natural.

For hygiene and ease of cleaning in the internal space of the bathroom, the use of coating material such as the ceramics was considered necessary.Starting from the idea that everything and everyone converts to the altar, the most important space of the church, the building has acquired a "funnel" format, being wider and taller at the entrance and tapering as it enters the room (Fig. 6).

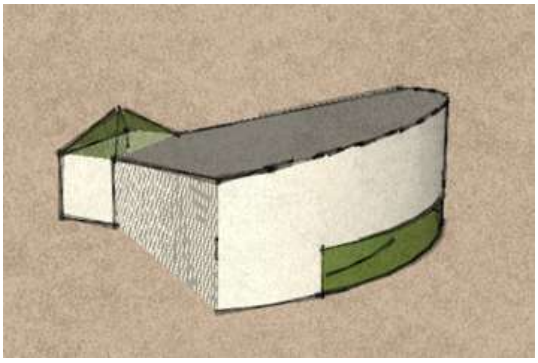

Fig. 6 Volumetry.
Source: Prepared by the authors.

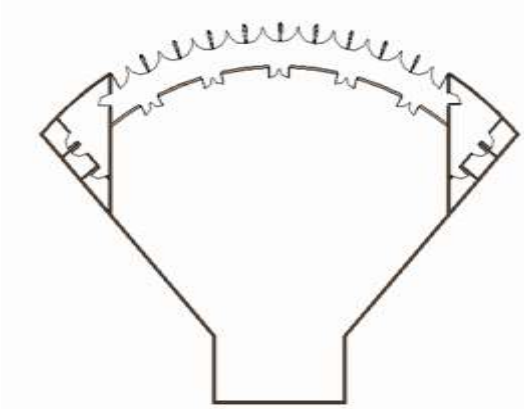

Fig. 7 Floor plan.
Source: Prepared by the authors.

The high ceiling in the entrance (Fig. 8) will promote a feeling of smallness before the building and spiritual elevation, concept widely used in the construction of several temples. It is worth mentioning that this format also allows an even more privileged view of the dam, moreover, it is going to favor a more generous entry of the winds coming predominantly from the southeast direction.

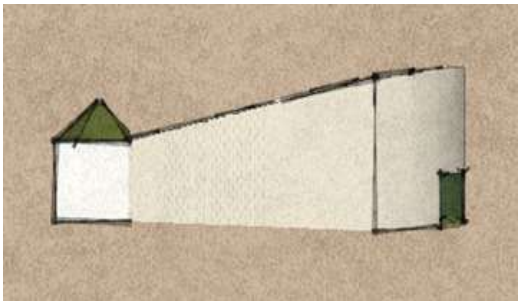

Fig. 8 Right foot difference.
Source: Prepared by the authors.

The roof was thought of as a slab of concrete that leans against the walls only in a few places, guaranteeing a small opening, a thread of light that brings lightness to the structure. For the floor, the burned cement was considered a great choice, due its high resistance to abrasion and humidity (Recife is a coastal city and therefore quite humid all year long). In addition, the appearance of this material promotes rusticity sought in this project. In the other hand, the altar space will have its own ceiling that will be higher than the one in the end of the "funnel"

format. This way, there will be a source of light "hidden" for those in the "audience," bringing a focus of natural light directly to the altar (Fig. 9), which, as been said, is the most important place in the church. This individual ceiling will be entirely of onyx, a stone that has a great aesthetic appeal and has a transparency that allows the entrance of light. Unlike the rest of the building, the walls of the altar will not have spaced blocks or openings that allows the entrance of threads of light. The idea is that all light in this space come from a single source: the onyx.

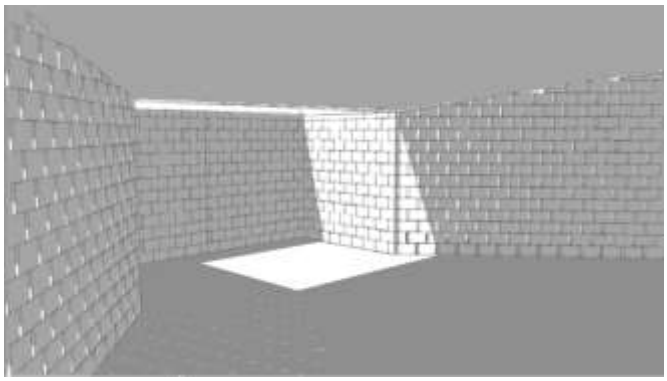

Fig. 9 Light on the altar.
Source: Prepared by the authors

The main façade will have a large glass slit (Fig. 10), followed by a small lobby where the church doors will be tall, proportional to the height. It will be through these doors that will pass the largest amount of light that will be filtered through the glass of the main entrance and will enter in an elongated way through the space.

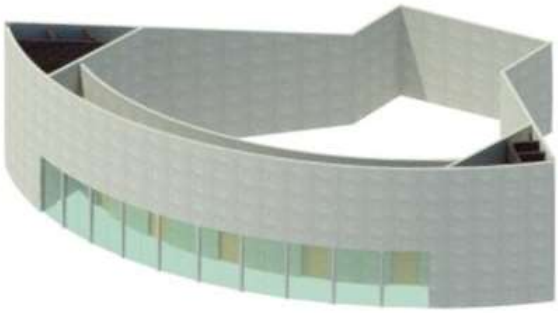

Fig. 10 Glass slit.
Source: Prepared by the authors.

## Conclusion

The use of rock as a structural and at the same time aesthetic element is part of a search for the truth of the material in a city in which new constructions are begun every day and most of them start from a pattern of forms and materials that hide or imitate other materials. The proposed church seeks to free itself from the common volumetry and common type of material, showing the strength of the rock as support and beauty while integrating with Pernambuco regionalism with its montage inspired by the cobogó.

Through the process of "building" the church, it was possible to see how much the rock became an intrinsic part in the concept sought for that space, how much its importance grew to the point of become the project itself: without the use of limestone and onyx, we would be facing a completely different edifice.

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## About the authors

Ana Karine de Souza, Proposta de uso de rocha em projeto arquitetônico no Recife

Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Av. da Arquitetura, S/n - Campos Universitários, Recife, 50740-550, Brazil. anaksouza96@gmail.com

Luana Oliveira de Souza, Proposta de uso de rocha em projeto arquitetônico no Recife

Universidade Federal de Pernambuco, Departamento de Arquitetura e Urbanismo, Av. da Arquitetura, S/n - Campos Universitários, Recife, 50740-550, Brazil. tamarindodesouza@gmail.com

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# Usage of stones: potential, lack of knowledge and opportunity

**Risale Neves**

**Synopsis**

Brazil has stone potential to be explored by architects for structural use in buildings and also other functional uses, which will be better explained. The leftovers from quarries, sawmills and stone stores are often not used which needs to be reconsidered, for the sake of environmental sustainability of these spaces. However, the aggravating factor of such context, is the unfamiliarity of the Brazilian architects in this field of knowledge, contributing to the preponderant lack of teaching in the architecture courses of the country, resulting in the lack of architectonical references in fields such as: structural and functional use and rock leftovers usage in projects exemplified in this article. The lack of opportunity for students, professionals, producers and users impoverish Architecture, raising debates in the search of the solutions.

**Keywords**

rocks, structures, functional uses, differentiated uses, lack of opportunities, teaching.

## Context

All over the world, works of stonemasonry are prominent either due to the ability of the stonemason masters or to the mastery of great architects. In Brazil, where works initially were erected in arenite and limestone with Portuguese influence during the colonial period, the building techniques changed, from the 1920's in the last century when steel, glass and concrete were introduced, banishing the tradition and the stones in buildings.

Today, the employment of stones in other countries is remarkable due to the great variety of uses, while there are only a few different uses in covering in Brazilian works. Interviewing Brazilian architects, Neves (2012) confirmed the use of natural stone of many types and formats in wall claddings, walls and prop walls; slabs of rocks in wall claddings, countertops and floor coating of constructions and also rock *filetados* in facades, with little emphasis in structures or architectonic composition, functional uses and leftover stones usage. Among the few structural uses of stones in Brazil are the cyclopean concrete in Carlos Bratke's works (SP) and the natural stone composing with steel and glass in a house in the state of Bahia (BR), by João Filgueiras, also known as "Lelé" (RJ). It is worth mentioning Rui Ohtake's use of onyx in architectural details in Hotel Unique (SP).

## Focus of the study

This study highlights three essential points: Brazilian rock reserves; the lack of knowledge of the reserves potential to most architects; which implies the lack of diversification of the quarry products. It is known that Brazil has potential and geodiversity of natural stones, though only 15% of its territory is geologically mapped. Despite this fact, Brazil is the 5th largest producer in the world, according to Mendes (2017). The igneous, sedimentary and metamorphic nature of the rocks present in the Earth's crust allows their use in building structures as well as other functional systems - which will be later explained,

provided that the particularities of each use are observed, mainly rock properties, and their aesthetic features. It is believed that Architects from other countries own such knowledge through their works, but it is certain that most Brazilian architects are neither unaware of these works nor take advantage of the leftovers from quarries and sawmills.

From this point of view, considering the Brazilian stone potential and the lack of knowledge from the architects, the quarry owners lose for not diversifying their product lines beyond slabs and tiles and do not sell off-standard materials - the so-called leftover stone. That extends to the sawmills and stone stores, whose leftover stone users are generally not architects, employing the stones in coverings and details. This lack of opportunity has been seen for quite some time.

## Definitions

The structural systems in architecture are defined by the arrangement of materials and techniques that sustain the buildings. The Greek and the Romans erected temple columns overlaying stone blocks that are able to bear, beside their own weight, the weight of beams and pediments, adding concentrated forces (Fig. 1). The Sagrada Familia Church, work of the Catalan Antoni Gaudi (1852-1926) started on the 19th century in Barcelona, Spain, shows monumental columns with the same overlaying block system, exquisitely molded in the shape of tree trunks (Fig. 2), without structural complexity, but with quality carving and accurate aesthetics.

Fig. 1 Segesta's temple. Source:https://www.brasilnaitalia.net/2013/08/segesta-tesouros-arqueologicos-na-sicilia.html (02.10.17)

Fig. 2 Base of the columns of the Sagrada Familia Church, Barcelona, Spain. Source: The author, 2011.

Moving towards the 21st century, there is the San Giovanni Rotondo Church in Foggia, Italy (2004), work of the Italian architect Renzo Piano, about which he comments: "the technique with which we made the large arches of San Giovanni Rotondo could give a new impetus to the use of this old material. […] I selected materials that express simplicity and solidity: local stone and wood, as well as the glass of the windows". It is a structure made of the regional limestone named Apricena, which forms an intricate support system made of arches held by steel cables (Fig. 3).

Another peculiar building due to its structure and plastic composition is the Bishop Edward King Chapel (Fig. 4), at the Ripon Theological College, Oxfordshire, by Niall McLaughlin Architects. The circular base is 3.5 meters high and covered in Clipsham stone, upon which there is another circular body of 4 meters made of blocks that measure 25 x 11 x 9 cm. For this work to be completed were used 36,000 blocks, sawed and carved by hand, at the front. It was shortlisted for the 2013 Stirling Prize of the Royal Institute of British

Architects and was the winner of the Building Project of the Year Award of the British Construction Industry Awards.

Fig. 3 Padre Pio Sanctuary. Source: The author, 2011.

Fig. 4 Bishop Edward King Chapel. Source: http://www.stone-ideas.com/2013/11/15/a-capela-do-ripon-college-na-inglaterra-exibe-na-fachada-uma-urdidura-em-rochas-ornamentais/ (14.04.2017)

The functional systems in architecture include the use of stones in the building structures, but, in this work, they will be addressed as the architectural compositions, which convey beauty to the shapes of buildings and have some specific function apart from structural. The Spanish architect Alberto Campo Baeza showed the alabaster in both aesthetic and functional uses in the award winner Caixa Geral de Depósitos of Granada, Spain (2000). In this work, known as "light impluvium", Baeza wished, through the stone's transparency, to capture natural lighting into the building. (Fig. 5). It is clearly neither a structural nor a covering use of stones.

Fig. 5 Interior of Caixa Geral, Granada, Spain (2000). Source: https://www.archdaily.com.br/br/801723/classicos-da-arquitetura-caja-granada-savings-bank-alberto-campo-baeza (01.11.2017)

Fig. 6 Delegación Provincial de Salud in Almeria, Spain – photography of panel at the International Architecture Biennial in São Paulo. Source: The author, 2005

In the work of the head office of Delegación Provincial de Salud in Almeria, Spain (2005), Baeza imagined the pivot panels of the façade, describing it as "se propone un edificio en el que las piedras com las que si construye se mueven, se abren o se cierran para dejar pasar al sol [...] cuando todas las contraventanas exteriores, que son las piedras que se mueven, están cerradas, el prisma se muestra como uma caja pétrea hermética. Y al abrirse o cerrarse, la fachada cambia" (Fig. 6). This was also not a structural or covering use, although the whole building is covered with the same material as the panels - lumaquela stone, a rosy shaded limestone.

In this scenario, leftover stones should be included, as importantly as the above-mentioned systems, especially due to their environmental benefits. Antón Garcia, Spanish architect, designed at the quarry the façade of the General Society of Authors and Publishers, located in Vista Alegre property in Santiago de Compostela, Spain. He recovered pieces of stone of various forms and sizes and arranged a mesh from the floor to the ceiling and through which the sunlight comes in all along the gallery (Fig. 7). In another example also in Vista Alegre property using the same stone, gris mondariz granite, abundant in Galicia, the architect projected The Galicia Musical Studies Center (Fig. 8), using blocks and discarded external slabs from sawmills leaving drilling separation traces of exposed blocks visible.

Fig. 7 Model of façade composition made at the quarry. Source: https://1.bp.blogspot.com/_PH6mtNlELPU/R0xMcXna38I/AAAAAAAAADU/7sdwOkXjAlg/s320/garcia-abril4+copy.jpg (14.04.2017)

Fig. 8 Façade of The Galicia Musical Studies Center. Source: The author, 2011.

## Final remarks and conclusion

The illustrated examples in this article reveal that through the architects' hands of other countries, stones became decisive for the buildings' aesthetics and play leading structural or functional roles in the architecture of buildings when used in differentiated ways (Neves, 2009). They show complex structural solutions, as well as simple ones, with modeling and arrangements of easy-to-build pieces, even at quarries. They show it is possible to explore the versatility of the stones in natural lighting and plastic composition effects, using translucent stone slabs in which with creativity, the leftover stones can also feature the main role in architectonic projects.

Meanwhile, the Brazilian architects are unfamiliar with these uses due to the lack of teaching at universities. There is no teaching because there are not professors who master this knowledge at the architecture faculties. This fact has been in discussion since 2002, and was the subject of the doctoral thesis *T* *es in Architecture*: *contributions to the process of specification* (NEVES, 2012).

In 2005, during the first Congresso Internacional de Rochas Ornamentais - I CIRO (Guarapari, ES, Brasil), the architect from Espírito Santo and honored professor Carlos Maximiliano Fayet, who was the president of the Brazilian Association of Architecture Teaching, ABEA, recommended other ways to promote rock knowledge, and not depend exclusively from formal education of universities.

In 2017, during the III Encontro Nacional de Ensino de Estruturas em Escolas de Arquitetura, (Ouro Preto, MG, Brasil), the author of this article stated: "there are few architects involved with the stone production chain in Brazil and even less with teaching, what leads us to the need of expanding the discussion […] The architecture is the main user of the building materials, and the stones, being natural materials, have their own specificities […] whose knowledge will guide the assignment granted to the architects by the Federal Law 12.378/2010 , to specify materials.

Therefore, students, professionals, producers and users come across the lack of opportunity. Students do not learn and professionals do not project using stones, leaving new production lines aside at quarries. Without further demands, the stonemasons do not diversify nor broaden their line of products. The users, on the other hand, do not enjoy the comfort, beauty and practicality given by natural stones, impoverishing architecture.

In view of this reality, one may conclude that it is indeed necessary to find new ways of promoting the knowledge rocks usage in architecture in Brazil, stimulate the creativity of Brazilian architects and the differentiated use of rocks in architectonical projects, in order to perfect the practices of already consolidated use and also diversify quarries production lines. To whom may this discussion be interesting?

The Brazilian rock producer sector is convened to identify architects, professors or not, interested in this subject offering them workshops, trainings and visits to reference works and fairs. That such identification may happen in many ways and the results of the new learning could stablish a positive feedback to the architecture courses in the country.

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## About the author

Professor Risale Neves Almeida, DSc in Geoscience –

Federal University of Pernambuco, Department of Architecture and Urbanism. Av. Professor Moraes Rego, 1235 – Cidade Universitária, Recife, PE. CEP: 50670-901, Recife-PE, Brazil. risale@hotlink.com.br

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# From thesis to teaching: the use of stones in architecture

**Risale Neves**

**Synopsis**

Since 2002, when I first realized that I did not know about the use of stones in architecture, and acknowledging that there was much criticism on the architects' unfamiliarity with these materials - what ends up in great damages to the stones used in buildings -, I decided to investigate the architects' knowledge on the subject. This initiative was held in a doctoral thesis, which reached the subject in two aspects: the access to information in Brazilian architecture schools and interviews with fellow architects, who work directly in projecting buildings and specifying materials. In conclusion, there had never been any teaching directed to the use of stones in architecture in Schools in Brazil. The doctoral thesis, therefore, proposed the creation of the first discipline on the use of stones in the Architecture and Urbanism Faculty at the Federal University of Pernambuco, Brazil.

**Keywords**

Stones, teaching, interviews, architects, schools.

## Context

For almost two decades there have been initiatives dedicated to stone mining, research and usage of stones in buildings, especially in the Northeastern capitals of Brazil, like mini courses, symposia and congresses, which contribute to the growth of the studies on these materials.

Since then, the Mineral Technology Center of the Ministry of Science, Technology, Innovation and Communication of Brazil (CETEM/MCTIC) has led investments in presentations and discussions about researches on stones and their inadequate specification and use, imputed to the fact architects lack the knowledge of stones' properties and technological characteristics.

Inspired by problems identified in 30 or 20-year-old buildings (or even newer) in urban centers and waterfront strips of coastal cities - having stones more exposed to weather conditions -, researchers, from graduate students to doctors in the field of Geology and Mining Engineering, use articles and lectures to call architects' attention on these discussions.

Even being material specification, an assignment granted to the architects by Federal Law number. 12.378/2010, few architects really seize the opportunity offered in the events related to the use of stones, what one could infer as being lack of interest in overcoming this unfamiliarity. This scenario led me to choose this theme for my doctoral thesis.

## Surveys on architecture teaching and interviews with architects

Driven by questions related to the knowledge architects would or not have about the use of stones in buildings, I decided to know, first of all, what architecture schools in Brazil offered so far (2010/2012) as technological basis for this use of stones.

Secondly, I interviewed experienced Brazilian architects dedicated to projecting buildings, in order to know on what basis they have relied when specifying marbles, granites or another kind of stone available.

I sought to find out what stones are more largely used in projects and their main functions, as well as the finish types. I also checked their knowledge related to the use of stones on the international scene, in which architects emphasize the use of stones as structural elements in architectonic composition, in a modern fashion.

The European experience, for instance, shows us how stones have been used in architecture, not only as coverings, in the last few years: the Basilica of San Giovanni Rotondo, in Italy, designed by the Genoese architect Renzo Piano; the Caja Granada Headquarters, in Spain, an award-winning work of the Spanish architect Alberto Campo Baeza; the Thermal Baths in Vals, Switzerland, work of the Pritzker Architecture Prize laureate Peter Zumthor; and General Society of Authors and Publishers Central Office in Santiago de Compostela, Spain, work of the Spanish architect Antón Garcia Abril. All of them evidence differentiated uses of stones nowadays.

## Findings on architecture teaching

As for the schools, there were 223 architecture schools in Brazil in 2010, according to the Ministry of Education. By the end of 2013, there were 280 accredited schools of architecture and, before 2017 ended, there were already more than 640 of them in Brazil. However, the study, developed between 2010 and 2012, used the 2010 figures.

Schools were questioned whether there was any curricular content directed to the learning of the technological properties and characteristics of the stones, aiming at their use in architecture. 150 schools of architecture answered the survey, 29 schools did not, and other 44 schools said they were beginning their activities, so they would not have any information to give.

Among the 150 schools that answered the survey, only 17 of them mentioned some content, which was available on their website or in the documents that were sent. Furthermore, amidst these 17 faculties, only two of them had appropriate bibliography. To sum up, we can say that there has never been any teaching focused on this theme in Brazil, since the establishment of the first schools of architecture around the 1930's.

## Interviewing the architects

When it came to the fellow architects, the interviews were the most interesting part of all the research for the doctoral thesis. They showed, with rare exception, the unfamiliarity with the subject since the early years of architecture school.

The interviews revealed some things that should be of interest to the natural stone producers in Brazil: the deep concern architects have over the unsuccessful uses seen in stones; the current preference for manufactured materials to avoid risks; and the disbelief in the empirical guidance given by producers, which is particularly relevant to the ones who specify materials, especially in the light of the Norma de Desempenho da Construção Civil, ABNT/NBR 15.575/2013, in force.

The reports about problems seen both in their own works and in their peers', match the defects previously pointed out by researchers in academic studies: detachments, surface abrasion, humidity stains, oxidation, loss of shine, and so on.

As for the most common uses in Brazil, covering comes first, including filleted stones, ventilated façades - which have been at least once used by 50% of the interviewed architects -, and natural stones, used in the Northeastern region as thermal protection, though empirically.

Few architects mentioned having used stones as structural elements, architectural composition or any other use apart from coverings (Neves et al, 2009). The international works depicted in the doctoral thesis (four of which were mentioned in this article) were recognized only by the architects in the academic field.

## The proposal for architecture teaching

In order to value stones as mineral wealth and aiming at their durability and beauty when applied in buildings, the doctoral thesis proposed an unprecedented discipline on the use of stones in architecture, today being held at the Architecture and Urbanism Faculty at the Federal University of Pernambuco, UFPE.

In the second half of 2013, the first class began their studies, and even some graduated students attended it, allowing the spread of this knowledge to professionals that had already entered the job market. New classes have been held every semester. As it is a 30-hour elective course, it is meant for only 15 students, being the Professor able to accept more enrollments, which has been happening, once classes have generally had around 20 students.

During the course, students get in touch with the use of stones in international architecture; the production chain; recurring damages to installed stones; types of stones, their properties, mineralogic composition and technological characteristics; specifying; installation. Students also interact at the Geology and Mineralogy laboratories, in order to be acquainted with stones and their composing minerals, under the direction of Professors Evenildo Bezerra de Melo and Lucila Prado Borges, from the Geology Department at UFPE.

Besides the above-mentioned activities, a practical class in a stone showroom and sale helps students consolidate what was addressed during classes. MARMOPEDRAS, a stone showroom and sale in Olinda, Brazil, is a partner in activities held by UFPE since 2013 and welcomes students every semester (Fig. 1 to Fig. 4).

Fig. 1 Laboratory of Geology UFPE

Fig.2 Laboratory of Mineralogy UFPE

Fig.3 Laboratory of Mineralogy UFPE

Fig.4 Stone shop Olinda, Brazil

## Conclusions

Due to the absence of teaching on the theme as previously mentioned, the opportunity to use stones in a leading role in architecture has been missed, especially in differentiated uses. Besides the lack of teaching, Brazilian stone producers and traders only emphasize the commercial focus, neither informing the geological nature of stones nor stating what the best usage would be.

It is worth mentioning that knowing what is the most suitable type of stone for each use is a subject that needs further studies, considering their multiple uses in architecture. Another aspect that deserves similar attention is the installation procedure adopted by the construction industry, not always appropriate. The constant emphasis on the “aesthetics” of the stones, given by specifiers, clients and even scholars, is yet to be reviewed.

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## About the author

Professor Risale Neves Almeida, DSc in Geoscience

Federal University of Pernambuco, Department of Architecture and Urbanism. Av. Professor Moraes Rego, 1235 – Cidade Universitária, Recife, PE. CEP: 50670-901, Recife-PE, Brazil. risale@hotlink.com.br

# TECHNOLOGY TECHNICAL SESSION

Blue Bahia granite quarry (Soc. Marmífera Company) - Photo: Nuria F. Castro (2018)

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# Diamond wire cutting test in Nordic winter time

**Seppo Leinonen**

**Synopsis**

Wire sawing is becoming more common in dimension stone quarries in Finland. Wire cutting improves overall efficiency of block production and carbon dioxide foot print is considerably lower compared to that caused by drilling and blasting. Winter season in Finland lasts 4-6 months, average temperature varies from south coastal areas -5°C to north areas -13°C. So, freezing conditions set a big challenge to water using wire quarrying. Winter time wire cutting was tested by Geological Survey of Finland in project "Resource Efficiency Development of Natural Stone Production". Project is funded by local municipalities, stone companies and European Regional Development Fund, ERDF. Experiences of wire sawing in Nordic winter time were positive and so far recommended to take the method to all seasons use in industrial production.

**Keywords**

Dimension stone, diamond wire, winter time, black stone, carbon dioxide.

## Background

A significant development in the Finnish stone industry took place in the 1970s. The extraction techniques got notable efficiency and production cost per ton of stone decreased considerably. This was achieved with easily used plastic tubes packed explosives, also speeding the operations by hydraulic drilling rigs and large wheel loaders. For example, a hydraulic drilling equipment is three times faster than old pneumatic technique. Although the drilling-blasting method is fast, it breaks the stone in all quarrying steps from primary extraction to final shaping the blocks, especially with black stones. Currently, more resource efficiency is being developed by stone-saving methods, including diamond saw cutting (Medda et al., 2015). Although it makes sense to gain more block for sales and reduce $CO_2$ emissions in the production at the same, when taking wires in all seasons use in Nordic countries, there is still the major challenge, how water using method operates in freezing winter conditions.

## Test conditions

Diamond wire sawing uses water for cooling and removing stone fines from the cut line. In Finland, winter time and frosts last for 120-180 days, i.e. 4-6 months (Fig. 1). In order to completely take the diamond wire cutting as a main quarrying method, it should be found ways of quarrying also in freezing conditions (Fig. 2). In addition to develop winter time technologies, it was also examined differences of the cutting performance with two black stone types. Test periods were carried out in Kivilahti diabase and Oulainen gabbro quarries, of which the winter seasons test in Kivilahti. Test period in freezing conditions was made in the first weeks of December 2016. Temperature was below zero in all days, varying from -2 degrees Celsius (°C) to -18. Temperatures in early mornings were typically some lower than daytimes. Lowest temperatures, when wire cutting has been done has been as low as -25°C. At that cold conditions, it is also possible to make block shaping by dry cutting. During winter test flushing water was taken from a local river. Pipe line was dug below surface. The

freezing of the pipeline was prevented by pumping water continuously and emptying the lines at the end of the working day.

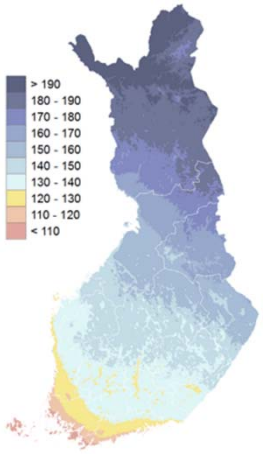


Fig. 1 Winter time in Finland, in days (Ilmatieteen laitos, 2017).

Fig. 2 A horizontal wire cut in frozen diabase at Kivilahti, air temperature -18°C (photo 12th December 2016).

## Black stone types

Wire sawing performance was compared at two different black stones, Kivilahti and Oulainen (Fig. 3). Kivilahti formation, located in Ilomantsi East Finland is a diabase dyke; Oulainen black, located in West Finland is a gabbro intrusion. Both stone types are fine grained (average dimension 1-2 mm), mineral contents plagioclase, amphibole, pyroxene and Fe-Ti –oxides. Oulainen gabbro includes in addition 20% biotite. Mechanical properties varies quite much between these two stone types, of which Oulainen is a moderately (Mesimäki, 1994) and Kivilahti a high strength black stone (Pirinen, 2010), Table 1.

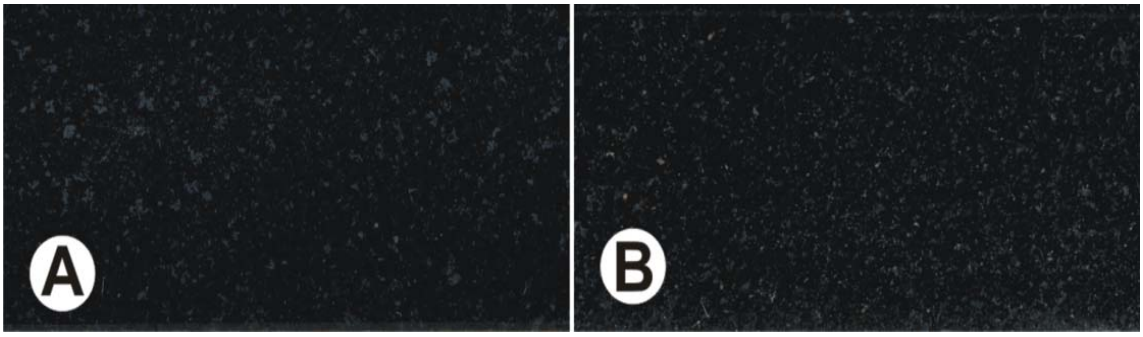


Fig. 3 A) Kivilahti diabase and B) Oulainen gabbro. Size in both samples is 80 mm (width) x 40 mm (height).

Table 1 Mechanical properties of Kivilahti diabase and Oulainen gabbro.

| | | Kivilahti | Oulainen |
|---|---|---|---|
| EN 13755 | Water absorption % | 0.03 | 0.09 |
| EN 1936 | Open porosity % | 0.1 | 0.29 |
| EN 1936 | Density kg/m$^3$ | 3060 | 2900 |
| EN 12372 | Flexural strength MPa | 32.7 | 18.4 |
| EN 1926 | Compressive strength MPa | 293 | 210 |

## Results

In winter time test the total cut was 374 m$^2$, most of that in horizontal direction. The test was succeed. There was no technical problems and pipelines didn´t froze even the water was taken straight from ice-covered river without any heating. The most critical moment of stuck wire by freezing is when sawing starts on frozen bedrock surface. It is also very important to avoid stopping the wire, especially for horizontal cutting. The frozen wire is easier to melt in vertically line by warm water. When the wire is already running as a depth of 2 meter in the rock, the risk of freezing is significantly reduced because at this level the temperature is not any more below zero degrees Celsius, $^o$C. Flushing water is able to take from local lakes, rivers or wells. It is also possible to bring water by tanks, in that situations heating should be arranged. It is recommendable to use heated water (+30$^o$C) always when the air temperature is below -10$^o$C or if there seem to appear any other risk of stuck wire. During the winter test water supply was 20-30 liter per minute, about the same than in summer operation (Fig. 4).

Fig. 4 Formation of ice on pulley and drive wheels. Photo was taken on 12$^{th}$ December, daytime temperature was -18$^o$C. Wire saw unit is Huada 55 kW, powered by a diesel aggregate Iwego 175 kW.

There is no significant difference in sawing performance comparing a single primary cut in summer and winter season at Kivilahti quarry. The speed of primary cut with a long wire was about 7.9 m$^2$ per hour (Table 2). The durability of wire is the same as in the summer operation, about 10 m$^2$ cut per wire meter. The optimal speed of wire was 30 meters per second (m/s) and an applied tension 75-90 amps (A). The length of the wire loop was 80 m at the start of the cut. Comparing the saw performance of the Kivilahti diabase and Oulainen gabbro, there is a remarkable difference. Gabbro is able to be cut two times faster (20.6 m$^2$) in an hour than more strength having diabase, 293 MPa compressive strength (that of gabbro 210). The high cutting speed is also able to be explained by little lower Mohs

hardness 5.7 (that of diabase 5.9). Oulainen gabbro contains otherwise the same minerals but also soft mica about 20%. Used wire in both test places was Tyrolit GSF 5 (with specification for hard granite). The number of diamond beads, 11.3 mm in diameter, were 40 per meter.

Table 2 Technical parameters of diamond wire sawing test in Kivilahti and Oulainen blacks.

| | | Kivilahti | Oulainen |
|---|---|---|---|
| Wire speed | m/s | 30 | 27-30 |
| Cutting performance | $m^2/h$ | 7.9 | 20.6 |
| Applied tension | A | 75-90 | 73-82 |
| Wire life | $m^2$/w-m | −10 | +10 |
| Energy consumption | KWh | 49 | 31 |

## Discussion

Considering a single cut there are no significant difference in performance of summer and winter time diamond wire sawing. At Kivilahti diabase quarry it is able to saw 7.9 $m^2$ per hour with a long wire loop. Kivilahti black is an example of a high strength stone, 293 MPa compressive strength by EN 1926. The need for energy in the wire cuttings was about 50 kW in an hour. $CO_2$ emissions for example of 10 $m^2$ cutting is 13 kg $CO_2$. An average $CO_2$ value of electricity power output in Finland is 0.209 kg $CO_2$ kWh. Wire sawing causes about 10 times smaller emissions than values of the drilling rig worked the same surface area, 110 kg. High $CO_2$ values of drilling machines comes from slow penetration in diabase (0.5-0.6 meter/minute) and need to make holes in tight row, 10-12 cm spacing. Comparing different black stone types, there is a major difference in cutting performance between Kivilahti and Oulainen. Kivilahti diabase represents a high strength black, instead Oulainen gabbro a moderately strength type (210 MPa) and able get great measurements as high as 20.6 $m^2$ opening per hour. Test results of wire sawing in Nordic winter time were positive and the method is recommended to take in industrial use, for all seasons.

## Acknowledgments

The author would like to thank the owners of the quarries - Kaivu ja Kuljetus Pyöriäinen Ay (Kivilahti diabase) and OK Graniitti Oy (Oulainen gabbro) to make the wire cutting tests possible. I also acknowledge The Regional Council of Pohjois-Savo for funding the project.

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## About the author

Seppo Leinonen, Head of Unit Industrial minerals

Geological Survey of Finland, P.O. Box 1237, FI-70211 Kuopio, Finland. seppo.leinonen@gtk.fi.

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# Innovative optimization in the diamond wire cutting process in quarries

**Jorge Miguel Lopes Frazão, Fábio Ribeiro André, Inês Paulo Frazão**

**Synopsis**

In the last 10 years the squaring phase in the natural stone extraction has evolved by means of the innovation and the technology used in the machines, that has led to an increase of productivity. Diamond wire is everyday more efficient, with more quality and better adapted to the stone characteristics. Combined with machines that allow a correct definition of parameters according to stone characteristics has given the rightful contribution making Diamond wire cutting a preferable cutting method. Arising from this evolution is the need for the constant optimization of processes and resources resulting in the development of a new machine concept for this squaring phase. The objective of this research is to describe the optimization in the process of transforming the bench into transportable blocks with diamond wires. The applied method is quantitative and the data collection was in Portuguese quarries. The results show a clear resource optimization, essentially when it comes to the repositioning and adjustment of the machine code name MFER because of its mobility and technology.

**Keywords**

Quarrying, Productivity, Innovation, Diamond Wire, Industry 4.0.

## Introduction

Natural stone extraction has associated challenges that besides being a natural element with intrinsic characteristics that influence the exploration methods (Frazao & Frazao, 2013). Bagherpour, Khademian, Almasi and Aalaei (2014) defend that diamond wire cutting machines have been used in stone industry since 1985 and have affected the production rate and efficiency considerably. Today, they are widely used in more than 90% of the natural stone quarries. “Stone blocks are frequently extracted from quarries by means of diamond wire, and the same technology is used to square blocks” (Turchetta, Sorrentino & Bellini, 2017). According to Bagherpour et al. (2014) since the costs of cutting wire constitute a big portion in exploitation costs, its optimization can lead to great improvements in mining economy. So, to minimize the operational costs, some investigations about this process is essential.

Diamond wire is a highly flexible cut off grinding process and is getting more efficient, better quality e better adapted to the different stone types (Denkena, Kolher & Ermisch, 2013). Allied to machines with Technologies that allow a correct definition of cutting parameters (production digitalization), adapted to the stone types and characteristics has given the contribution for making the Diamond wire cutting the preferred cutting method (Monteiro, 2014).

Production digitalization, the so called 4th industrial revolution, industry 4.0, according Bechtold, Kern, Lauenstein and Bernhofer (2014) represents the change of the production paradigma. Is being pushed by three big changes, exponential capacity of computers, the quantity of digital information and the new strategies (people, research and technology). Industry 4.0 connects incorporated technological production systems and smart production

processes. In the case of Natural Stone Sector, in extraction, there has been evolution in the area of data management and integration.

## Objective

From the constant technology innovation and the need for constant process and resources optimization arise the development of a new machine concept for the squaring phase making a new different approach for Diamond wire cutting but common in drilling, i.e. vertical cutting. This study assess this concept machine MFER for the squaring phases in terms of productivity.

## State of the art

The extraction process has 4 phases (Fig.1). For the drilling phase, there is a Tracked Down the Hole Machine (MFFR) that increases the productivity comparing with the traditional methods in more than 90% (Frazão & Frazão, 2015). For the tilting phase, there is an Hydraulic Stone Bench Pusher (TB) to increase the productivity in this process in more than 80% (Frazão & Frazão, 2013). Finally, to the squaring process it has the Tracked Drilling Machine (MPL) that can increase the productivity between 30 until 70% (Frazão & Frazão, 2015).

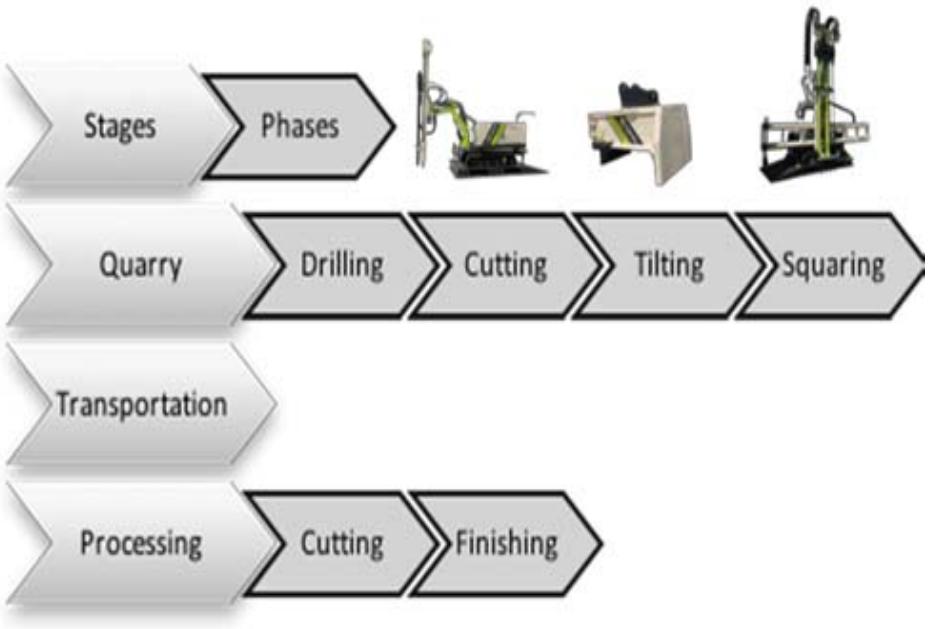


Fig. 1 Steps and stages on stone extraction with Fravizel prototypes. Source: Frazão and Frazão, 2013

The first phase where diamond wire is used is in cutting (phase 2), a.k.a. primary cut (Fig.2). In squaring (secondary cut), besides the use of the MPL is usually used the stationary wire and saw machines. Considering the substitute cutting method has the stationary wire machines, after the bench is tilted down, the machine has to be placed over the tracks, leveled, pass the Diamond wire under the bench and them cutting. In this phase the substitute is positioned perpendicular to the cut bench (Fig.3).

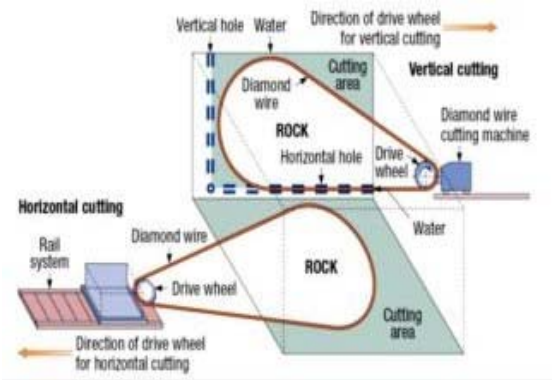


Fig. 2 Cutting Process in the extraction of stone bench. Source: Bagherpour, Khademian, Almasi and Aalaei (2014)

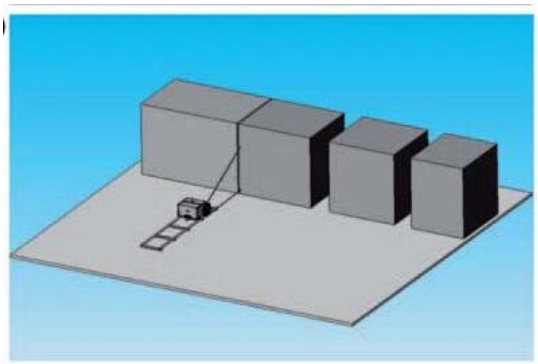

Fig. 3 Production via diamond wire cutting method. Source: Sariisik and Sariisik (2013) cited in Ozkan, Sarusuk and Ceyland (2014)

## Methods and materials

The used method to this investigation was qualitative by observation and has been applied for a sample in a Portuguese limestone quarry.

## Conclusion and results

There are still many problems to be solved for diamond wire cut technology, even though many companies employ frames with diamond wires to cut and to square stone blocks. The poor surface finishing, the process dangerousness and the high cost of the cutting operation, due to the low efficiency and to the numerous breaking of the wire, that is expensive, represent the principal technological limits of this process. Turchetta, Sorrentino and Bellini, 2017). So the innovative concept is applied by the machine code name of MFER (Fig.4).

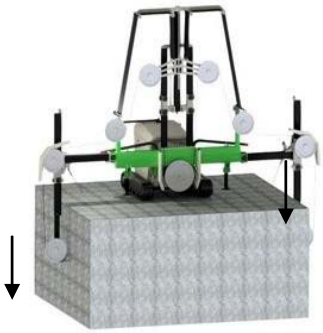

Fig.4 MFER 3D scheme

Fig.5 MFER cutting process

The MFER is a tracked machine and is placed by a carrier machine (wheel loader) over the cut bench (Fig.5). From there is does all the necessary steps to square the bench, like moving, align and cutting without the need of another machine. It has an extendable structure that can adapt to a bench up to 8m wide and 3,5m high. The cutting process is similar to a mono-wire, vertical cutting.

The results demonstrate a low setup and alignment time compared to the substitute. Has shown in table 1 the MFER has an average setup and alignment time of 5m36s. This is so because the machine is working on top of the bench, making vertical cuts while the substitute has a worse performance because they have to transported my means of another

machine, setting the wire under the bench and be manually leveled and aligned. Cutting times are similar.

In this study it was observed that in the substitute machine the wire has no water for cooling in the return segment of the cut, i.e., although there are abundant water on top of the cut, when the wire return to the machine the water is thrown away by the wire speed. The reduction of environmental impacts by the means of less nonrenewable resources used will be further analyzed in the future. The MFER advantages are not just related to time reduction, but also in the quantity of resources allocated to this phase, specially compared when it is necessary to relocate the substitute machine between cuts with a wheel loader and its operator. Was possible to observe the increase of safety with a remote control technology of the machine. Also it allows to manage data introduce in the machine, connecting with other systems (Industry 4.0). The attractiveness and consequent competitiveness of the sector depends a lot on the technology used and business strategy should be aligned with the resources available in the sector (Frazão, 2016). It is important that the technology interact with the human and be intuitive and efficient (the minimum resources and time).

Table 1 Cutting process with MFER

| Task | Machine Resources | N | Human Resources | N | Results |
|---|---|---|---|---|---|
| Place MFER on bench | Wheel Loader | 1 | Wheel loader operator<br>MFER operator | 2 | 4 min |
| Positioning and leveling MFER for cutting | Not needed | 0 | MFER operator | 1 | 5m36s |
| Cutting | Not needed | 0 | MFER operator | 1 | 8m$^2$/h |

Note: Personal observation from field visits (2017)

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## Acknowledgments

We thank Fravizel, Filstone and Solancis for their collaboration and support.

## About the authors

Jorge Miguel Lopes Frazão, Engineer

Fravizel S.A., Department of R&D, Zona Industrial Pé da Pedreira, Alcanede 2025-999, Portugal. JFrazao@fravizel.com.

Fábio Ribeiro André, M. Engineer

Fravizel S.A., Department of R&D, Zona Industrial Pé da Pedreira, Alcanede 2025-999, Portugal. Fandre@fravizel.com.

Inês Paulo Frazão, MSC

Fravizel S.A., Department of Marketing, Zona Industrial Pé da Pedreira, Alcanede 2025-999, Portugal. ifrazao@fravizel.com.

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# A new scientific approach to determine the stone workability

**Lorena Zichella, Rossana Bellopede, Fiorenza Baudana, Paola Marini**

**Synopsis**

The prediction of stone - diamond wire interaction is important for the extractive sector, both to improve the productivity and efficiency of quarry work and to avoid dangerous and expensive endeavours of cutting when an unknown stone has to be introduced in the plant. Combining two simple test as the measurement of ultrasonic pulse velocity of the stone and the Knoop micro hardness, a scientific classification of workability have been found. In particular, in this work the application of this scientific classification methodology to the stone plant has been studied, performing UPV measurements on stone block before their cutting The correlation of ultrasonic measurements by indirect method with the index HK25 allowed to order the stones in classes of workability that correspond to what the owners of the plant used to give to such stones. Moreover the correspondence with the in situ cutting parameters has confirmed the reliability of this scientific methodology.

**Keywords**

Stone workability, diamond wires, ultrasonic pulse velocity, cutting technique.

## Introduction

The concept of workability and stone machining has been, for the past thirty years, one of the main area of investigation in national and international researches. Moreover, nowadays this topic has not only a great importance for the conventional economy but also a strategic importance for the Circular Economy.

The prediction of stone - diamond wire interaction is crucial for the extractive sector, both to improve the productivity and efficiency of quarry work and to avoid dangerous and expensive endeavours of cutting when an unknown stone has to be introduced in the plant. The diamond wire users themselves determined an empirical classification of the stone (Industrial Workability Classification) mainly taking into account the greater or lesser ease of cutting. However the new classification suggested by Bellopede et al. (2014) has been obtained by means of a scientific approach with easy and expeditious test methods. In particular, while the IWC is characterized by 9 classes, with the new technical classification the classes decrease to 7, thus reducing the case of overlapping and uncertainty due to the intrinsic variability of the materials.

Diamond-wire cutting operations are affected essentially by two different kinds of parameters: partially controlled and non-controlled. The partially controlled ones refer to the properties of the cutting tools and equipment, such as the cutting speed (peripheral speed of the diamond-wire – m/s), the feed rate (cm/h), and the machine absorption (ampere/m). Instead, the non-controlled parameters refer to the stone properties, such as the petrographic and mineralogical composition, grain size, water content, weathering, discontinuities/anisotropy and hardness.

Previous studies (Bellopede et al 2014, Amaral et al 2000, Ersoy et al 2005, Gokhan at al 2013) demonstrated that the uncontrolled parameters can be measured indirectly by different techniques but the Knoop micro-hardness and the Ultrasonic Pulse Velocity (UPV) measures best correlate with workability and are therefore more significant . From 1982 Mancini and Morandini and more recently, in 2003, Beste and Jacobson have underlined the importance of the micro-hardness measurement to study the tool wear. However, in literature, the relationship between petrographic characteristics and the industrial process involved in cutting and finishing stones is noticeably unknown, as pointed out by Riberiro et al (2007). UPV measures can be considered an expedite and reliable testing of the mechanical properties of a rock (quarry face or block), and gives also available information on the stone slab quality (Bellopede et al 2005, Vasconcelos et al 2008).

The aim of the present work is to evaluate the applicability of this scientific classification methodology to the stone plant.

## Materials and Methods

The following siliceous stones with industrial index of workability (IWC) between 3-4 have been tested:

-a diorite (DIO), with IWC 3 composed by 65% of plagioclase, 30% of hornblende and biotite and 5% of opaque minerals; the grain size distribution is from 0,01 to 2 mm;

-a sienite (SIE), with IWC 3 composed by 50% of feldspar, 25% of biotite and hornblenda, 15% of quartz; the grain size distribution is from 0,03 to 2 mm;

- a granite (RBE), with IWC 3-4 composed by 60% of plagioclase and K- feldspar, and 30% of quartz; 10% of biotite; the grain size distribution is from 0,05 to 12 mm;

- a granite (GRP), with IWC 4 composed by 65% of K- feldspar and plagioclase, 30% of quartz, 5% of biotite and pyroxene; the grain size distribution is from 0,1 to 12 mm.

Indirect and direct UPV measurements have been performed in situ on stone block. The same slabs has been additionally tested in laboratory by means UPV in indirect method and Knoop hardness measurements. Knoop hardness measurements are conducted with a load of 1,96 [N], with a sequence of number of identifications per sample of 40 points. The HK25 has been chosen as the index of correlation with the UPVs, as it represents the least hard minerals and the micro-fractures or voids, therefore HK25 better represents the anisotropy and the weaknesses of the stone investigated. The ultrasonic pulse velocity (UPV) was determined using a PUNDIT–CRO instrumentation connected to oscilloscope software for a lap-top, with conic 33 kHz frequency transducers. Measurements were made indirectly by placing the transmitter transducer on a fixed point and the receiver at progressive distances (each 25 mm: from 25 mm to 175 mm) on the same specimen surface (specimen dimensions 200mm x 200mm x 20 mm). For the direct methods the receiver was placed on the opposite surface respect the transmitter.

## Results

In the Tab. 1 the results of ultrasonic and microhardness measurements of the different 4 rock tested are reported. In the same table with the data of feed rate and machine absorption [A] taken during the cutting process are shown.

As it is possible to note from the figure 1, where also other rocks of different petrographic nature are reported in red, the scientific classification based on the indirect UPV and HK25 measurements match with the IWC of the four stone tested. In the figure 2 the well correlation between the machine absorption and the quartz content is shown. However, the cutting parameters weren't measured for all the stones, consequently it not possible to demonstrate the full correlation with quartz content. The correlation among machine absorption [A] and HK25/UPVind (as mean values of UPV performed by indirect method on the block) is reported. The exponential regression has a correlation coefficient of 0.91. The correlation between HK25, UPV and workability class demonstrated in the previous research (Bellopede et al, 2014) has been confirmed here.

Table 1 Rock tested, cutting parameters, ultrasonic (mean value of 10 measurements) and micro hardness (HK25) measurements.

| Rock type | Acronym | Feed rate (cm/h) | Machine absorption (A/wire) | UPV indirect method on block perpendicular direction (m/s) | UPV indirect method on block parallel direction (m/s) | UPV indirect method on slab perpendicular direction (m/s) | UPV indirect method on slab parallel direction (m/s) | UPV direct method on block (m/s) | HK25 – MPa- |
|---|---|---|---|---|---|---|---|---|---|
| Diorite | DIOs | 16.5 | 1.43 | 2287 | 2352 | 2708 | 2443 | 5450 | 2789 |
| Sienite | SIE | 24.4 | 1.65 | 2482 | 2172 | 2449 | 2299 | 4730 | 3602 |
| Granite | RGB | 25.00 | 2.78 | 2387 | 2310 | 2754 | 2430 | 3530 | 4049 |
| Granite | GRP | 23.8 | 2.83 | 2601 | 2510 | 2785 | 2780 | 4500 | 5234 |

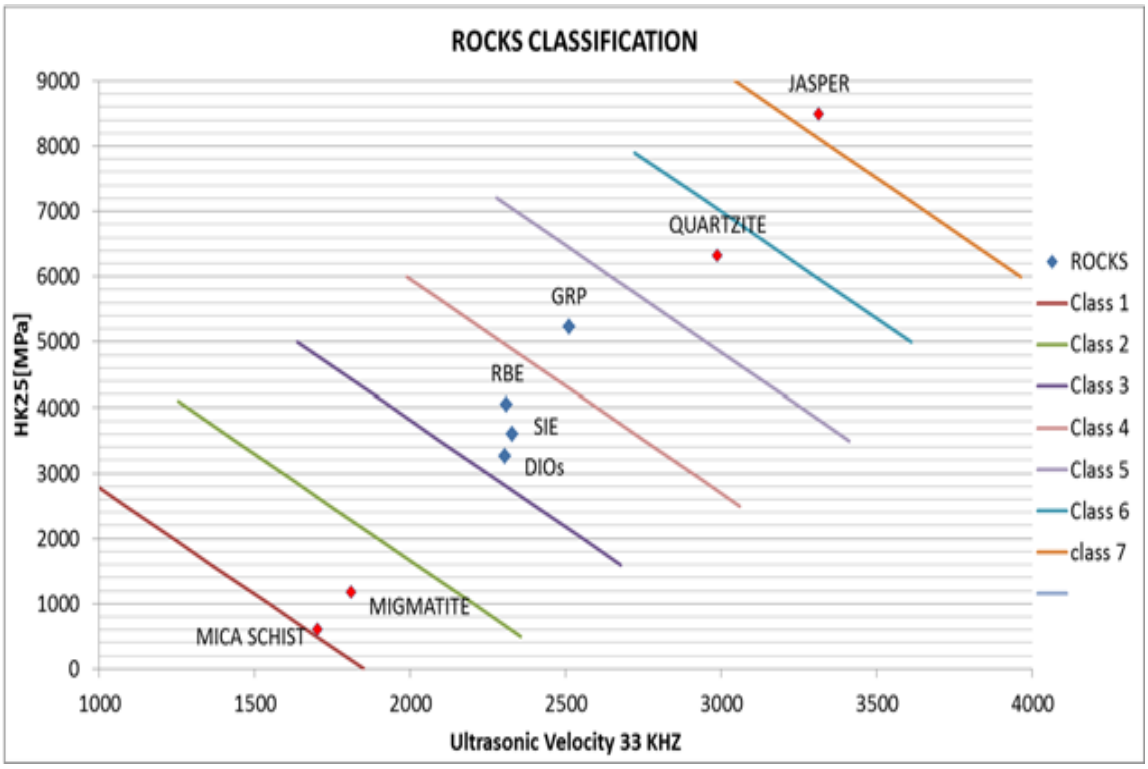


Fig. 1 Scientific classification of tested stone

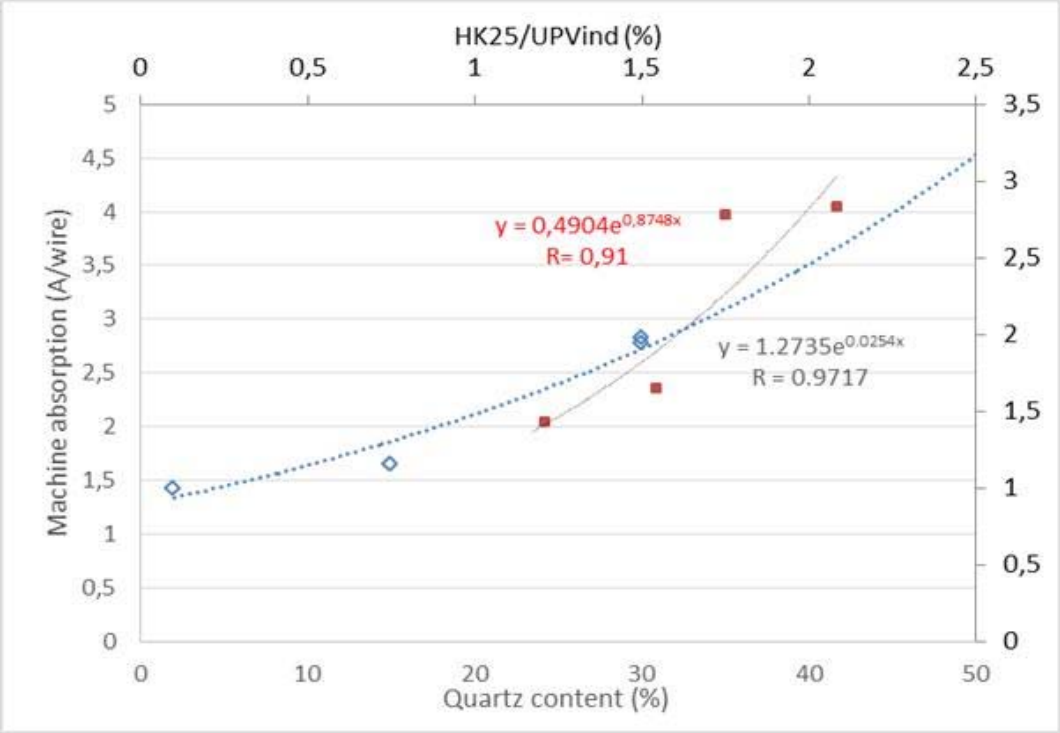


Fig. 2 Machine absorption vs H25/UPVind and vs quartz content for RBE, SIE, DIOs and GRP

## Discussion and conclusions

The in situ measurements on blocks on different types of siliceous stone allowed to verify the reliability of the different measurement techniques used and to validate a new scientific classification for the workability of natural stones.

The ultrasonic measurements on blocks are well correlated with those performed on the slabs on the same stone. Moreover indirect UPV measurements can be considered reliable as they match with data resulting from direct method.

The correlation of ultrasonic measurements by indirect method with the index HK25 allowed to order the stones in classes of workability that correspond to what the owners of the plant used to give to such stones. The correspondence with the in situ cutting parameters has confirmed the reliability of this scientific methodology. This proposed scientific classification help the choice of the cutting parameter (feed rate, cutting speed) to achieve technical and economic enhancement in plant.

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## About the authors

Zichella Lorena, Eng

Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. lorena.zichella@polito.it

Bellopede Rossana, PhD, Eng

Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. rossana.bellopede@polito.it

Baudana Fiorenza, Dr

Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. fiorenza.baudana@polito.it

Marini Paola, Prof.

Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. paola.marini@polito.it

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Application of castor oil polyurethane resin in the dimension stone block infusion reinforcement process

**Leonardo Luiz Lyrio da Silveira, Bruna dos Santos Cezar Ferreira, Phillipe Fernandes de Almeida**

**Synopsis**

The resin infusion of dimension stone block is a step in the process of stone processing that aims to provide increased physical-mechanical resistance to the block, thus ensuring that the process occurs safely and without damaging the geometry of the slabs obtained. Therefore, in order to increase the eco-efficiency of this sector, the search for an alternative to the use of epoxy resin, whose compounds are not in accordance with the sustainability precepts, by an ecological non-toxic castor oil-based resin may provide a global market variance of Brazilian materials. For this, the tensile strength of the resins in carbonaceous and silica materials was measured, observing their respective behaviors. The results obtained were satisfactory, showing that the castor oil resin presented good behavior in relation to the tensile strength in the stone block resin infusion process. These results allow one to infer that the use of castor oil resin to replace the epoxy resin currently used will lead to an environmental gain to this stage of dimension stone processing.

**Keywords:**

Resin, infusion, polyurethane, castor oil.

## Introduction

Natural and covering stones correspond to lithologic types extracted from blocks or tiles that can be sawed in different forms and benefited by squaring, polishing and gloss. The quality control in all the stages that the natural stones are submitted, along with their intrinsic characteristics are important factors for the production of high quality slabs. Due to this, fragile or low-cohesive stones, such as some quartzites and pegmatites usually, for example, require differential treatment prior to sawing the blocks, a procedure known as resin infusion. This process has been done to increase physical-mechanical strength of the block in order to ensure that the sawing process of the block occurs safely. However, there is still no literature that shows the minimum values that the resin/stone interface must have in terms of tensile strength/adhesiveness so that the sawing process of a resin infused block occurs within minimum safety parameters. The resin infusion process is carried out from the application of an epoxy resin.

Mineral fillers and fiberglass mesh are also used which form a combined structure that surrounds the entire block. It is worth mentioning that the epoxy resin is composed of mineral and non-renewable raw material, besides having in its composition Bisphenol A and Epichlorohydrin, compounds that are not in accordance with the precepts of sustainability currently fundamental to the success of any industrial sector. In view of this scenario, some studies related to the use of ecological resins, optimization of the stages of natural stones processing and aspects of sustainability in the mineral sector have already been conducted, being able to be listed below the most important ones used in this research: Silveira (2008), Peiter (2013), among others.

## Objective

To analyze the performance between surfaces of natural stone resin with epoxy and castor oil-based polyurethane in relation to tensile strength. In order to define possible substitution of the resin currently used by another one derived from non-toxic vegetable matter.

## Methodology

### Materials

In order to perform this research, two types of stones, one of carbonate composition and another of silica, were selected. Aiming to know the behavior of the resins in these two large groups of natural stones. A quartzite, with a commercial name White Macaúbas and a marble, known as White Shadow, were chosen mainly because they are often resin infused in the beneficiation industry (Figure 1).

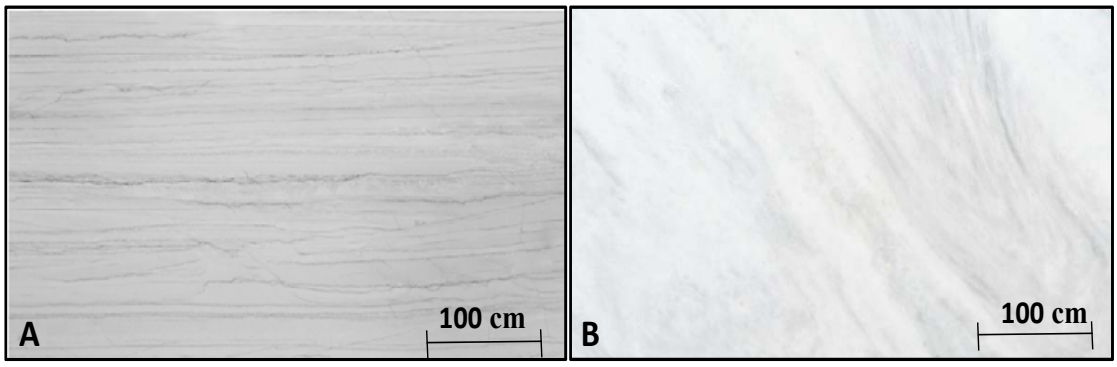


Fig.1 Polished slabs of stones:White Macaúbas (A) and White Shadow (B).

The resins used were castor oil polyurethane synthesized from ricinoleic acid and an epoxy composition commonly used for this purpose. To drill holes in the stones, a bench drill rig owned by Federal Institute of Espírito Santo (IFES) was used and the tensile strength test was carried out with the aid of a pulling device with a digital pressure gauge.

### Methods

For the preparation of the resins the technical recommendations of the manufacturers were followed, as follows: for the polyurethane resin of castor bean the proportions of polyol and pre-polymer 1: 1.2 and of the epoxy resin and enduring of 1: 0,3. Subsequently, the resins were applied to the rock samples (Figure 2A). To perform the assay the resin samples remain for 48 hours for the curing process to take place completely. The standard adopted was ABNT NBR 13528:2010 - "*Revestimento de paredes de argamassas inorgânicas - Determinação da resistência de aderência à tração*" (Adapted).The stone samples were then submitted to the execution of the holes to delimit the distribution of the test samples, with a circular section 50 mm in diameter, spaced approximately 60 mm apart and with a depth of approximately 5 mm. The surfaces of the samples were again cleaned for carrying out the gluing of the tablets (Figure 2B). After this step, the tensile strength test was performed with the support of the pull-out apparatus, whose rupture load was supplied through the digital pressure gauge coupled to the equipment (Figures 2C).

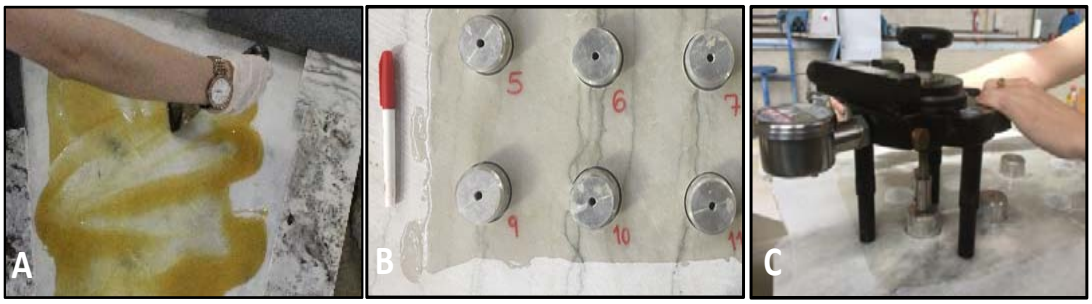


Fig.2 Example of application of the resin on the stone sample: (A) Sample ready for the test and (B) Reading of breaking load by the pulling device (C).

## Results and Discussions

The pull-out tests performed provided positive results related both to the use of the vegetable resin applied to the carbonate and silica materials and to the use of the conventional epoxy resin in the same materials. The compositional characteristics of the stone greatly influence the adhesive properties of the stone/resin system. The results of the tests performed in White Shadow marble with the castor oil resin presented 49% higher values than those with epoxy resin. In the case of the White Macaúbas quartzite, the values for the epoxy samples were 77% higher than those obtained for with castor oil polyurethane (Figure 3). The mineralogical composition of the rock is the most important factor for the results for the tensile strength, although in both cases all the samples presented considerable results of tensile strength, being observed in some cases the rupture of most of the samples (Figure 4).

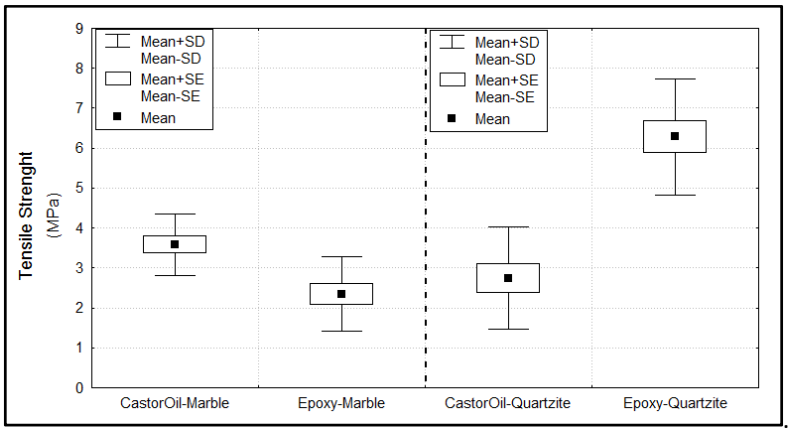


Fig.3 Results of tensile strength of marble resin with castor oil resin and epoxy resin (A)and Results of tensile strength marble resin with castor oil resin and epoxy (B).

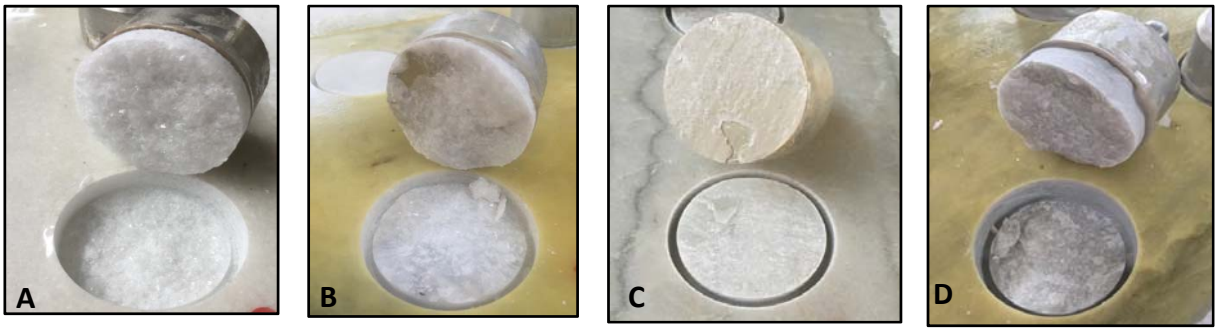


Fig. 4 After the test. Marble with epoxy resin (A) and castor oil resin (B) and Quartzite with epoxy resin (C) and castor oil resin (D).

## Conclusion

The use of products of vegetable origin in the industrial processing of ornamental rocks, in detriment to resins derived from petroleum, as the epoxy resins, contributes to a greater ecoefficiency of this productive chain allowing a differential of the Brazilian products in the international market. The polyurethane castor oil resin showed good behavior in relation to the tensile strength in the stone block resin infusion process, especially in the marble sample, although for the quartzite the results of tensile strength in the epoxy resin samples were higher. As there is no specification in the literature concerning minimum acceptable adhesion values for industrial resin infusion step, this paper aims to collaborate to increase the technical knowledge about this process. For future researches, it is suggested the performance of pull-out tests in different rock materials with addition of mesh and mineral fillers, to analyze the shear aspect of the kinematic mechanism that occurs in sawing of blocks of natural stone, as well as to better understand the variables that influence the adhesion process.

## Ackowledgments

To the CNPq for the scholarship granted, to the professionals of CETEM and IFES and the companies Magban and Imperveg.

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## About the authors

Leonardo Luiz Lyrio da Silveira, PhD

Centro de Tecnologia Mineral – Núcleo Regional do Espírito Santo (NR-ES/CETEM-MCTIC), Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code 29.311-970, Brazil. E-mail. leolysil@cetem.gov.br

Bruna dos Santos Cezar Ferreira, Mining Engineer

Federal Institute of Espirito Santo State, Department of Mining Engineering, Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code 29.311-970, Brazil. E-mail. brunaferreiragmb@gmail.com

Phillipe Fernandes de Almeida, M.Sc.

University of Sao Paulo, Department of Architecture and Urbanism, Avenida Trabalhador São Carlense, 400, São Carlos-SP, Zip Code 13.566-590, Brazil. E-mail. palmeida@sc.usp.br

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL April 26-29, 2018
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# The evolution of the stone workforce

**Joana Paulo Frazão, Rui Moreira de Carvalho, Inês Paulo Frazão, José Paulo Afonso Esperança**

**Synopsis**

We are facing accelerated changes in the market and an exponential evolution of the technology profile, and the processes that it impacts. This development has an impact on companies' human resources. Thus, it is important to analyse the changes that this paradigm shift (Industry 4.0) carries. To identify contributions for the understanding of the human resources profile evolution in this new Industrial age, we study this theme in a specific sector, the stone sector in Portugal. Through a systemic analysis, we intend to understand the profile evolution of the workforce in this sector. We seek to understand the changes in the market in question,its current profile and its technological evolution. With an exploratory approach of qualitative content, we performed a documentary analysis and interviews. The results showed a significant increase in the export of stone (value and quantity) and an increase in the amount of human resources per company, despite the decrease in the number of companies and people, in general. The dominant workforce profile was described through age, seniority, qualification, profession, literacy, and remuneration. Finally, we explored, in a labor context, the evolution of the human resources profile in the new technologies and model of organization that accompanies the new industrial paradigm. At the end of the study, a discussion of the results and conclusion was made.

**Keywords:** Industry 4.0, Technology, Workforce, Exports, Stone.

## Introduction

We are facing an accelerated production of knowledge and technology. New technologies have penetrated deeply into the economy (Carvalho, 2014). It is predicted that 47% of current professions will have a high probability of job loss in the next decade, being replaced by technology. This new era is characterized by the so-called Fourth Industrial Revolution, ie Industry 4.0. (Frey and Osborne, 2013)There is a transformation of the professions and types of work into a digital based culture, where new concepts, technologies and processes are continually developing (Gamboa, 2017). There is a mismatch between people's skills and what companies need to compete on an international scale (Figueiredo, 2016). The companies greatest challenge in implementing the new work philosophy is their lack of skilled workers. (Lorenz, Küpper, Rüßmann, Heidermann, & Bause, 2016). Thus, it is important to analyze the changes that this paradigm shift (Industry 4.0) carries.

The evolution of the stone sector is notorious. This development is only possible with access to technologies (Carvalho, 2010) and this change has a great impact on organizations performance. It forces them to understand and integrate dynamic organizational capacities (Gatignon, Gotteland & Haon, 2016). The short-term sector's challenge is to have the capacity to respond to the new communication languages and, more importantly, to have people with adequate training available to work in this new language (Ferraz, 2016). To achieve the competitive advantage, it is important to develop skills tailored to all areas of the organization by focusing on People, Technology and the Market (Akwei & Peppard, 2007).

## Objectives and Motivation

The goal of this investigation is to understand the changes that the 4$^{th}$industrial revolution bring to the Stone industry. For that, we carried out an exploratory research in order to understand their workforce evolution. Based on the exploratory study of the relationship between People, Technology and Market, it is hoped to offer clues to increase the competitiveness of Stone companies.

## State of the art

In relation to **Technology**, the development of research and development (R&D) projects in the Stone sector in Portugal, such as Jet Stone, Inovstone and Inovstone 4.0 have developed their competitiveness. These projects are based on the lean philosophy and the digitalization applied to the technology that assumes the elimination of waste throughout the supply chain, increasing flexibility and productivity (Silva, 2014). The so-called 4$^{th}$ industrial revolutionraises the analysis of workforce skills. This revolution is characterized by the change of the machine-man relation to machine-machine (Rifkin, 2016).

Regarding **People**, in Portugal, according to the Natural Stone Academy (2015), the Stone Sector needs more technicians and staff with specific training (Cevalor, Valor Pedra, Ester, University of Évora, Instituto Politécnico de Portalegre, 2015). According to Lorenz et al. (2016) companies can benefit from Industry 4.0 depending on how well they create and manage newly qualified talents. By requiring new skills, there will be job losses in some categories of work (such as manufacturing and maintenance) and gains in others (such as information technology).It is the judgment that transforms acquired knowledge and skills into competences (Suleman, 2016). According with the study of the World Economic Forum (2016) the three most valued skills are Complex Problem Solving, Coordination with others and People Management. However, by 2020 it is expected that the most important will be Complex Problem Solving, Critical Thinking and Creativity. It should be noted that Quality Control and Adaptability are expected to no longer be in the top ten and that Emotional Intelligence and Cognitive Flexibility will be added.

Concerning the **Market**, in 2015, the stone sector in Portugal, has exported to 127 Countries. It was the 9th Country of the World International Trade of Natural Stone with a coverage rate of imports of 897%, a Turnover of 952 Million, and exports of 330 Million Euros (48% outside Europe). It has about 2700 companies with 16,000 workers. (Assimagra, 2016). The market is facing uncertainty due to the new demand model and the new technologies (Hemmati, Feiz, Reza, & Iman, 2016; O'Shannassy, 2008). Silva (2014) argues that specialized projects have been the basis of the increase in exports of the Stone sector and that much of its growth isdue to the business development model. It also suggests that between the stone and the footwear sector there was what is called cross-fertilization. There was an exchange of knowledge of the technologies used due to the physical proximity between the localized industries, for example in the zone of Benedita.

## Method

This exploratory research has a qualitative approach through interviews and documentary analysis. Data was extracted from the National Institute of Statistics and 1.596

companies and 14,307 workers were analyzed. In the interviews, the sample was defined by convenience selecting two participants belonging to Stone companies.

## Results and Discussion

The sample of stone workforce (n = 14,307) refers to October 2014 and represents about 90% of the total sector (n = 16,119). The male gender represents the majority (88%). The most represented age group is between 35 and 54 years old, where workers under 25 years of age represent only 3%. With regards to qualification, qualified professionals are the most relevant representing about 40%. This shows an evolution compared to the study carried out by Suleman (1998), where the volume of labor was supported by skilled personnel were only 25%. This suggests that companies in the sector are reactive to the problem identified in the lack of skilled workers.

In terms of evolution (Fig. 1), the number of people in the sector decreased (43%) in the period between 2004 and 2014. When we cross the work force number with different indicators we find a proportional decrease with the number of companies (-30 %), turnover (-36%), versus production (-37%). When dividing the remuneration of the company by the number of workers we observed that the number of workers was reduced but the remunerations per employee were increasing (9%). These values suggest that the trend has been the increase of workers per company with higher qualification skills. The exports in quantity have evolved about 30% and in value about 44% in the last 11 years. It suggests that the sector is exporting products with more added value.

The most important skills to industry found in this investigation were adaptability, responsibility, team work and vision.

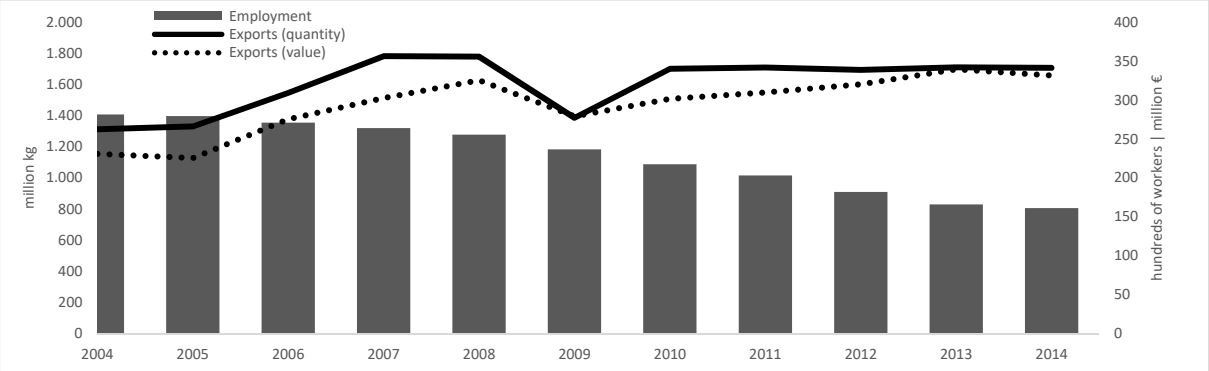


Fig. 1 Exports and Employment - Portuguese Stone Sector

## Conclusions

This research is about the workforce path and profile in the stone sector. Although technical skills are very important for technological development, they can change according to technology while others, like soft skills, remain.

We realized that in the past 11 years (2004 to 2014) there was a decrease in the number of companies, human resources, production and turnover. On the other hand, there was a change in the business model embodied by the significant increase in exports.

However, it is important to realize that the skills required for the jobs are changing therefor it is important to keep up with the changes in progress (WEF, 2016).

Technology tends to make work more attractive to young people. As suggested by Suleman (1998), it is necessary to identify strategies for attracting qualified and informed young people, as well as to improve the sector image. The industrial revolution will have a transversal impact in various sectors and the Stone Sector is not an exception.

## Acknowledgments

We thank Fravizel, Mineral Resources Cluster, ISCTE-IUL, ISG and Marlene Ribeiro for their collaboration and support.

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## About the authors

Joana Paulo Frazão, MSc

Master in Social and Organizational Psychology and Ph.D. Student in Management,ISCTE-IUL - InstitutoUniversitário de Lisboa. Assistant Professor, ISG- Instituto Superior de Gestão. Portugal.

jpfrazao@fravizel.com

Rui Moreira de Carvalho, PhD

PhD in Management, ISCTE-IUL – Instituto Universitário de Lisboa. Associated Professor of Management, ISG-Instituto Superior de Gestão. Portugal.

rui.moreira.carvalho@gmail.com

Inês Paulo Frazão, MSc

Master in Marketing and Ph.D. Student in Management, ISCTE-IUL - InstitutoUniversitário de Lisboa. Assistant Professor of Management, ISG- Instituto Superior de Gestão.Portugal.

ifrazao@fravizel.com

José Paulo Afonso Esperança, PhD

PhD in Economics from the European University Institute, Florence, Italy. Full professor of Finance, ISCTE–IUL-Instituto Universitário de Lisboa. Chairman of AUDAX-ISCTE- center focused on entrepreneurship and family business and Dean of ISCTE Business School. Portugal.

jose.esperanca@iscte.pt

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ILHEUS (BAHIA)
BRAZIL
April 26-29, 2018
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# Stone efficiency through the Industry 4.0

**Agostinho da Silva, Andreia Dionísio, Luís Coelho**

**Synopsis**

Conceptualized under Service Science Theory, will be introduced a Framework to assess the impact of Industry 4.0 (I4.0) on Portuguese Ornamental Stone (OS) firms' response to the threats arising from the procurement model resulting from Building Information Modelling (BIM).

The transition witnessed from the Third to the Fourth Industrial Age leads to the emergence of paradigms such as BIM, seeking efficiency in Architecture, Engineering and Construction (AEC) through a global approach and procurement oriented towards standardized products and I4.0, where production comes to be supported by Cyber-Physical Systems (CPS).

Integrated in the AEC supply chain, the OS sector shows Portugal to be the eighth country in OS trade worldwide, and the second per capita, with its competitiveness coming from customization. BIM represents threats for its sustainability, particularly in firms of the Cluster Portugal Mineral Resources (CPMR).

The literature review showed that Service Science (S-S) is an inter-disciplinary scientific area that combines organization with technological knowledge, with a view to categorizing, innovating and creating value for service-systems.

**Keywords**

Service Science, Industry 4.0, Internet of Things, BIM, Cyber-Physical Systems, Ornamental Stone

In recent years, widespread use of the Internet has created the concept of electronic procurement, often by simply connecting to inter-organizational virtual platforms, also known as e-marketplaces (Grilo and Jardim-Goncalves 2011), where buyers and sellers share information about prices and the type of products offered, while also carrying out payment and product transactions. However, this procurement model, although effective when structured (when the buyer knows exactly what he intends to buy), has a very low volume of transactions in e-marketplaces whenever it is a question of complex levels of customized product specification, as general happens in the IC (Marinho 2014).

With as yet unpredictable impacts on the supply chain, BIM (Building Information Modelling) procurement will imply a reinvention of the business model itself in some sectors within the AEC (Architecture, Engineering and Construction) (Ibem and Laryea 2014) especially in those that base their competitiveness on product customization, asin the case of OS in countries such like Portugal. Since customization is one of the main competitive advantages of Portuguese OS (Ornamental Stone) companies, when competing with ceramic materials for example, this possible movement in the AEC towards standardization will create, from the outset, a real problem for its sustainability. However, the threat can be transformed into an opportunity, if in the face of the creative constraints imposed on

architects by the standardization of building elements in BIM, Portuguese OS suppliers allow architects to create their projects from customizable virtual elements in BIM, especially if combined with a productive response to designers' creativity (Heidari et al. 2014). The concept of Smart BIM Objects (Chen et al. 2015) has become a subject of study for many researchers in recent years. Virtual, standard and dynamic objects are easy to understand, but it is not yet possible to predict the implications for the processes that allow their production. (Heidari et al. 2014). During the design phase, the assignment of specifications (Dimensions) to the virtual IFC (Industrial Foundation Class) elements added to the digital building can be seen as the creation of their fingerprint (Sehgal, Patrick, and Rajpoot 2014), which some authors call the object's "DNA" (Matthews et al. 2015), the guidelines for the subsequent purchase and manufacture of the products. One of the characteristics of using BIM is that all the elements and stages of the work are correlated, meaning, a priori, that each element's fingerprint contains its eight dimensions. That correlation will facilitate its monitoring through BIM during the entire product lifecycle (Marinho 2014).

The main focus of this research work is precisely the search for a solution to the threat resulting from BIM procurement. Concerning the possible impact of the I4.0 operations model on OS companies' response to the new BIM procurement, and if this is positive, I4.0 may even turn the new threat into a new opportunity.

The literature review revealed that from 2010 the empirical research related to digital processes and ICT was intense, the emergent paradigm of I4.0 being referred to very often from 2011. However, despite all this investigation oriented to the digitization of processes, there has been little study of the impacts of the transition from traditional production processes to digital processes (Drath and Horch 2014), and there is almost no scientific literature about the impact of this transition on specific threats identified in companies, clusters or ecosystems. Ford (2015), for example, considers the interests behind the "main stream I4.0" to be partial, to the point of considering "The benefits and return on investment (ROI) are not as black and white as you might think, and the engineers would like them to be. Industry 4.0: Who Benefits?"(Ford, 2015, p.30).

Although the digitization of processes is a cross-cutting paradigm for all areas of the economy, the literature review shows there is a shortage of authors describing digitization in an interdisciplinary way, and even fewer describing I4.0 from the Service Science perspective.

Service Science is an interdisciplinary scientific area and therefore (Rennung, Luminosu, and Draghici 2016), the research proposed in this thesis is of academic and practical interest, Service Science providing the theory and the decisive contribution to the understanding of value co-creation interactions among actors.

For Service Science, the impact of innovation on processes should be measured through the Innovation Outcome[1] (IO) concept (Spohrer 2007), which results from the evolution of

[1] Innovation Outcomes means the innovation results in Service Science

the main stakeholders' concerns, designated in this thesis as Key Concern Indicators (KCIs), inverse to the traditional concept of KPIs ( $= \frac{1}{}$).

Guided by the pragmatist paradigm, we have developed an empirical framework designated by Inovstone4.0 (Fig. 1) to describe and compare the value creation interactions in a sample of OS companies when they evolve their operations from the CBP (Current Best Practices) mode to the future Industry 4.0 (I4.0) mode. Following Service Science Theory the conceptualization of the empirical framework have started by characterizing the resources, variables and stakeholder concerns parameterization, including the metrics to be used in data collection, according to the objectives (Maglio and Spohrer 2008).

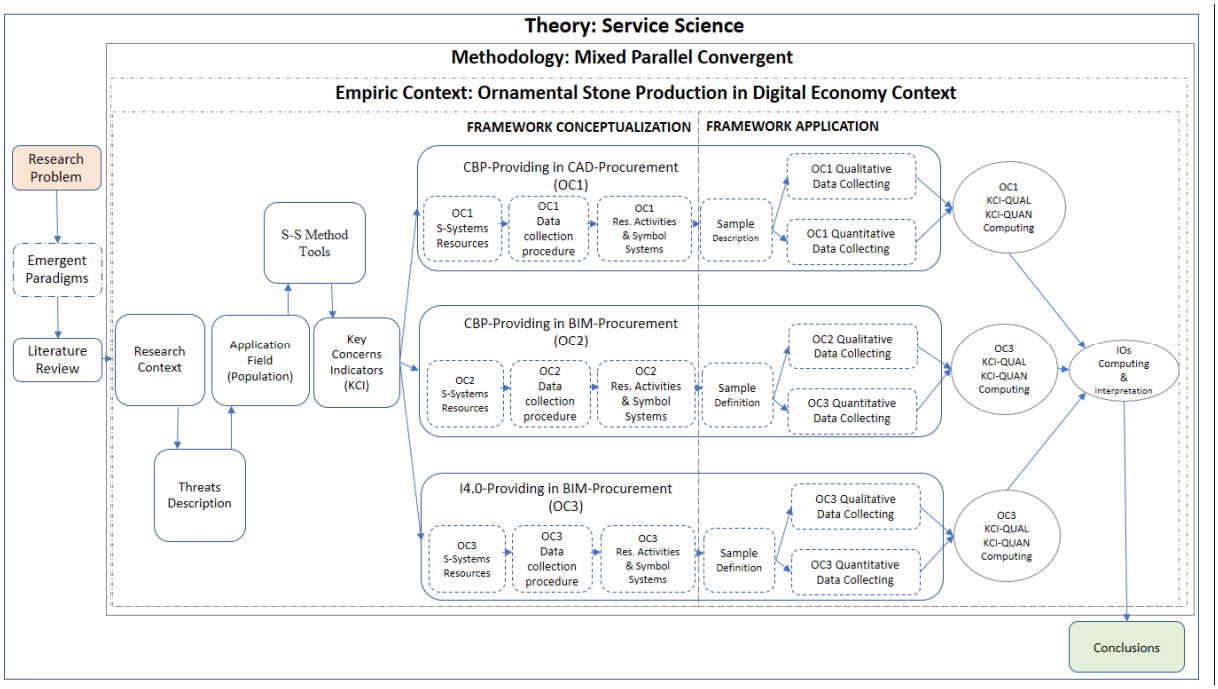


Fig. 1 Inovstone4.0 Framework Architecture

By applying the Inovstone4.0, the intention is to evaluate the impact of I4.0 on the response of OS companies to the Threats from BIM procurement in the AEC, resulting in the following objectives: (i) to describe and configure stakeholder's resources, in the context of providers in current best practices operations mode (CBP-Providers) and customers in current (CAD-Procurement), designated by "OC1" (Operation Context); (ii) to describe and configure stakeholder's resources, in the context of CBP-Providers and customers in BIM-Procurement, designated by "OC2"; (iii) to describe and configure stakeholder's resources, in the context of providers in Industry 4.0 operations mode (I4.0-Providers) and customers in BIM-Procurement (OC3), designated by "OC3" (iv) to determine the Step Outcomes (SO) and Key Concern Indicators (KCI) in each Step of the service process, in the three operation contexts (OC1, OC2 and OC3)and (v) to determine the Innovation Outcomes (IO) in the three operation contexts (OC1, OC2 and OC3).

## Acknowledgments

The authors would like to thank the research project Inovstone4.0 partially funded by Agencia Nacional de Inovação and Compete2020. We also acknowledge the European Commission, for funding the research projects Jetstone, Inovstone and Flextone.

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## About the author(s)

Agostinho da Silva

Universidade de Évora, Portugal

Andreia Dionísio

Universidade de Évora, CEFAGE, Portugal

Luís Coelho

Universidade de Évora, CEFAGE, Portugal

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# Natural stone slabs for building façades: pull-out strength at anchoring point

**Sérgio Trajano Franco Moreiras; Antenor Braga Paraguassú; Phillipe Fernandes de Almeida.**

**Synopsis**

International standards prescribe minimum thickness of 30 mm for natural stone slabs in ventilated façade claddings using metallic anchors. The Brazilian standard does not provide minimum thickness guidelines, but 20 mm thickness is commonly used. Therefore, this work proposes a design methodology for the dimension of rock plate ventilated façades considering the stress at the anchor point. Therefore, façade prototypes (200 mm wide and 200 mm high) of the Brazillian syenogranite Red Capao Bonito with polished finishing were constructed. Considering only the maximum stress at the center of the 600 mm x 1000 mm plates, they could be scaled using 20 mm. However, when considering the anchor point resistance of the granitoids Red Capão the thicknesses calculated were 30 mm. These results indicate that the minimum thickness of 30 mm for slabs in ventilated façades is more consistent than the minimum thickness of 20 mm used in national practices.

**Keywords**
Stainless steel anchor; Strap 2016 structural analysis software; Red Capão Bonito syenogranite; Breaking load at pin hole.

## Introduction

In the stone slab cladding system using stainless steel anchors, the plate is set apart from the building structure, forming an air layer on the inner side of the slab, which is responsible for the thermal insulation, particularly when air circulates in the interior of the system. This fastening system has other advantages, such as water tightness and protection of the building from aggressive weathering agents.

With respect to design, Brazilian standards do not set guidelines to determine the minimum thickness of plates, the calculation methodology and safety factors. The minimum thickness used nationally is 20 mm, but the international standards ASTM C 1242:2012, DIN 18516-3:2013 and EN 1469:2004 prescribe a minimum thickness of 30 mm.

The most commonly used system in Brazil for façade claddings is the four-point attachment using pin-shaped stainless steel anchors in the hole of the slab (German system). The German standard DIN 18516-3:2013 establishes the settings for this system: minimum distance between the center of the hole and edges of the plate at 2.5 times the plate thickness, minimum plate thickness of 30 mm, minimum 8 mm diameter of the hole and 5 mm of the pin. The minimum gap around the circumference of the hole should be 1.5 mm.

According to Moreiras (2008), the most vulnerable region of the plate, that is not considered in usual projects, and which exhibits a great deal of pathologies in ventilated facades is the anchor support point, where drilling the plate weakens the rock.

In this context, this paper proposes a structural design methodology for ventilated façades using natural stone slabs, evaluates the effect of using 20 mm-thick plates in Brazilian buildings and also evaluates the effects of strength at the anchoring point.

## Methodology

### Materials

The syenogranite Red Capão Bonito is extracted in the municipality of Capão Bonito, located in the southwest of the state of São Paulo. It is a medium to coarse-grained rock, with sparse feldspar megacrystals and orange-reddish coloring. The mineralogical composition is 45% perthitic microcline, 35% quartz, 15% plagioclase (oligoclase) and 5% biotite. The aesthetic and chromatic patterns of the polished surface are formed by the interconnection of the microcline, quartz and biotite grains. The red surface patterns are due to the microcline and the translucent light shades are from the quartz and the black biotite spots.

### Ventilated façade design

Two sizes of slab were pre-defined to develop a methodology of the plate thicknesses. The first one for plates of 600 mm width and 1000 mm height and the second one for plates of 900mm width and 1500 mm. Then the design approach was outlined in its two parts.

In the first part (presented in Moreiras 2012), the plate thickness is determined on the basis of the maximum stresses acting at the center of the plate and the four points bending tensile strength. In the second part, the thickness is determined based on the load acting in the anchor point and the pull out strength.

### Anchoring point strength design

To determine the plate thickness considering the strength at the anchoring point the first step was to determine the breaking load (according to standard EN 13364:2002) at the point of anchorage between the slab hole and the pin-type metallic anchor to each granitoid at 20 and 30 mm thickness (Fig. 1).

The specimens of thicknesses up to 70 mm have dimensions of 200 x 200 mm. The hole is 10 mm diameter, 30 mm depth and is located at the center of the lateral side of slabs. The load application point is at the central axis of the hole at 2 mm from the face and the loading rate is 50 N/s until failure.

Then, it was determined the allowable load for 20 and 30 mm thickness by dividing the breaking load by the safety factor. After, these results were extrapolated for a range for 20 mm to 55 mm thickness.

Fig. 1 Test to determine resistance at the anchor point for pin-type metallic inserts.

The calculated thickness of Part 2 is the correspondent thickness value of the extrapolated data to 20 to 55 mm immediately above the acting load at the anchoring point. The acting load at the anchoring point for 600 x 1000 mm slabs is 0.37 kN and 0.87 for 900 x 1500 mm slabs.

## Results

The acting loads on the anchoring point were obtained from the distributed load, which are: 0.37 kN for plates of 600 x 1000 mm and 0.83 kN for plates of 900 x 1500 mm. Table 4 shows the allowable loads on the anchoring point according to the 20 for 55 range thickness of the plate. The calculated thickness in part 2 was the thickness in Tab. 1 with respective load value immediately smaller than the acting loads. The calculated thickness for slabs 600 x 1000 mm were 26 mm for the Red Capão Bonito. The calculated thickness for slabs of 900 x 1500 mm was 43 mm for Red Capão Bonito.

Table 1 Allowable loads on the anchoring point according to the thickness of the plate.

| Thickness (mm) | Capao Bonito Red | Thickness (mm) | Capao Bonito Red | Thickness (mm) | Capao Bonito Red | Thickness (mm) | Capao Bonito Red |
|---|---|---|---|---|---|---|---|
| **20** | 0.22 | **29** | 0.45 | **38** | 0.68 | **47** | 0.91 |
| **21** | 0.25 | **30** | 0.48 | **39** | 0.71 | **48** | 0.94 |
| **22** | 0.27 | **31** | 0.50 | **40** | 0.73 | **49** | 0.96 |
| **23** | 0.30 | **32** | 0.53 | **41** | 0.76 | **50** | 0.99 |
| **24** | 0.32 | **33** | 0.55 | **42** | 0.78 | **51** | 1.02 |
| **25** | 0.35 | **34** | 0.58 | **43** | 0.81 | **52** | 1.04 |
| **26** | 0.37 | **35** | 0.61 | **44** | 0.84 | **53** | 1.07 |
| **27** | 0.40 | **36** | 0.63 | **45** | 0.86 | **54** | 1.09 |
| **28** | 0.43 | **37** | 0.66 | **46** | 0.89 | **55** | 1.12 |

### Compatibility of results

Table 2 presents the compatibility of results of steps 1 and 2. The final thickness was the value available in the market, higher than the highest value obtained between the two parts.

Table 2 Thickness calculations (e) of step 1, step 2 and compatibility of results for the “granites” Red Capão Bonito and White *Desiree.*

| | 600 x 1000 mm | 900 x 1500 mm |
|---|---|---|
| | Capao Bonito Red | Capao Bonito Red |
| **Part 1 (mm)** | 17 | 24 |
| **Part 2 (mm)** | 26 | 43 |
| **Compatibility (mm)** | **30** | **45** |

## Conclusions

Considering only the maximum active stress at the center of the plate, a 600 x 1000 mm plate of 20 mm thickness can be used. However, when the support stress is taken into account, the thickness calculated was 30 mm for the “granite” Red Capão Bonito. Considering only the maximum active stress at the center of the plate, a 900 x 1500 mm

plate of 26 mm thickness can be used. However, when the support stress is taken into account, the thickness calculated was 45 mm for the “granite” Red Capão Bonito.

These results are strong indications that the international standards recommending minimum thickness of 30 mm for plates in non-adherent systems are more consistent than the minimum thickness of 20 mm used in national practice. These results also agree with results presented by Camposinhos and Camposinhos (2009).

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## About the authors

Sérgio Trajano Franco Moreiras, Prof. Dr.

Maringa State University, Technological Department, Angelo Moreira da Fonseca Avenue, 1800. Umuarama, paraná, Brazil. Zip Code: 875040-280, strajano@gmail.com.

Antenor Braga Paraguassú, Prof. Dr.

University of São Paulo, Geotchnical Department, Trabalhador São Carlense Avenue, 400, Sao Carlos, São Paulo, Brazil Zip Code: 13566-590, E-mail: nonus@sc.usp.br.

Phillipe Fernandes de Alemida, Researcher Msc.

University of São Paulo, Institute of Architecture and Urbanism, Trabalhador São Carlense Avenue, 400, Sao Carlos, São Paulo, Brazil Zip Code: 13566-590, E-mail: palmeida@sc.usp. br

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# Testing method for characterizing adhesive systems used to produce multi-layered composites made of natural stone

**Madalena Barata Garcia, Vera Pires, Virgínia Infante, Pedro Amaral**

**Synopsis**

This work presents a battery of tests used for the characterization of the adhesive system of an asymmetric sandwich composite of natural stone, cork agglomerate and glass-fibre reinforced epoxy. This class of structural composites is designed to have high stiffness/strength-to-weight ratios and in order to achieve them one of the challenges is to understand the mechanical behaviour of each component and the type of interaction between them. Being aware that delamination is known to be its principal mode of failure, several tests and standards have been developed to determine the debond fracture toughness of a composite, but none includes testing an asymmetric designed composite made of more than two constituents (usually a core and two fibre-reinforced skins). One of the tests represents an approach to further determine the delamination causes of the composite and, consequently, its limitations concerning practical use. Results demonstrated that there is in fact a significant influence of the stone finish in the results of both the delamination and stiffness tests, more than that of the employed cork agglomerates.

**Keywords**

Asymmetric composite, sandwich composite, cork agglomerate, stone, delamination.

## Introduction

In the last few years, composite materials have been an emerging topic since their properties and characteristics can almost be chosen by joining two or more materials into one. These “new” properties have drawn a lot of attention, especially in the high-performance application industries.

Sandwich panels are a class of structural composites and they are designed to have high stiffness/strength-to-weight ratios. This study focuses on an asymmetric composite made by a core of cork agglomerate with low specific weight, two fibre-reinforced epoxy skins with low thickness and high stiffness and a stone layer on top. This asymmetric composite aims to solve some of the problems of the use of stone panels but keeping the aesthetics and the natural feel through the addition of cork agglomerate (CA). Optimized CA have been produced and studied and have proved superior ability to substitute others, presenting some advantages (Gil 2009). For example, when comparing cork with other core material usually used, like Nomex honeycomb or Rohacell foam, cork-epoxy agglomerates present a significantly better core shear stress limit, which reduces the crack propagation region (Castro et al. 2010).

Optimized CA have been produced and studied and are now considered a viable substitute to other core materials, presenting some advantages (Gil 2009). For example, when comparing cork with other materials like Nomex honeycomb or Rohacell foam, cork-epoxy agglomerates present a significantly better core shear stress limit, which reduces the crack propagation region (Castro et al. 2010). Reis & Silva 2009 studied the mechanical behaviour of the CA through shear and three-point bending tests concluding that cork-based cores are suitable as core materials when comparing with the results from the honeycomb-

based cores. Castro et al. 2010 developed a CA formula and studied the mechanical properties by three-point bending, impact and thermal conductivity tests. One important conclusion was that CA present better core shear stress limit when compared to other materials, reducing the crack propagation region. Fernandes et al. 2011 performed different characterization tests to CA boards with different formulations and an excellent recovery capacity was verified in the displacement curves as an intrinsic characteristic of the material. Furthermore, they observed a high-energy absorption capacity with minimum damage occurrence but referred the need of reinforcement strategies to reach higher stiffness. Sadeghian & Hristozov 2016 studied a sandwich composite with a CA core with natural fibres in the skins and compared with the typical honeycomb and glass fibre combination. The most common failure mode of the specimens was the shear failure of the core (both honeycomb and CA cores) and the structural performance between the two formulations was comparable. All these results validate CA as a core for sandwich composites.

On the base of previous research, delamination is considered to be the principal mode of failure of composite materials, consisting on the failure of the interfaces mainly between different oriented layers, or, in this case, layers with different materials. Among different tests to measure delamination resistance, it is important to define the failure modes and what they mean in terms of criteria of comparison between specimens. Failure modes of composite sandwich beams depend on the type of loading, constituent material properties and geometrical dimensions (Daniel et al. 2009). The existent standards to test the adhesion between layers of composites do not include composites with an asymmetric design and with stone being one of the constituents, and so a new test for this purpose was developed.

## Materials and methods

The sandwich specimens were manufactured by hand lay-up method, in temperature and humidity controlled conditions with 68% mass fraction of resin/fibre. The materials used to produce the specimens were 8mm thick “Branco do Mar” (referred as white stone) and “Vidraço Azul” (referred as blue stone), obtained by a wire metal saw without any lubricating agent; cork agglomerates with 15mm thickness from two different suppliers (ACC and GN); epoxy resin with 20 minutes pot time hardener; biaxial fibreglass and interlaced fibreglass with two different surface densities (interlaced has half density of biaxial fibreglass). In Table 1 a test matrix is presented with all the configurations produced, as well as the codes used for each one.

Table 1 Test Matrix

| | White Limestone | | Blue Limestone | |
|---|---|---|---|---|
| | Finishing A | Finishing B | Finishing A | Finishing B |
| ACC CA | WAS | WAA | BAS | BAA |
| GN CA | WGS | WGA | BGS | BGA |

Nomenclature: First letter - W: white stone; B: blue stone; Second letter - A: ACC CA; G: GN CA; Third letter - S: sawn finish; A: smooth finish

### Bending stiffness test

The setup for the test is a four-point bending one, according to ASTM D7249. The compressive load is applied by an Instron 5566 universal testing machine, with the load-

displacement data being collected using a 10kN load cell. The tests were displacement controlled with a velocity of 3mm/min and a preload of 10N was applied before each test. For the white stone a correlation was used to relate the maximum load (y) with the thickness (x) of the specimen (y=351.3x-6132.2). This relation was calculated for several four-point bending tests until fracture and it was observed that the results varied with the variation of the thickness. In the case of the blue stone, this variation was not significative and the load used was 602 N (with an accuracy of 1%). The mid-span deflection (Δ) was calculated as the difference between the deflection value in the middle of the specimen minus the deflection measured on top of the left roller. These deflection values were measured with deflection gauges. Three specimens of each configuration were tested, being each one tested two times with a resting time of one minute.

### Delamination test

Specimen preparation is required, consisting on gluing the previously cleaned metal sheet (90mm x 130mm) on top of the stone with a fast-curing polyester adhesive. According to the product instructions, the drying time is 24h but this time was increased to 5 days to ensure maximum fixation. After mounting the setup, the specimen is placed and clamped 100mm from the composite end and the arm is aligned 10mm from the other side. The same load conditions as in the bending test were used. The digital microscope Dino-Lite Edge, used to record images to determine the *a* value, is turned on simultaneously as the test begins.

## Results and discussion

### Bending stiffness test

The stiffness values obtained are summarized in Table 2. The maximum stiffness value was obtained for BAS (blue stone, ACC cork, sawn finish) and the minimum for BGA (blue stone, GN cork, smooth finish). The reinforced cork was tested as a reference.

Table 2 Stiffness values ($10^6 Nmm^2$)

| | Average | Maximum | Minimum | StdDev |
|---|---|---|---|---|
| BAS | 151.63 | 184.58 | 118.68 | 32.95 |
| BGS | 139.57 | 166.26 | 112.87 | 26.69 |
| WGS | 128.85 | 153.77 | 103.93 | 24.92 |
| WAS | 112.42 | 126.58 | 98.26 | 14.16 |
| WGA | 94.10 | 107.33 | 80.88 | 13.23 |
| WAA | 91.34 | 102.00 | 80.67 | 10.67 |
| BGA | 77.40 | 92.46 | 62.35 | 15.06 |
| Cork | 67.87 | 89.95 | 45.80 | 22.08 |

Comparing the different variables in the study and the values obtained, the finish seems to be the most relevant variable concerning stiffness.

### Delamination Test

Looking at the graphic for the blue stone specimens in Fig.1-a, the load displacement curve is linear until the energy accumulated in the interface is enough or separation to occur. This event happens at once in this case, being represented as a sudden decrease in load. In most specimens, delamination is observed either between the stone and the GFRE layer, or the stone layer fails. When the test jig forces the CA to bend, it induces an extension on all the composite layers which bend in the elastic regime as much as its stiffer material, in this case, the stone layer. Additionally, the lowest bonding energy is found between the GFRE and the stone, due to the stone chemical stability. So, when reaching the stone's bending limit, the accumulated energy will be released at this interface and delamination occurs. This was the case for BAS, BGS and BGA specimens.

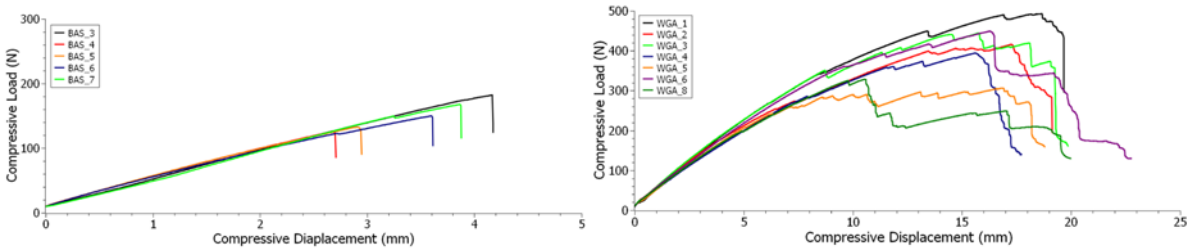


Fig. 1 Load displacement curve a) for BAS specimens b) for WGA specimens

For the white stone specimens, the observed behaviour was very different as the delamination was continuous instead of instantaneous, as it can be seen in Fig.1-b. There is a constant increase followed by a maximum and the load decreased in multiple peaks. Nevertheless, instead of representing several millimetres of delamination at once as in the preliminary test, in this case the peaks represented something different. The first peak in all specimens represents in fact the start of delamination, and the following decrease the continuous delamination. After this local minimum, the load either starts to increase again or remains constant until delamination is complete. This was the case for WGS, WAS, WGA and WAA.

## Conclusions

The surface roughness analysis showed that the superficial finish that is applied corresponds to very different roughness measurements, and so no generalization about the use of a specific finish must be made; in fact, when analysing the results of the stiffness tests, the effect of the smooth finish in the blue stone overcame the influence of the stone type being the results from the white stone (which was expected to be less rigid) higher.

The delamination test should be performed with a cut between the stone and the first glass fibre reinforced epoxy layer to avoid negative contribution of resin waste that accumulates on the delamination front during production. The difference in behavior of specimens produced with different stones relays on the intrinsic properties of the stone, being the most relevant for this case the open porosity. However, a further study with more stones is necessary in order to validate the exact causes. This proved to be a good method to understand the adhesion between layers, and the desired result for this application should be continuous delamination.

## Acknowledgments

The authors acknowledge the support from Galrão, SA and Urmal, SA for providing the raw materials. Funding: This study was developed by Frontwave, SA with the support of Instituto Superior Técnico from Lisbon University. The results presented in this paper were obtained in the frame of the project 10.472 STORK, funded by the European Regional Development Fund (FEDER) through the Alentejo Regional Operational Programme (PO Alentejo). This work was also supported by "Fundação para a Ciência e a Tecnologia" (FCT), through the Institute of Mechanical Engineering (IDMEC) under the Associated Laboratory for Energy, Transports and Aeronautics (LAETA), Project UID/EMS/50022/2013.

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## About the author(s)

Madalena Barata Garcia

Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. madalena.barata.garcia@tecnico.ulisboa.pt

Vera Lúcia Cordeiro Pires, Dr.ª

Frontwave - stone technology, Monte Novo de Santo António Apartado 141, 7100-999 Estremoz, Portugal. vera.pires@frontwave.pt

Virgínia Isabel Monteiro Nabais Infante, Prof.ª

LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. virginia.infante@tecnico.ulisboa.pt

Pedro Miguel Gomes Abrunhosa Amaral, Prof.

LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. pedro.amaral@tecnico.ulisboa.pt

GLOBALSTONE CONGRESS2018
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# Approaching early medieval Hispanic quarries (8th-10th c. AD). Geology and archaeology in action

**Enrique Álvarez Areces, María de los Ángeles Utrero Agudo, José Manuel Baltuille Martín**

**Synopsis**

Thanks to different research projects funded by public bodies, geological and archaeological methodologies have been applied to undertake by the first time an innovative research of early medieval Hispanic quarries and ecclesiastical buildings (8th-10th c. AD). Archaeology has made possible to obtain the chronological sequence of constructions, which has been completed by the petrographic characterization of those materials employed in every single historical phase. Geological surveying fieldwork and laboratory tests have contributed to locate the quarries likely exploited all throughout the history of the building, the methods of exploitation and the reasons for its use. These results renew thus the historical interpretation of early medieval Hispanic churches by introducing original aspects regarding the manufacturing of this architecture and mean the first attempt to approach coeval quarries, hitherto invisible in traditional research.

**Keywords**

Spain, Early Middle Ages, quarries, heritage, rocks characterization.

## Geology and archaeology working together

All the activities that make possible the building process of a stonework construction (selecting and obtaining material, transport, setting and embellishment) may be approached by geological and archaeological means. Thanks to the analyses of those traces preserved at the quarries (traces of tools, stones found on site), at the landscape (roads for transport), at the construction site (kilns, mortar-mixing basins) and at the building itself (techniques, traces of tools, putlog holes), these craft activities and the persons responsible for them (artisans and commissioners) are visible to us. In order to get this, archaeology and geology have to work in a coordinated way within a real interdisciplinary frame. But, why and how?

Constructions are actually archaeological sites, since they are the result of a long process of successive transformations (constructions, destructions and restorations) taken place throughout its history. By applying stratigraphic and typological criteria, archaeology may read this evolution and obtain thus the chronological sequence of buildings.

Once the construction is understood as an archaeological object, it is then possible to analyse its stone materials, since these are temporally sequenced. It is so possible to know if stone was freshly quarried or, by contrast, if it was reused from previous constructions; and when the stone was placed in the building, either in the original phase or later on. These facts have obviously relevant implications when looking for the likely quarrying areas, measuring the deterioration process of the material and deciding about its conservation and restoration strategies.

Analyses of stone materials (petrography, petrophysic, atomic absorption, OSL, X-ray fluorescence and diffraction) selected from the building help to characterise them and guide consequently the geological surveying fieldwork aimed to pinpoint the quarrying areas likely exploited. Examining the quarry provides valuable information about the methods of

exploitation, its chronologies and evolution; about the reasons for using and/or abandoning it and about the building technique by taking into account the natural feature of the stones and the structural, constructive and decorative requirements of the construction, among others. Petrographic studies of selected samples in the buildings and quarries, according always with the archaeological sequence, lead finally to establish correlations between both sites and relate them in different moments of its history.

## Early medieval Hispanic architecture: from the quarry to the building

It has been in the last five-year period that an interdisciplinary research has been started with the aim of broadening our knowledge of early medieval Hispanic building technology (8th-10th c. AD). This investigation has focused on the churches (Fig. 1) of San Pedro de La Mata (Toledo), San Miguel de Escalada (León), San Cebrián de Mazote (Valladolid) and San Isidoro (León). Although all of them are of early medieval origin, they were strongly modified by a long succession of construction activities, each one of them employing different materials coming from different quarries, but also reemploying old elements. Information obtained has led to important outputs (Álvarez, Utrero and Baltuille 2017; Utrero et al. 2016; Utrero et al. 2017), which can be summarised as it follows.

Fig. 1 From top, down: San Pedro de La Mata (Toledo), San Miguel de Escalada (León), San Cebrián de Mazote (Valladolid) and San Isidoro (León).

Archaeological and geological investigations of the early medieval phases of these churches elucidates how rough stone masonry was obtained in the nearby quarries, while ashlar stone material was exploited in quarries located a bit further. The latter was selected by the better quality of the stone, necessary to cut in detailed elements, such as imposts, voussoirs or regular ashlars. This selection shows that there was a previous planning of the building project, a proper knowledge of the surrounding areas, a search for materials by the builders and an understanding of the technical features of materials, which were accordingly chosen for different purposes.

Geological surveying fieldwork found quarries not huge neither in extension nor in depth (Fig. 2). Some of them were exploited coevally for a same building project, since they were soon exhausted because of its superficial character. They were easily and economically worked, because natural cracks were made use of and there was no waste material. Besides, transport was not expensive, since all quarries were located close to the construction site. These circumstances changed in the Late Middle Ages (from 12th c. onwards), when transport networks improved and quarries were in use for longer periods to supply larger constructions, as it is shown by the example of San Isidoro.

Fig. 2 From top, down: quarries related to San Pedro de La Mata (Toledo), San Miguel de Escalada (León), San Cebrián de Mazote (Valladolid) and San Isidoro (León, currently in use).

Geological structure of these outcrops enable also explaining the selection and use of the stone in the buildings. The thickness of the sedimentary strata or the alteration and cracking process of the granites, for instance, determine, in cases, the form of the building element obtained. This aspect shows a direct relationship between the building technique and que geological outcrops and confirms again the high competence of the artisans and masons responsible for providing these constructions with appropriate material.

## And the future? A long way to walk

These first results are encouraging but insufficient, highlighting thus the long way to walk in terms of methodology and knowledge before coming to general conclusions. Archaeological sequence must become the frame within which the geology must approach the building, with the aim of being so secure that every historical phase is correctly sampled by taking into account the origin (new or reused) and lithology of the materials. States of conservation, durability and erosion process of materials, among others, will be so rightly valued taking as basis the time gone from its first use and later alterations that might have modified them.

Besides this, the amount of studies of (early) medieval quarries and buildings must increase without leaving aside that they are both archaeological and geological sites. Working in this direction, thanks to currently ongoing research and restoration projects, we will be able to cross the disciplinary boundaries, enlarge our knowledge and improve the preservation of architectural and geological heritage for future generations.

## Acknowledgments

We would like to acknowledge the funding provided by national (MINECO, projects HAR2012-35222, HAR2017-84927-P) and regional governments (Junta de Comunidades de Castilla-La Mancha, Junta de Castilla y León); the work done by the staff of the stone laboratories at the Instituto Geológico y Minero de España (IGME), and the support given by further institutions in charge of the heritage here studied (Museo de León, Museo de Valladolid, Junta de Andalucía). We are also grateful to the project IGCP-637 for the financial support to participate in the Global Stone Congress 2018 with this contribution.

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## About the authors

Enrique Álvarez Areces, PhD

Instituto Geológico y Minero de España (IGME), Departamento de Investigación en Recursos Geológicos, Calle Ríos Rosas 23, Madrid 28003, Spain. e.alvarez@igme.es. Hired Researcher, geologist.

María de los Ángeles Utrero Agudo, PhD

Escuela de Estudios Árabes – Consejo Superior de Investigaciones Científicas (EEA-CSIC), Calle Frailes de la Victoria 7, Granada 18010, Spain. mariaangeles.utrero@eea.csic.es. Tenured Researcher, archaeologist. https://csic.academia.edu/MaríadelosÁngelesUtreroAgudo

José Manuel Baltuille Martín, MSc

Instituto Geológico y Minero de España (IGME), Departamento de Investigación en Recursos Geológicos, Calle Ríos Rosas 23, Madrid 28003, Spain. jm.baltuille@igme.es. Head of Unidad de Piedra Natural y Patrimonio Monumental, geologist.

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Behaviour of multi-textural ornamental rocks under Brazilian test conditions

**Javier Martínez-Martínez, Enrique Álvarez Areces, José Manuel Baltuille Martín, Jorge Fernández Suárez**

**Synopsis**

The presence of fractures, stylolites, veins and brecciated textures can increase the aesthetical quality of some ornamental stones. However, all these kind of discontinuities can affect the mechanical response of materials, decreasing their tensile strength and, consequently, their mechanical quality. In this paper, two brecciated dolostones and a fractured limestone are studied under Brazilian test in order to analyze the influence of discontinuities and complex textures on the tensile strength of rocks. The fracture pattern and the rupture mode of each sample during the splitting test was also studied. Results reveal that veins and, especially, stylolites facilitate the apparition and propagation of cracks, decreasing the tensile strength of rocks. Contrarily, the clast boundaries in brecciated textures do not constitute preferential weak planes. Consequently, the highest tensile strength (10.46 MPa) is registered on the most homogeneous sample of the fractured limestone. However, the presence of veins and stylolites in this variety cause the strength decrease until the same level than the mechanical response of those samples with the most complex brecciated textures (~4.50 MPa).

**Keywords**

Tensile strength, limestone, dolostone, stylolite, fracture mode.

## Introduction

The knowledge of the mechanical properties of rocks is an important point in order to guarantee their correct use as both dimension and ornamental stone. In particular, tensile strength is a decisive parameter that determines the suitability of a rock variety to be used as slabs in cladding, paving or steps. The aesthetical value of some ornamental rocks are focused on their complex petrofabric. Fractures, stylolites, veins and brecciated textures are appreciated and their presence increase the aesthetical quality of the rock. However, all these kind of discontinuities can affect the mechanical response of materials, decreasing their tensile strength and, consequently, their mechanical quality.

The aim of this paper is to study the influence of cracks, veins and brecciated textures on the tensile strength of different ornamental stones with multi-textural petrofabrics.

## Materials and methods

Three commercial varieties of carbonate rocks with multitextural petrofabrics were selected (Fig. 1):

***Marrón Emperador (ME):*** brown brecciated dolostone with high structural complexity. Clasts are defined within a dense network of fractures and veins. Clast size distribution is highly heterogeneous, varying from 0.5 cm to ~4 cm in diameter. Three different textural components can be recognised in this rock: i) massive dolomite clasts (porosity <1%); ii) porous matrix (porosity ~5%); and iii) white calcite cement filling fractures and veins.

***Beige Serpiente (BS):*** Cream-coloured brecciated dolostone. Clasts in this stone are surrounded by a porous fine-grained matrix (matrix porosity ~10%). In general terms, clast size distribution in this rock variety is more homogeneous than it is in ME, varying their diameters between 1 and 2 cm.

***Rojo Cehegín (RC):*** Red fractured biomicritic limestone. RC has a large number of veins filled with white calcite crystalline cement. Stylolites can be frequent, having an insoluble filling constituted by quartz, oxides, and clays (kaolinite, smectite). Some samples can show high density of discontinuities.

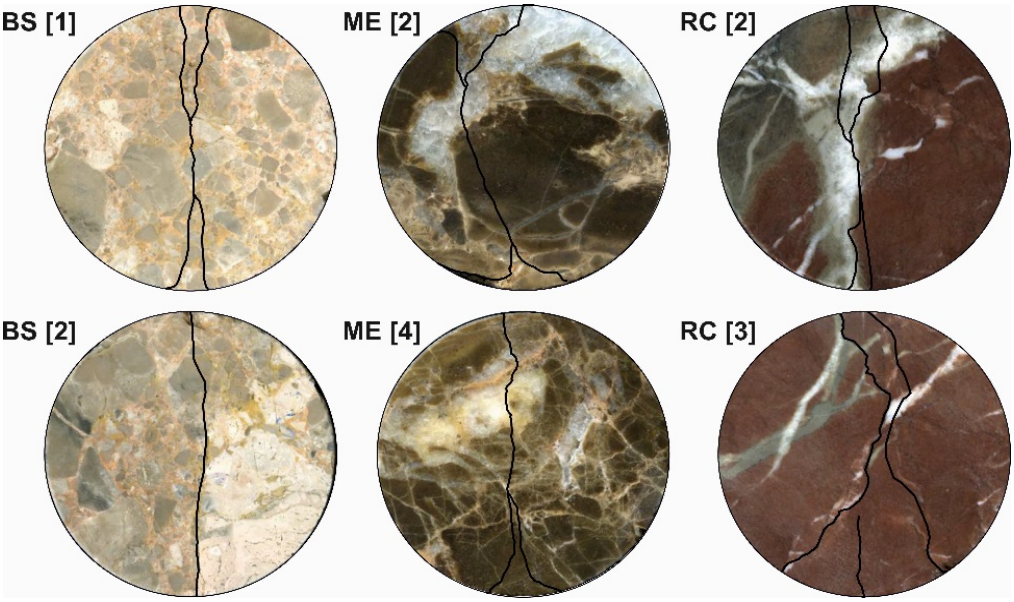


Fig. 1 Studied ornamental stones: Beige Serpiente (BS), Marrón Emperador (ME) and Rojo Cehegín (RC). Black lines drawn inside the samples correspond to the trace of the fractures developed after Brazilian test.

Six disc-shaped samples (50 mm diameter x 30 mm thickness) per rock variety were used in this study. Tensile strength of rock was calculated from the indirect tensile (Brazilian) test (Rocco et al., 2001), using a uniaxial compression press with a loading capacity of 100 kN, at a constant displacement rate of 1 mm/min. The disc-shaped samples were loaded diametrically and compressed vertically till failure. The indirect tensile strength, $\sigma_t$, was calculated as

$$t = \frac{2F}{\pi D t} \quad [1]$$

Where F is the applied load when the sample fails; and D and t are the diameter and thickness of the disc-shaped sample.

## Results and discussion

Table 1 shows the tensile strength obtained from this study. All three studied rock varieties present similar tensile strengths, but the higher scattering is measured in RC. Tested samples develop different kinds of fractures after failure in the Brazilian test. It is possible to differentiate three fracture patterns according to the relative position of the fracture (Tavallali and Vervoort, 2013): Central Fracture (CF), Non-Central Fracture (NCF) and Defect Activation (DA) patterns. On the one hand, the Central Fracture pattern (CF) occurs when fracture is developed parallel to the loading direction and it is located in the central

part of the sample (Fig. 1). This ideal situation is the predominant pattern for samples of all three studied rock varieties, especially in BS and ME (Tab. 1). On the other hand, Non-Central fractures (NCF) are developed outside the central part and they use to show curved lines, starting at or around the loading platens. NCF pattern is frequent in RC samples. In general terms, CF can be associated with high values of tensile strength, whilst NCF uses to be developed in tests where the rock sample achieves medium-low strengths.

Table 1 Tensile strength, fracture pattern and rupture mode obtained in the tested rocks. For abbreviations meaning, see the text.

| | **BS** (sample number) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | Mean |
| $\sigma_t$ (MPa) | 8.29 | 4.44 | 8.24 | 7.62 | 7.68 | 6.93 | 7.20 ± 1.44 |
| Fracture pattern | CF | DA+CF | CF | CF | CF | CF | |
| Rupture mode | W | I | W | W | I | W | |
| | **ME** (sample number) | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | Mean |
| $\sigma_t$ (MPa) | 6.64 | 4.38 | 9.84 | 7.53 | 8.34 | 4.94 | 7.11 ± 1.85 |
| Fracture pattern | CF | NCF+DA | CF | CF | CF | CF | |
| Rupture mode | W | W | W | W | W | I | |
| | **RC** (sample number) | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | Mean |
| $\sigma_t$ (MPa) | 9.28 | 10.46 | 4.93 | 6.12 | 7.69 | 9.68 | 7.36 ± 2.18 |
| Fracture pattern | DA+CF | DA+CF | DA+NCF | DA+NCF | DA+NCF | CF | |
| Rupture mode | W | W | S | W | W | I | |

Both kinds of fracture patterns (CF and NCF) can be initiated and/or propagated along a preexisting petrographic component (fracture, vein, stylolite, clast). In this case, the rock failure is due to a Defect Activation (DA). This type of fracture pattern (DA) is compatible with the previous two types (CF and NCF). Only one sample of ME and BS show DA pattern (BS2 and ME2 in Tab. 1 and Fig. 1). In the case of BS2, the crack growth is along the flat side of a big clast; whilst in the case of ME2 the crack propagation is though the macrocrystalline cement of a white vein. In both cases, the tensile strength reached at the end of the test is lower than it is without DA. In the rest of the samples of ME and BS, the crack initiation and propagation is independent of petrographic elements such as clast boundaries or the presence of fine-grained matrix. In fact, the fracture propagation in becciated textures is ussually intra-clasts, instead inter-clasts, revealing that the contact clast-matrix is strong and cohesive and it does not act as a discontinuity. Similar behavior was found in Lavrov (2002) for similar materials.

Contrarily, the DA fracture pattern is the most common mechanism in RC samples. Macrocrystalline cement in veins and stylolites constitute the preferential propagation ways

for fractures (Fig. 1). Failure strength registered in samples where fractures are initiated or propagated along stylolites (i.e. RC3 and RC4 in Tab. 1 and Fig. 1) is lower than samples where the DA is associated with veins (i.e. RC1, RC2 and RC5). This is due to the presence of weak minerals (clays) filling the stylolites.

From the obatined results, stylolites and veins are especially sensitive to be activated during the loading process when they are located in the central band of the sample (near the plane of loading) and they present a parallel or sub-parallel orientation with respect the load direction. Similar result was obtained by Tavallali and Vervoort (2013).

Finally, three different rupture modes can be identified attending to the final geometry developed by the tensile fracture (Rocco et al., 1999): Ideal Rupture Mode (I); Rupture mode with wedge formation (W); and Rupture mode with secondary crack formations (S). In the first case (mode I), the sample breaks into two halves, across the plane of loading (Tab. 1 and example BS2 in Fig. 1). In the second case (mode W), the main fracture is divided into several secondary cracks near the zone where the load is applied, forming a fan (Tab. 1 and examples BS1, ME2, ME4 and RC2 in Fig. 1). This rupture mode is the most frequent in the tested rock varieties. The last mode (mode S) is characterized by the development of a complex parallel crack system (example RC3 in Fig. 1).

## Conclusions

Different fracture patterns and rupture modes are observed when carbonate rocks with multi-textural components are tested in the Brazilian test. The most common behaviour is the rock failure by means of Central Fracture pattern and rupture mode with wedge formation. However, stylolites and veins are especially sensitive to initiate and propagate cracks, favouring the sample collapse by means of Defect Activation pattern. The fracture propagation in becciated textures is ussually intra-clasts, revealing that the contact clast-matrix does not act as a weak discontinuity. The highest tensile strength (10.46 MPa) is registered on the most homogeneous sample of the fractured limestone. However, the presence of veins and stylolites in this variety cause the strength decrease until the same level than the mechanical response of those samples with the most complex brecciated textures (~4.50 MPa). Consequently, the failure strength is inversely correlated with the development of fractures by means of defect activation mode, especially when cracks are developed along stylolites.

## Acknowledgments

The authors are grateful to the project IGCP-637 for the financial support to participate in the Global Stone Congress 2018 with this contribution.

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## About the authors

Javier Martínez Martínez, PhD

Geological Survey of Spain (IGME), Geological Resources Department. Unit of Natural Stone and Monumental Heritage. Ríos Rosas, St. 23, Madrid, 28007, Spain. javier.martinez@igme.es

Enrique Álvarez Areces, PhD

Geological Survey of Spain (IGME), Geological Resources Department. Unit of Natural Stone and Monumental Heritage. Ríos Rosas, St. 23, Madrid, 28007, Spain. e.alvarez@igme.es

José Manuel Baltuille Martín, MSc

Geological Survey of Spain (IGME), Geological Resources Department. Unit of Natural Stone and Monumental Heritage. Ríos Rosas, St. 23, Madrid, 28007, Spain. jm.baltuille@igme.es

Jorge Fernández Suárez, PhD

Geological Survey of Spain (IGME), Geological Resources Department. Unit of Natural Stone and Monumental Heritage. Matemático Pedrayes, St. 25, Oviedo (Asturias), 33005, Spain. j.fernandez@igme.es

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# Image analysis for stone durability: two different techniques

**Rossana Bellopede, Fiorenza Baudana, Lorena Zichella, Paola Marini**

**Synopsis**

The presence of pores, cracks and micro-cracksin compact rocks is one of the main features that govern the processes of decay of stone materials and, although the marbles are characterized by a modest porosity, there is a clear correlation between the presence and movement of fluids of the water, and the phenomena of alteration. Through the study of porosity it is possible to better understand the phenomena of alteration and degradation in order to obtain useful information in the field of modern building, but also for the protection and recovery of historical and artistic heritage goods. The purpose of the research is to characterize the physical and mechanical properties of four different varieties of marble, exposed to external degradation agents for about ten years and then compared with the original properties measured on slabs of the same marble protected from atmospheric agents. The study was conducted through the characterization of physical and mechanical parameters directly correlated with the degree of alteration of the materials: water absorption by contact sponge(UNI 11432), water absorption at atmospheric pressure(EN 13755), flexural strength (EN 12372)and bowing(EN 16306 par. 8.2). In addition, to verifying the porosity of the materials studied, two different image analysis techniques were compared: ImageJ with Jpore and AGA.The results obtained from the two techniques found a better analysis of the degradation with Image J than the AGA that cannot be representative of the tendency to decay or bowing of the marble.

**Keywords**

total optical porosity, adjacent grain analysis, decay, fabric, porosity

## Introduction

Decay affects aesthetics and structurals (including microstructurals) characteristics of natural stones. The progress of decay leads to a worsening of mechanical properties of materials, such as the increase in water absorption, due to the increased porosity of the rock.On the base of recent researches Akesson et al. 2003, (Bellopede et al 2016, Andriani and Germinario 2014) there is a direct connection between durability of natural stones and structural characteristics observable by microscopy analysis. Lots of recent works are referred to the Image Analysis methods for the evaluation of decay in natural stones. These techniques are potentially useful but they are not yet standardized: for this reason it is necessary to validate the test methodology and to verify the test results reliability.

## Total Optical Porosity method

Total Optical Porosity (TOP) determination has been performed using the free software Irfan View 4.40 and the macro file jPOR.txt (Grove and Jerram, 2011) for ImageJ. Four different kind of marbles has been tested; for each one, six thin sections has been made and soaked with epoxy resin and methylene blue as illustrated in Fig. 1a. In order to obtain a better analysisof the increase of decay, five thin sections obtained from the weathered marble has been cut, respectively three along the upper (P1), medium (P2) and lower (P3) sections parallel to the exposed surface and two along a transversal section (the external T1

and the internal T2). The impregnation process was repeatedly performed under vacuum in order to obtain a smooth surface when viewed against light .All the thin sections have been analysed using the optical macroscope LEICA MZ6 and the PANASONIC LUMIX DMC-GF6 digital camera. For each thin section, ten photos have been made uniformly spaced among its surface (Fig. 1b) and then pre-processed using Irfan View. Each 24-bit image has been converted to an 8-bit image using the custom blue palette of jPOR created in order to reach a colour thres holding that requires less preprocessing and removal of noise, thereby reducing inter-operator variability. The threshold values used to determine the porosity were left as constant as possible (lower threshold = 0 and upper threshold = 69/70) in order to find representative and comparable results between different marbles. At the end of this process, the average porosity value has been calculated and compared for each thin section.

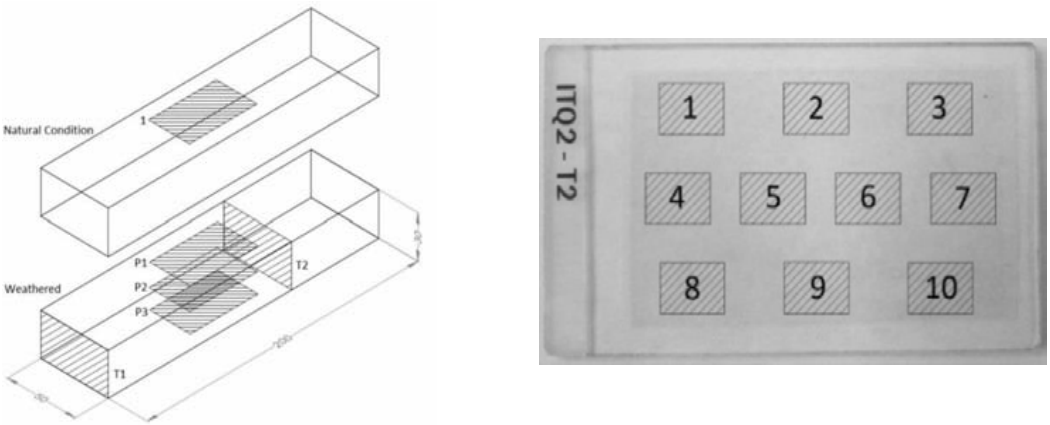


Fig. 1 a) On Left: Cutted areas from the specimens to obtain thin sections. b) On right: Position of pictures taken from thin section for image analysis.

This new unconventional technique was used to verify if the marbles shows different kind of weathering after being subjected both to natural ageing and to accelerated ageing tests (Bellopede et al 2016). Even if the values on the TOP are characterized by high uncertainty, for GI marble has been possible to detect the different answer in term of porosity distribution between artificial and natural weathering, giving an explanation to the different results obtained by means of conventional tests (with particular reference to water absorption and bowing values).

## AGA method

The AGA Analysis (AGA) was carried out in accordance with the EN 16306 Annex C (2013) by means of the free software ImageJ in order to calculate the number of adjacent grains (AG) around median-sized grains. This analysis method gives information on the microstructure of natural stone and its potential durability (Åkesson et al. 2010); it has been suggested as a screening method. Initially, the value of the median grain size has been calculated, measuring the Feret diameter (longest axis) of at least 100 grains along the plotted linear traverses (Figure 2). Afterwards, at least 50 median sized grains were chosen and a manually count of the number of their adjacent grains was carried out; the mean value of all counts represents the AGA index. According to Annex Cof EN 16306, values from 8 upwards represent marbles with good characteristics, an AGA of 7 is intermediate, and 6

indicates a low level material. Is important to highlight that, according to the standard, this classification is valid only for calcitic marbles.


Fig. 2 Linear traverse method for determination of the grain size distribution

## The stone tested

The marble tested and the petrographic characteristics are shown in Tab. 1. GI, SG and PS are mainly calcitic while IK is composed by 96% of dolomite.

Table 1: Marble tested and petrographic descriptions

| MARBLE TYPE | DESCRIPTION |
|---|---|
| GI | Italian marble totally calcitic composition with polygonal structure and equigranular grains (size from 0.1 to 0.5 mm) with no presence of subgrains |
| SG | Portuguese marble: composition is mainly calcitic. Grain size from 0.7 to 1 mm. Rare quartz grains Seriate polygonal/ interlobate. No subgrains |
| IK | Greeke marble: composition is 96 % dolomitic. Grain size from 0.05 to 0.17 mm Interlobate/polygonal. Inequigranular. Few subgrains |
| PS | Portuguese marble: composition is totally calcitic. Grains size from 1 to 2.8 mm Seriate polygonal. Subgrains |

## Results

In the table 2 the result of change in flexural strength, UPV water absorption and bowing after 20 thermal cycle in presence of humidity according EN 16306 are shown. The results of the image analysis by means AGA and JPOR are reported in table 3.

Table 2 Results of physical mechanical properties, also after artificial ageing tests.

| | Flex. Str. | UPV | Water abs | Bow |
|---|---|---|---|---|
| | % | % | % | mm/m |
| GI | -40 | -55 | 46 | 0.89 |
| SG | –19 | –19 | 12 | 0.04 |
| IK | 12 | -14 | -0.9 | 0.05 |
| PS | -21 | -8 | -6 | 0.06 |

Table 3 JPor results and AGA.

| | | NAT.CONDITION | ARTIFICIALLY AGED | | | | |
|---|---|---|---|---|---|---|---|
| | AGA | JPor (1) | JPor(P1) | JPor(P2) | JPor(P3) | JPor(T1) | JPor(T2) |
| | | % | % | % | % | % | % |
| GI | 6.1 | 0.34 | 0.66 | 0.77 | 0.29 | 1.84 | 0.42 |
| SG | 6.8 | 0.16 | 0.40 | 0.07 | 0.21 | 0.18 | 0.16 |
| IK | 7.7 | 6.29 | 15.50 | 5.89 | 13.02 | 4.57 | 8.13 |
| PS | 10 | 0.20 | 0.04 | 0.11 | 0.03 | 0.02 | 0.07 |

## Discussions and conclusions

From the results obtained AGA cannot be fully representative of the tendency to decay or bowing of the marble. Infact SG, despite the AGA value 6.8 (indicating a low level material according Annex C of EN 16306), doesn't show bow tendency and decreasing in mechanical properties (tables 2 and 3).For the future revision of the EN 16306, test method is therefore advisable, because of the difficulties of interpretation, to build a broader database and understanding by training and inter-comparison trials among laboratories trained on the AGA calculation. Major investigations could be executed focusing on the influence of grain size on bow tendency and the Image analysis an instrument to evaluate this further feature.

The use of Total Optical Porosity by means of JPor and soaked thin section could be useful to better explain the decay mechanism of stone tested. In particular the comparison of the results obtained from the specimen portion P1with the sections formed by the central part P2 is an indicator of the evolution of porosity or cracks inside the stone For example, GI, with high value of water absorption after artificial ageing (table 2),is characterized by high values of TOP both in the upper and in central parts of specimen (P1 and P2 thin section) respect the TOP calculated in natural condition (1 thin section - table3).IK, instead, with a very low water absorption, show values of TOP higher in correspondence of the upper and bottom portions (P1 and P3 thin sections) and lowest value in the center of specimen (P2 – table 3).

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## About the authors

Bellopede Rossana, PhD, Eng
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. rossana.bellopede@polito.it

Baudana Fiorenza, Dr
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. fiorenza.baudana@polito.it

Zichella Lorena, Eng
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. lorena.zichella@polito.it

Marini Paola, Prof.
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. paola.marini@polito.it

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# The fundamental resonance frequency measurement: critical evaluation of test method on natural stone

**Fiorenza Baudana, Rossana Bellopede, Silvia Forbino**
**Lorena Zichella, Paola Marini**

**Synopsis**

Fundamental Resonance Frequency method (FRF) is foreseen by European Standard for the evaluation of the durability and state of conservation of natural stones. For these reason it is important to understand if this technique, widely applied in the determination of mechanical property of industrial materials as concrete and ceramics, can provide reliable results in the applications on natural stone. In this work, European Standard EN 14146:2004 (natural stone test method) has been analysed, starting from the comparison with American ASTM C215:2014 (concrete specimens test method). Four different stones have been tested with FRF method in order to obtain values of dynamic modulus of elasticity, following respectively EN and ASTM instructions. The same samples have been additionally tested with Ultrasonic Pulse Velocity (UPV) measurement, in direct mode, by means European Standard EN14579:2004. Results obtained with FRF method following both ASTM and EN Standards are comparable for all the rock samples and these values do not differ significantly from dynamic modulus of elasticity from UPV measurement. Both ASTM and EN standard can be applied testing natural stones but with accurate consideration about rock fabric, sample dimensions, position of supports and location of the impulse. Indication suggested for artificial material as concrete can be therefore used in natural stone samples with approximate homogeneous composition and structure.

**Keywords**

Dynamic modulus of elasticity, standardized test method, ultrasonic pulse velocity.

## Introduction

The value of dynamic modulus of elasticity, used to express mechanical properties of rock materials, may be obtained by means of two non-destructive tests: Ultrasonic Pulse Velocity (UPV) and Fundamental Resonance Frequency measurements (FRF). The first technique measures P and S ultrasonic wave velocity transmitted in a stone specimen, while the second one measures the mechanical resonance frequency.

UPV test is one of the most common methods used to assess the state of conservation of a stone element measuring elastic modulus; it gives accurate results, well correlated to mechanical properties of stones tested even with flexural strength measurements. Different kind of rocks has been tested with this method and lots of data are available in literature (Luodes et al. 2017, Bellopede et al. 2016, Rasolofosaon et al. 2000). The European test method for determination of UPV in natural stones, both in laboratory and in situ, is the European Standard EN 14579:2004.

The determination of dynamic modulus of elasticity with the FRF method in natural stones is foreseen by the European Standard EN 14146:2004. Moreover this technique is required by the EN 14066:2013 to evaluate the damage caused on natural stones to the thermal shock cycles. The determination of resistance to thermal shock cycles is required for CE marking of natural stone products as slabs for cladding (EN 1469:2013), modular tiles (EN 12057:2004) and slabs for floor and stairs (EN 12058:2004).

Considering therefore the requirement of European Standards for the evaluation of the durability and state of conservation of natural stones, it is important to understand if this technique, widely applied in the determination of mechanical property of industrial materials as concrete and ceramics (considered as homogeneous, elastic isotropic materials) can really provide reliable results in the applications on natural stones. For this reason, the European Standard for the determination of dynamic modulus of elasticity by measuring the fundamental resonance frequency in natural stones (EN14146:2004) has been analysed, starting from the comparison with ASTM C215:2014.

## The European and International Standards on the Fundamental Resonance Frequency measurements

The FRF method measures the modulus of elasticity exciting a specimen by means of a mechanical impulse and analysing the transient natural vibration during the subsequent free relaxation. Complex vibratory phenomena are generated on depending on the nature of the material (Chantre et al, 1978). Specimens can be excited into longitudinal, flexural (indicated as “transverse mode” by ASTM Standards) and torsional modes in order to obtain, respectively, the modulus of elasticity (E) in either flexural and longitudinal mode and the modulus of rigidity (G) in the torsional one. The method is limited to specimens with regular geometries (rectangular parallelepiped, cylinder and discs) with no discontinuities (large cracks) for with analytical equations are available. Concerning the standardized test methods, while EN 14146 refers to natural stones, ASTM C215 covers the determination of dynamic elastic properties for concrete specimens.

### Apparatus and test specimens

The equipment used for FRF measurement, suggested in both EN 14146 and ASTM C215 instructions, is made by an impulser, a receiver (pick up transducer) to convert the mechanical vibration into an electrical signal, an electronic system and a support system. According to the standardized methods, test specimens shall be prismatic or cylindrical in shape. Both EN 14146:2004 and ASTM C215:2014 foresee that the length of cylindrical square or rectangular based prisms shall be at least twice the largest dimension of the base.

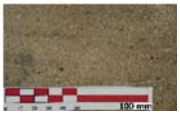
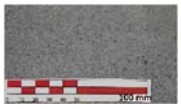
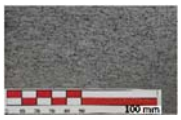
### Supports and Location of the impulse/transmitter

Both EN14146 and ASTM C215 foresee to work on an isolated surface using specimen stands. EN suggest the use of rigid rectangular or square section prismatic metal stands (in longitudinal and torsional mode), whose width is less than 5% of the length of the specimen, or triangular section prisms (in flexural mode). Standards suggests that the specimen supports shall be located in correspondence of the specimen nodal points for different modes of vibrations. The difference between the two standards is the location of the impulser/transmitter that should be positioned at the extremity of the specimen (opposite to the receiver) according to EN, at the center of the specimen according to ASTM.

## Materials and methods

Specimens with dimensions 400x100x100mm (rectangular parallelepiped) have been tested: Trachite (TRA), Red Balmoral Granite (RO), Basalt (BA), Gneiss Lodrino (LO) (Tab. 1).

Table 1. Description of rock specimens: origin, textural and mineralogical characteristics.

| Rock specimen | Acronym | Textural and mineralogical description | Macroscopic aspect |
|---|---|---|---|
| Trachite | TRA | Fine grained volcanic rock from Banari (Sardinia) with a porphyritic structure; it is mainly composed of alkali feldspar (sanidine, orthoclase), subordinate plagioclase, biotite, amphibole and pyroxene. |  |
| Red Balmoral Granite | RO | Non-foliated, equigranular, medium-grained red granite from Finland. This intrusive rock is mainly composed of alkali feldspar, quartz, plagioclase, biotite and muscovite. |  |
| Basalt | BA | Fine grained volcanic rock from Sardinia with a porphyritic structure, mainly composed of plagioclase, pyroxene (augite), olivine and subordinate hornblende, biotite and opaque minerals (hematite and magnetite). |  |
| Gneiss Lodrino | LO | Foliated metamorphic rock from Swisse characterized by alternating layers composed of different mineral. Main composing minerals are feldspar (albite, alkali feldspar), quartz, biotite, muscovite, and subordinated amphibole |  |

FRF measurements were performed with a Resonance Frequency meter 58-E0035/C (Fig. 1) equipped with a display of harmonic frequencies in order to better evaluate the results. To excite the response, a light and elastic tap was executed following Standard suggestion. To detect the resulting vibration and converting it into electrical signals, a hand-held piezoelectric detector was used in contact with the test sample. In ASTM instructions more detailed information regarding the position of nodal points are given. Concerning the FRF in transversal mode, as the execution according EN didn't give reliable results, impacts in the center according ASTM have been executed; however the $E_{transv}$ has been calculated with the EN equation. The Ultrasonic Pulse Velocity (UPV) have been measured in direct mode by means PUNDIT device in order to verify the reliability of FRF results.

Fig. 1 Resonance Frequency meter 58-E0035/C.

## Results

Table 2 resumes data obtained by means of both FRF measurements according EN 14146 and ASTM C215 (converted in GPa), and UPV measurements, with their value of uncertainty (e = std/$E_{mean}$*100) calculated as ratio between standard deviation (std) and mean value ($E_{mean}$) in percentage. FRF data obtained were used to calculate values of elastic modulus of elasticity (E) and modulus of rigidity (G) using different equations following EN and ASTM instructions. UPV values of E were obtained according with Santamarina J.C. (2001) equation.

Table 2. Comparison FRF results according EN 14146:2004, ASTM C215:2014 and UPV.

| | E (UPV) | | E transv (FRF) | | | E long (FRF) | | | G tors (FRF) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | E (GPa) | (e) % | EN (GPa) | ASTM (GPa) | (e) % | EN (GPa) | ASTM (GPa) | (e) % | EN (GPa) | ASTM (GPa) | (e) % |
| TRA | 33.9 | 0.35 | 32.7 | 32.6 | 0.57 | 30.9 | 30.9 | 0.56 | 12.3 | 12.3 | 0.73 |
| RO | 30.7 | 0.93 | 30.3 | 29.7 | 1.21 | 27.0 | 27.0 | 0.61 | 13.6 | 13.6 | 0.12 |
| BA | 54.2 | 0.33 | 48.5 | 48.1 | 1.11 | 45.8 | 45.8 | 0.55 | 18.3 | 18.3 | 0.63 |
| LO | 40.3 | 0.00 | 37.4 | 37.3 | 0.84 | 36.7 | 36.7 | 0.53 | 13.0 | 13.0 | 0.57 |

## Discussion and conclusions

The $E_{long}$ and G, obtained with ASTM and EN Standards equations, are the same for all the rock tested. Instead, $E_{transv}$ calculated according EN is different from $E_{transv}$ calculated according ASTM because of different factor corrections suggested by the two standards. The results of dynamic modulus obtained by means UPV are in all cases higher than those obtained by FRF measurement.

In conclusions, considering the results obtained, both ASTM and EN standards can be applied on natural stones taking into account sample dimensions, position of support and location of the impulse and rock fabric (presence of anisotropy, large cracks or voids). So, indication suggested for concrete, can be used in natural stone samples with approximate homogeneous composition and structure and in absence of fractures.

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## About the authors

Baudana Fiorenza, Dr
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. fiorenza.baudana@polito.it

Bellopede Rossana, PhD, Eng
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. rossana.bellopede@polito.it

Silvia Forbino, Eng
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. s214368@studenti.polito.it

Zichella Lorena, Eng
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. lorena.zichella@polito.it

Marini Paola, Prof.
Politecnico di Torino, DIATI, Corso Duca degli Abruzzi, 24, 10129, Torino, Italy. paola.marini@polito.it

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL April 26-29, 2018
CONNECTING MINDS IN THE WORLD OF STONE

# The evolution of the Stone Cluster

**Inês Paulo Frazão, Rui Moreira de Carvalho, Joana Paulo Frazão, José Paulo Afonso Esperança**

## Synopsis

The scope of this investigation is to analyse the evolution of the Stone sector and the impact of network relations for the gain of competitiveness. A Cluster is identified as an instrument capable of creating favourable conditions for an ecosystem conducive to innovation, cooperation and scale. The Stone Cluster, which started in 2009, assumes favourable characteristics for a qualitative analysis, focusing on the emergence of partnerships and on a creation of a database for future monitoring. We carried out an extensive documentary analysis in the Stone companies that belong to the Cluster, we evaluate the evolution of the sector before and after its formation. The results suggest that the companies, that belong to the Cluster, show a positive evolution compared to the sector in general, namely twice of the exports due to the introduction of innovative technologies and processes, promoting cross-learning.

**Keywords:**

Business Network, Cluster, Innovation, Exports, Stone.

## Introduction

"Stone" is an easily exportable product. And, Portugal, despite being a relatively small country, has a great diversity and quantity to offer to the international market. According to Anil Taneja (2016) the companies of Stone, worldwide, are in difficulties and need to innovate and to adapt. There are several challenges for which companies must be prepared.

To Portuguese companies to enter this new era, an instrument capable of creating favourable conditions for the creation of an ecosystem conducive to innovation and competitiveness is what are called “Clusters” (Amaral, 2015). A Cluster is a concentration of companies with similar characteristics that cohabit in regions of proximity that tend to collaborate towards efficiency gains (Porter, 1985). The Stone sector, through its sector associations, is promoting a set of value creation initiatives aimed to gain competitiveness. The associations are promoting a project that develops the Cluster concept (networked companies). In 2009 was created the Cluster “ValorPedra” based on the Science and Technology System (STC). In 2012 a "national" brand was created for the sector: STONE.PT.

This research aims to observe the evolution of the Stone Cluster and the impact of network relations for the gain of competitiveness.

## State of the art

The main question is how can you adapt the resources and capabilities to a market that is constantly changing. According to Teece (2007), organizations need to develop their dynamic capabilities, i.e, their ability to find change in a dynamic environment. Cardeal and António (2012) emphasize that dynamic capabilities are the necessary to transform resources into competitive advantage. During a period of changes in a company's environment, there is a relationship between dynamic capabilities and competitive

advantage (Seyed Kalali and Heidari, 2016). Dynamic capabilities (CD) are organizational processes designed to change the enterprise resource base to achieve competitive advantage in a rapidly changing environment (Ambrosini and Bowman, 2009). It is recognized that a company may have access, albeit limited, to the resources of other companies through, for example, to a partnership (Dyer and Singh, 1998). The networking is clearly linked to the development of dynamic capabilities (Eriksson, 2014; Parida, 2008). Vahlne and Johanson (2013) argue that the interaction between the markets is carried out within the networks, learning, creating, internationalizing, and improving their dynamic capacities. So it's important to be an insider in these networks.

Recognizing the need for collaboration is an important step in developing a partnership. However, many companies that identify this shortage do not know how to start it. Thus, a "mobilizing" agent (institution or individual) may be required to initiate the process. This "mobilizing" agent to be effective must offer credibility and expertise, personal or institutional, reliability and a sense of neutrality (Carvalho, 2014). Can this "mobilizer" agent be the Cluster?

In 2015 the Stone sector exported to 127 Countries, were the 9th Country of the World International Trade of Natural Stone, has an import coverage rate of 897% and a turnover of 952 Million. Its export were 330 Million Euros (48% outside Europe) and had about 2700 companies with 16,000 workers.

The Stone Cluster has horizontal cooperation (Stone companies) and vertical (suppliers). The strategic axes are the internationalization of the Portuguese Natural Stone, the sustainability of Cluster activities, bet on the qualification of resources and territories, bet on organizational, productive and technological innovation. Since its formation, the Cluster has led several anchor projects: (1) Valorisation of Natural Stone; (2) Environmental Sustainability of the Extractive Industry and (3) New technologies for the competitiveness of Natural Stone.

Recently, ValorPedra was been renamed Portugal Mineral Resources Cluster, extending its scope also to metallic minerals. R&D activities are in products and processes, increasing productivity and extending the value chain. Since 2000, the industry has developed projects to eliminate wastage throughout the supply chain, increase flexibility, enable tailor-made projects, increase productivity, increase raw material added value and protect the environment. The projects in the Stone sector were JetStone (2005), InovStone (2010) and InovStone 4.0 (2017). It is estimated that these projects will have yielded between 180 and 240 million euros in exports by 2014 and will have leveraged the creation or maintenance of more than 2,000 jobs.

## Method

The approach is qualitative and the instrument is a documentary analysis (12 databases and 6 sources) for the Stone sector and the Cluster Stone companies.

## Results and Discussion

The Cluster has 39 entities (16 Stone companies, 6 of equipment and 17 of STC). The 16 Stone companies that integrate the Cluster have an average age of 33 years and export about 60% (2015) of their production. The main destinations are non-EU markets (68%).

Regarding turnover and exports, although turnover fell from 51 (2010) to 49 million euros (2015), exports increased from 23 (2010) to 29 million euros (2015).

The exports in both the Stone and Cluster Stone businesses increased significantly. However, in the companies of Stone Cluster (N = 16), exports increased twice as much (25%) than in the sector (12%). Comparing the evolution of the companies of Cluster Stone with the sector, in the period from 2010 to 2015, Cluster companies tend to present better results.

The export of the Stone sector increased from three hundred and three million euros (€ 303 million) in 2010 to three hundred and thirty million euros (€ 338 million) in 2015. By the other hand, the export of the Cluster Stone Companies increased from approximately twenty-three million euros (€23,1 million) to approximately twenty-nine million euros (€29 million), in 2010 and 2015 respectively (Tab. 1).

Table 1 Exports in the stone sector and in the cluster 2010-2015.

| | **2010** | **2015** |
|---|---|---|
| Companies exports of stone cluster | 23 137 923 € | 29 024 406 € |
| Stone Sector Exports | 303 000 000 € | 338 000 000 € |

The export of the stone cluster companies comparing with the stone sector more than double as you can see in the Fig 1.

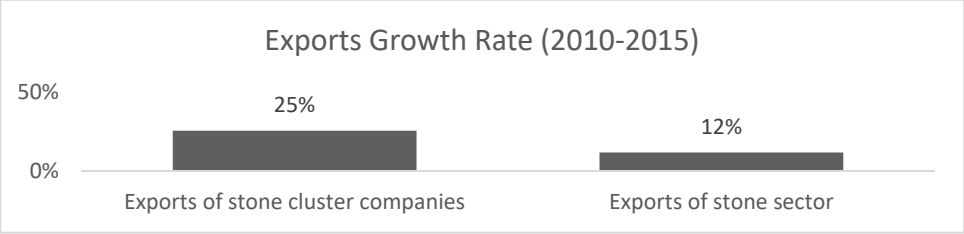


Fig. 1 Evolution of the Exports in the Stone Sector and the Cluster Stone Companies (2010-2015).

For the analysis of the results we chose to observe the sector from 2004 to 2009 (before the creation of the Stone Cluster) and from 2009 to 2014 (after the creation of the Stone Cluster). The evolution of exports was greater after the formation of the Cluster (2009-2014), increased by 23%, than in the period before the formation of the Cluster (2004-2009) in which they increased by 6%. Consequently, the coverage (exports / imports) of the sector grew more strongly after the formation of the Cluster (371%) than in the period prior to the formation of the Cluster (171%).

In terms in of the employment the stone cluster companies present better results and in the qualified workforce is higher (Frazão, 2016). As reported in the literature by Jankowska and Glowka (2016) Cluster entities increase their involvement in international markets. This demonstrates that enterprise networks enhance the ability to innovate, speed of response to market, levels of quality and strategic flexibility (Carvalho, 2009). It also reflects that

strategic alliances arise as a logical and suitable response to the rapid and intense changes in economic activity (Doz and Hamel, 2000).

It is possible to observe a collective efficiency gain in Cluster companies. In the case of the Stone Cluster, it is possible to create positive conditions for the creation of an ecosystem favourable to innovation and competitiveness (Amaral, 2015). Research suggest that networking tends to allow the gain of competitiveness. Turning potential competitors into allies and suppliers of complementary goods and services helps to develop new businesses, enabling prominent rivals to be neutralized as threats, and companies with complementary goods and creating network economies (Carvalho, 2014).

As suggested by Bovet and Martha (2001) the concept of value chain tends to be replaced by the concept of value networks. The premise is, do the companies in the Stone sector realize what they benefit being part of the Cluster?

The Cluster can act as a mobilizing agent to provide a stimulating environment for innovation and knowledge creation (Obadic, 2015).

## Conclusions

As seen above the companies that belong to a strong networked structure (cluster) tend to present better results. That lead us to the point that one of the main future threats is to survive with the changes brought by new technologies. So, is it possible to do it without being networked?

## Acknowledgments

We thank Fravizel, Mineral Resources Cluster, ISCTE-IUL, ISG and Marlene Ribeiro for their collaboration and support.

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## About the authors

Inês Paulo Frazão, MSc

Master in Marketing and Ph.D. Student in Management, ISCTE-IUL - Instituto Universitário de Lisboa. Assistant Professor of Management, ISG- Instituto Superior de Gestão. Portugal.

ifrazao@fravizel.com

Rui Moreira de Carvalho, PhD

PhD in Management, ISCTE-IUL – Instituto Universitário de Lisboa. Associated Professor of Management, ISG- Instituto Superior de Gestão. Portugal.

rui.moreira.carvalho@gmail.com

Joana Paulo Frazão, MSc

Master in Social and Organizational Psychology and Ph.D. Student in Management, ISCTE-IUL - Instituto Universitário de Lisboa. Assistant Professor, ISG- Instituto Superior de Gestão. Portugal.

jpfrazao@fravizel.com

José Paulo Afonso Esperança, PhD

PhD in Economics from the European University Institute, Florence, Italy. Full professor of Finance, ISCTE–IUL- Instituto Universitário de Lisboa. Chairman of AUDAX-ISCTE- center focused on entrepreneurship and family business and Dean of ISCTE Business School. Portugal.

jose.esperanca@iscte.pt

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# Industry 4.0 benefits to the stone sector

**Agostinho da Silva, Andreia Dionísio, Luís Coelho**

**Synopsis**

Guided by the pragmatic paradigm and using mixed methodology of parallel convergence, the Inovstone4.0 Framework, conceptualized under Service Science Theory was applied a representative sample of OS Portuguese Companies. This allowed the measurement of the evolution of Key Concern Indicators (KCI) indexed to stakeholders' concerns, when operations change from the current situation to BIM procurement and I4.0 production.

The results obtained showed significant relief of stakeholder concerns regarding delivery time, costs, sustainability and product quality, when BIM operations evolve to I4.0, allowing the conclusion that in technical terms, the impact of I4.0 on the threats arising from BIM procurement in the sample is clearly positive.

**Keywords**

Service Science, Industry 4.0, Internet of Things, BIM, Cyber-Physical Systems, Ornamental Stone

The Framework Inov4.0|F (Inovstone4.0) (Silva 2017) was applied to a sample of OS Portuguese Companies CPMR, under conditions, for data collection in three different operation contexts: (OC1) CBP-Providing in CAD-Procurement operations mode, in which providers have produced in CBP mode and customers have carried out the procurement as in the AECSC (Architecture, Engineering and Construction Supply Chain; (OC2) CBP-Providing in BIM-Procurement operations mode, in which suppliers kept the production in CBP mode and customers shifted procurement to BIM and (OC3) I4.0-Providing in BIM-Procurement operations mode, in which suppliers shifted operations to mode I4.0 and customers kept the procurement in BIM.

From the results, we have found that Inov4.0|F as supported by Service Science Theory made it possible to measure the different stakeholder (k) Concerns through specific qualitative indicators and metrics (KCIQUAL-K), and the respective confirmation by quantitative indicators (KCIQUAN-K) in the three operations contexts (OC), from which it was possible to measure the evolution of these Concerns by using IOQUAL-K and IOQUAN-k Innovation Outcomes (Lusch and Nambisan 2015). Supported by S-S theory, where service innovation (Stoshikj, Kryvinska, and Strauss 2016) is the result of the interactions between service systems, Inov4.0|F revealed that in OC3 there were 24 direct interactions between BIM-Customer and I4.0-Provider, mainly involving the Cockpit Back-Office resources.

Analysing the second set of 9 steps of the S-Print process, the FP-I4.0 of the products was found to be terminated and from that, their Smart Object generated. It was also found that during Steps 10-18, all the human and technological Cockpit resources were called upon to intervene in every step, finding 54 interactions between the I4.0-Provider and BIM-Customer, ending Step 18, with confirmation of payment and the digital information shifting from FP-I4.0 status to Smart Object status.

During product execution, Phase 2 of the service process, the number of interactions remained high (56 interactions), which meant that the BIM-Customer had significant interest in remote monitoring of production operations executed by I4.0-OS-Provider resources.

In Phase 3, Cockpit Back-Office resources were found to be most requested and were active in all steps of this phase, with thirty-four interactions between BIM-Customer and the I4.0-Provider being recorded in steps 28-37, ending with recycling of the product at the end of its life cycle.

As a result of these value-creation interactions, it was possible through application of Inov4.0|F to measure the Customer Satisfaction Index evolution, through the evolution of concerns associated with the quantitative indicators (KCIQUAN-C), finding that in BIM-Procurement when production shifts from CBP mode to I4.0 mode, the IOQUAL-C PLTCQUAN-C associated with “Product Lead Time Concerns” relieved 58%, the PLWTCQUAN-C associated with “Product Labour Work Concerns” relieved 30% and the PQCQUAN-C associated with “Product Quality Concerns” relieved 53% (Fig. 1), thus confirming the average relief of 59% found in qualitatively assessed concerns.

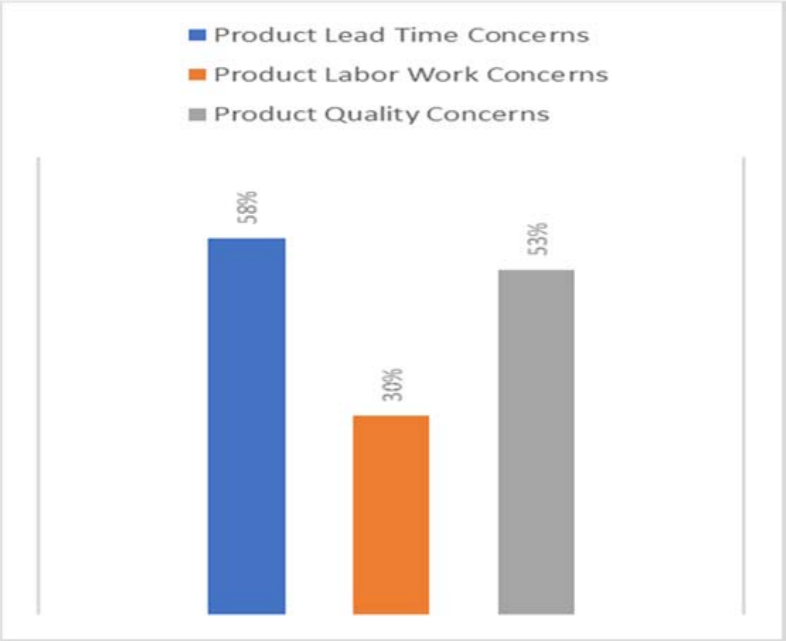


Fig 1 Customer Satisfaction Index (CSI) I4.0 Quantitative Impact | Customer Concerns Relief (%).

Likewise, by applying Inov4.0|F, it was also possible to measure the Provider Performance Index evolution, through the concerns associated with the Provider concern indicators (KCIQUAL-P), (qualitative) in the BIM-Procurement context and the production shifts from CBP to I4.0, where we found an average trend in concern relief of 69%, confirmed by IOQUAN-P (quantitative), where the concerns related to Threat 2 (faster delivery trend) relieved 51%, the concerns related to Threat 3 (lower costs trend) relieved 33%, the concerns related to Threat 4 (lower emissions trend) relieved 32% and the concerns related to Threat 5 (lower non-quality tolerance) relieved 31% (Fig. 2).

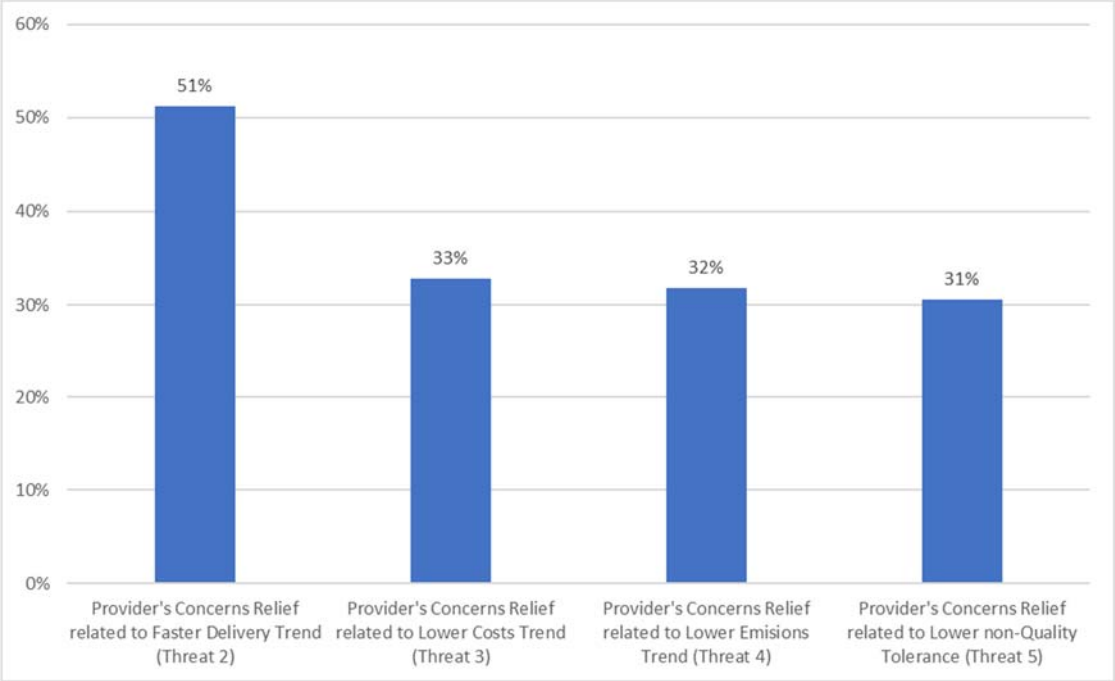


Fig 2 Provider Performance Index (PPI) I4.0 Quantitative Impact | Provider Concerns Relief (%).

It was also possible to measure evolution of the Sustainable Innovation Index and the Conformity Index through the evolution of OS-Competitor Concerns (KCIQUAL-CP) and Authorities Concerns (KCIQUAL-A), which in both cases, in the BIM-Procurement context when production shifts from CBP to I4.0, we found an average gain in IOQUAL-CP of 36% and an average gain of 78% in IOQUAL-A, in the sense of favouring the OS-Provider business if it produces in I4.0 mode.

## Acknowledgments

The authors would like to thank the research project Inovstone4.0 partially funded by Agencia Nacional de Inovação and Compete2020. We also acknowledge the European Commission, for funding the research projects Jetstone, Inovstone and Flextone

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## About the authors

Agostinho da Silva

Universidade de Évora, Portugal

Andreia Dionísio

Universidade de Évora, CEFAGE, Portugal

Luís Coelho

Universidade de Évora, CEFAGE, Portugal

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# Flexural fatigue behavior of two different limestone sandwich composites

**Ilaria Andreazza, Madalena Garcia, Vera Pires, Virgínia Infante, Pedro Miguel Amaral**

**Synopsis**

The constant quest for enhancement of the cost-performance relationship of materials is also active in the architecture field. A new concept of cladding has been invented since a decade, with the aim of maintaining the much-appreciated look of natural stone, and at the same time increasing its toughness, safety, and diminishing its specific weight. This has been possible backing a stone veneer with lighter and more resilient materials such as honeycomb or, in the present case, cork agglomerate. Although such claddings do not have a structural role, their characterization in fatigue is needed because throughout their life they will be loaded with a force variable in time coming mainly from the wind. Two cyclic tests have been chosen on the basis of a literature research, and carried on. The material used is made of a layer of limestone and a layer of reinforced-cork agglomerate; the reinforcement is done with glass fibers on both sides. Two configurations using limestones having different modulus of elasticity and porosity, have been manufactured and tested. The tests are four-point bending tests had a load ratio of 0.1 and maximum load taken as a percentage of the maximum static load, i.e. from 0.70 and 0.85 of the static load for configuration named L1C1, and from 0.40 to 0.70 of the static load for configuration L2C1.A continuous test was carried out up to 500'000 cycles or up to failure of the material, and a test with resting time after each block of cycles was used to evaluate the influence of the viscoelastic recovery of the cork. The microstructure of the stone has also been analyzed with X-Ray Computerized Tomography, a novel technique in the field of rock science.It has been possible to evaluate the validity of the test, the occurrence or not of fatigue on the materials composing the layers, and to give a qualitative indication of the behavior of the material in service. There has been observation of different failure modes for the two configurations, and for the same configuration tested with and without stops. The failure modes vary according to the maximum load; stone indentation was always observed in the composite with the weakest stone, fiber breakage was observed for the first time on the other configuration. The tests with resting time showed a dramatic increase in lifetime compared to the lifetime of continuous tests, and were used to confirm the occurrence of permanent damage in the cork layer.The absence in the literature of research on the fatigue of asymmetric sandwich composites makes the present work innovative in the field.

**Keywords**

Asymmetric composite, sandwich composite, cork agglomerate, stone, delamination.

## Introduction

A large amount of literature is present nowadays in the field of mechanics of composite materials, with comprehensive references on the study of fatigue in fiber-reinforced plastics (Harris 2003) and in sandwich structures (Daniel et al. 2010; Carlsson & Kardomateas 2011; Allen 1969), for example. Unlike for crystalline materials, though, composite fail during fatigue not because of the propagation of a single crack, but they rather accumulate damage in a general fashion (Talreja 2008). Therefore, it has not yet been possible to identify and develop a unique model to predict the fatigue life of a class of composites, because of the too many variables involved in the damage accumulation.

The composite material object of this paper aims at replacing natural stone in all the applications where the latter is used because, besides retaining the look of a stone cladding, it brings advantages in terms of cost, design, safety, and stability. These advantages are a direct consequence of its lower weight compared to natural stone. Its structure comprises of a first stone layer, a layer of glass fiber reinforced-resin (GFRE), a cork agglomerate layer, and a last layer of GFRE.

Earlier studies (Gomes 2016; Ribeiro 2016) focused on the development of an optimized production process, and on the mechanical characterization of the material. The mechanical properties compared in order to find the best compromise between production-cost and performance, were the bending stiffness and the flexural strength.

An additional study was conducted (Correia 2016), which focused instead on the development and execution of a test to investigate the fatigue resistance of the composite. The test developed used a mixed control system: both extreme displacements and maximum force were imposed on the machine. During each cycle the specimen must reach the maximum force previously imposed, while the minimum force fluctuates, keeping the extremes of deformation constant. In doing so, the problems encountered in pure load control and pure strain control were overcome. Respectively, in pure load control the cork viscoelasticity led to excessive deformation amplitudes of the specimen, which could be harmful for the testing machine, while in pure strain an excessive decrease of the maximum load (due to mechanisms of stiffness reduction) never led the specimen to failure. The fatigue test was organized in blocks of 105 cycles, with the maximum load increasing of 10% of the monotonic tensile load during each block. The experiments conducted did show that there was a temperature dependence on the number of cycles at failure, as well as a mean-stress dependence; however, it is still not known which mechanism act to initiate and propagate the damage until failure. It was the purpose of this research to try to discover the causes that lead to fatigue failure of the present composite, in prospect of a future use of the material in environments subject to cyclic forces. In order to attain it, the previously developed test was of no use, and another one had to be developed prior to testing.

The challenge of the present work resides in the fact that no literature exists in the topic of fatigue behavior of cork or of cork agglomerates, if not for observation of macroscopical behavior (Reis & Silva 2009). Moreover, the asymmetrical geometry of the assembly makes it incorrect to apply the simplifications that have been used in the study of symmetrical composites.

In summary, the work will have two main objectives: first, a cyclic fatigue test is going to be designed for this new material. The parameters chosen (e.g. control mode, stress state, maximum load) don’t necessarily come from stress states encountered in application of a real part, but rather relate to materials properties. In the second part, the specimens are going to be tested and the failure modes evaluated through optical, and mechanical methods, for the two composites configurations (two types of limestones and one cork type).

## Materials and Methods

The studied composite material is made by a limestone backed by a glass-fabric reinforced cork sandwich. By varying the type of limestone only, two configurations were obtained, and named L1C1 and L2C1. The mechanical characteristics of the various layer will be hereafter presented, as given by the materials producers.

Two different Portuguese limestones were selected to form the stone layer of the composite material: *Branco do mar* (L1, white limestone) and *Vidraço de Ataíja azul* (L2, blue/grey limestone). The cork agglomerate was provided by a Portuguese manufacturer. Resin impregnated biaxial woven fabrics stiffen the cork layer (above and below it). The fabrics in the two layers have different grammage, being the one in contact with the stone of higher grammage in order to permit a smoother Young's modulus gradient.

The static and fatigue testing was performed using the same geometry, with the stone layer on the compressive side. The chosen test is a four-point-bending test; the measures of the outer span l1, inner span l2, and specimen width, b, are 250, 83.3, and 50 mm respectively. The testing machine for both tests is the servo-hydraulic Instron 8800, with load cell of 100 kN. The cylindrical rollers have a radius of 20 mm.

Static tests were carried out to determine the failure load ($F_{UF}$) of the materials, which will then be used to define minimum and maximum force ($F_{MIN}$, $F_{MAX}$) of the fatigue cycles. The tests are conducted at constant velocity of 5 mm/min.

Continuous fatigues tests were performed in load control, at a frequency of 2.7 Hz for L1C1 and of 4 Hz for L2C1, sinusoidal waveform, load ratio R = 0.1, and maximum load chosen as a percentage of the static failure load. Due to time limits, all the tests were stopped at 500'000 cycles, or when catastrophic failure occurred. The fatigue test variables ($R$, $F_{MIN}$, $F_{MAX}$, $F_A$) are dependent by the relations $R = F_{MIN}/F_{MAX}$ and $F_A = (F_{MAX} - F_{MIN})/2$. Therefore, only two variables need to be arbitrarily chosen.

Interrupted fatigue tests, with a resting time of 24 hours between blocks were conducted for L2C1 at load percentages of 45, 50, 55, 60%. The number of cycles in a block is equal to 70% of the failure cycles ($N_f$) in the continuous tests.

Several parameters were calculated from the raw data of the testing machine, such as relative and absolute stiffness, accumulated deformation and dissipated energy.

## Results and discussion

The results of the static tests are shown in Fig.1; the red lines indicate the limits between which stiffness is calculated in the cyclic tests.

The unevenness of specimen thickness, t, influences the failure load of L1C1. As for L2C1, there has been no identified dependence $F_{UF}(t)$ both because a) the standard deviations of the thickness measurements on the same specimen are lower than in L1C1, and b) the variability of the average of the thicknesses is low. It has been therefore concluded that $F_{UF}$ of L2C1 can be taken as the average of the failure loads: 2409 N.

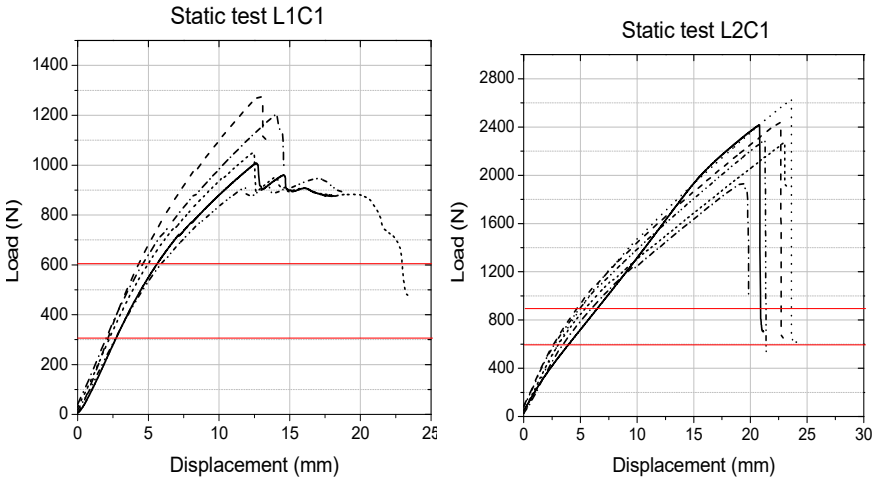


Fig. 1 Load-displacement curves for the static tests L1C1 and L2C1

The maximum force ($F_{MAX}$) of the fatigue cycle is always calculated as a percentage of the static failure load. In all cases, L1C1 failure occurred due to crushing of the stone layer; L1C2 instead showed different modes of failure according to the applied load percentage:

- For $F_{MAX} > 60\%\ F_{UF}$ failure occurred due to indentation of the limestone, as was in L1C1.
- For $45\%\ F_{UF} < F_{MAX} < 55\%\ F_{UF}$, we observed a change in failure mode: failure occurred because of breakage of the lower layer fibers, and crack propagation in the cork layer in the direction of maximum shear stress.
- For $F_{MAX} < 45\%\ F_{UF}$ , no fracture was observed.

Tests with resting time were carried out for L1C1, at the load percentages already mentioned; only the results of 55% will be reported here, the others showing similar trends. The test at 45% did not show any sign of failure after two blocks of 500'000 cycles. The tests at 55, 60, and 60% instead failed showing a common feature: multiple macrocracks at 45° orientation on the cork layer located at the right- and at the left-side of the left and right roller, respectively.

## Conclusions

Two material configurations have been manufactured, L1C1 and L2C1, differing only by the type of limestone used in the upper layer. The measurements of thickness and the static flexural tests showed that the load at failure of L1C1 varies linearly with the composite thickness, while load at failure of L2C1 does not show correlation with thickness.

The limestone in configuration L1C1 determines the cyclic failure of the composite, being it always due to stone crushing; it is believed that failure at low cycles is due to the impact of the loading pin, while at high cycles it is due to overcoming the limit deflection of the composite; infinite life occurs for $F_{MAX}$<70%. For configuration L2C1, failure at high cycles also happens caused by the impact of the loading pin; for a $F_{MAX}$<55% though, the failure mode shifts to lower fiber breakage, and below 45% the composite can sustain infinite cycles. To have an increased fatigue resistance, it is convenient to improve the quality of the lower fiber layer, namely its grammage and geometry.

The resting time between cycles has a life-increasing effect, also to be attributed to the cork because of its viscoelasticity. It is therefore not possible to apply a damage predicting law in the form of a Miner's law. This adds further complication where one wants to model

the composite behavior, but in sight of a future application where the composite component is subject to variable loads coming from the wind, the component life is positively affected. In tests with resting time, the failure occurred for cork shearing, demonstrating another possible mode of failure, for L2C1.

## Acknowledgments

The authors acknowledge the support from Galrão, SA and Urmal, SA for providing the raw materials. Funding: This study was developed by Frontwave, SA with the support of Instituto Superior Técnico from Lisbon University. The results presented in this paper were obtained in the frame of the project 10.472 STORK, funded by the European Regional Development Fund (FEDER) through the Alentejo Regional Operational Programme (PO Alentejo).

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## About the author(s)

Ilaria Andreazza Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. ilaria_andreazza@yahoo.it

Madalena Barata Garcia Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. madalena.barata.garcia@tecnico.ulisboa.pt

Vera Lúcia Cordeiro Pires, Dr.ª Frontwave - stone technology, Monte Novo de Santo António Apartado 141, 7100-999 Estremoz, Portugal. vera.pires@frontwave.pt

Virgínia Isabel Monteiro Nabais Infante, Prof.ª
LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. virginia.infante@tecnico.ulisboa.pt

Pedro Miguel Gomes Abrunhosa Amaral, Prof.
LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. pedro.amaral@tecnico.ulisboa.pt

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# Mechanical behaviour of asymmetric sandwich composite structures made of natural stone and cork agglomerate

**João Ribeiro, Madalena Garcia, Joel Pinheiro, Virgínia Infante, Pedro Amaral**

**Synopsis**

Cork is a natural material with a cellular structure in the microscopic level that is preponderant in terms of mechanical properties. This cellular structure can be compared with the honeycomb structure that has been used in composite materials in the last decades, making cork one of the possible substitutes to be used as cores in sandwich composites. Being relatively recent, these materials have great prospects for dissemination but the mechanical behaviour of these structures still needs to be further studied. This work's purpose is to investigate and characterize an asymmetric and non-conventional structure that does not fit in the current flexure testing standards. Five different test methodologies were studied and tested and it is proved that "Linear regression from stiffness as a function of the support span" method may be used for the determination and characterization of the flexural stiffness of asymmetrical and unconventional sandwiches structures.

**Keywords**

Asymmetric, sandwich composite, cork agglomerate, flexural stiffness.

## Introduction

Sandwich composites combine the lightweight, low density and low strength resistant cores with two stiff and compressive resistance skins (Sadeghian & Hristozov, 2016). Some of the most common materials that have been used as cores are expanded plastics and aluminium honeycombs and the skins are normally made of steel, aluminium or fibre reinforced plastics (Allen, 1969). Other materials have been used as substitutes for cores, such as syntactic foams (Islam & Kim, 2011; Kumar & Ahmed, 2014) and polypropylene foams (Arbaoui et al. 2016) for different applications.

Cork is a natural material with a cellular structure in the microscopic level that is preponderant in terms of mechanical properties (Jardin et al., 2015). This cellular structure can be compared with the honeycomb structure that has been used in composite materials in the last decades, making cork one of the possible substitutes to be used as cores in sandwich composites (Meraghni et al., 1999). As cork is an expensive material due to its long production cycle, optimized cork agglomerates made with the remains of the bottle stopper production have proved superior ability as a core material of sandwich composite (Gil, 2009). Also, the impact on these materials is being studied and promise to be of great importance in the future, combining good environmental performance with low environmental impact (Soares et al., 2011).

A proper application for CA as a core material could be the functional reinforcement of materials with others features and characteristics, like brittle materials, significantly improving their mechanical behaviour. Hence, this work's purpose is to investigate and characterize a specific reinforcement system adapted to the stone material with low thickness, taking advantage of its high compressive strength and transmitting shear stresses

and tensile forces to the reinforcement layers (Anon, 2014). Thus, it was idealized a composite sandwich composed of two fibre-reinforced polymer skins with low thickness and high stiffness, and a core made with a low specific weight cork agglomerate, enhancing also the thermal and acoustic insulation capability of stone materials. The use of a stone layer as a reinforcement on top of the sandwich generates complexities on the mechanical behaviour of the composite. The sandwich faces Young's modulus, whose analytical determination is not trivial due to the asymmetry of the sandwich implies that the usual beams theories and the current flexure testing standards (like ASTM-C393 14 or ASTM-D7250 15) cannot be applied. Subsequently it was necessary to develop a specific and valid method to characterize the flexural stiffness of unconventional composites sandwich.

Five different characterization methods were selected from the literature and were verified using four-point loading tests (this test was chosen instead of the three-point bending test to avoid crushing of the brittle material by dividing the rollers wedging stresses on two points). The "Linear regression from stiffness as a function of the support span" method was verified to be the most adequate for the composite asymmetric layout. This verification opens the possibilities of sandwich configurations that have until now been mostly a core material faced with two skins.

## Materials and Methods

### Materials

The sandwich layered composite was constituted by a 5mm Gascogne blue stone layer, epoxy reinforced with biaxial fiberglass (for the intermediate layer) and interlaced fiberglass (for the bottom skin, with half of the surface density), and a 10mm CA layer. Gascogne blue is a 100% calcitic limestone, with grey-bluish shades that gains an excellent polishing and is acknowledged all over the world. This limestone is quarried in Leiria district (Portugal). The CA was provided by a Portuguese cork supplier (ACC) (density of 200 kg/m$^3$ and shear modulus of 5.9 MPa (Composites 2009)).

### Specimen Manufacturing

The sandwich specimens were manufactured by hand lay-up method, with 65% mass fraction of resin/fibre, in temperature and humidity controlled conditions.

The specimen's dimensions were defined according to the restrictions of the bending test machine, including the permitted spans, and the rules defined in ASTM-C393 (l=300mm, S=250mm and S/d=16.7). The specimens were produced in blocks and were then cut in the defined dimensions.

### Linear regression from stiffness as a function of the support span

According to (Allen, 1969; Deshpande & Fleck, 2001; Mancuso et al., 2015) the flexural stiffness of a non-conventional composite sandwich and non-normalized structures can be obtained through several tests by using a geometrical ratio. Each specimen is tested with the same loading type but the supporting span is increased (S=100mm, S=150mm, S=200mm, S=250mm) and the test should stop before achieving the onset of any permanent deformation or damage in the sandwich skin facings and core. Deducing the mid-span deflection equation (1) and replacing L=S/3 (4P test with third point distance), the mid-span deflection as a function of the applied load, bending and shear stiffness can be obtained,

which then can be transformed into the following equation, similar to an equation of type y=mx+q:

$$\left(\frac{\Delta}{S}\frac{1}{P}\right) = \frac{1{,}7}{96D}S^2 + \frac{1}{6U} \qquad [1]$$

Plotting the previous equation as a function of $S^2$, it is possible to determine a linear regression from the obtained results for each typology, yielding the mean results for D from the graph slope and for U from the interception of the regression line:

$$D = \frac{1.7}{96\,m}; \qquad U = \frac{1}{6\,q} \qquad [2]$$

where m is the slope of the linear regression and q the interception of the linear regression.

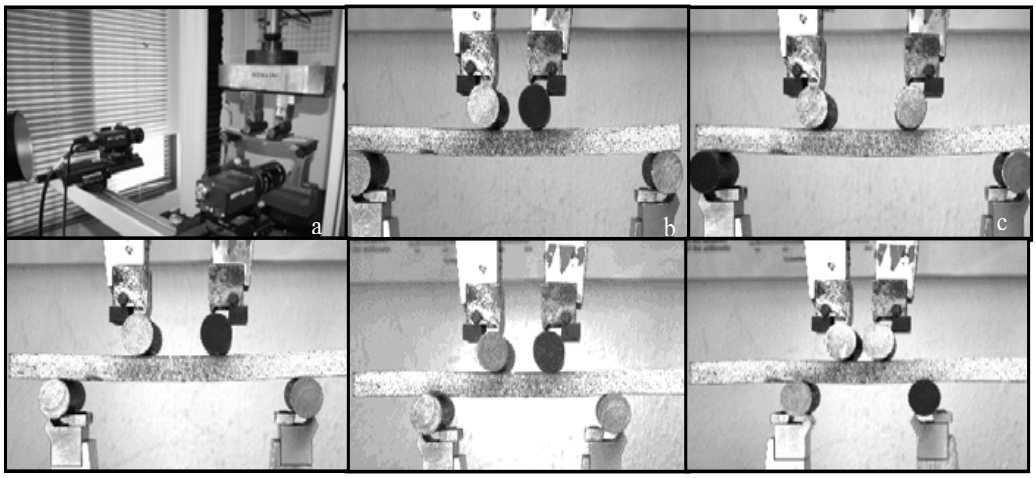


Fig. 1 VIC test a) Test apparatus; b) L=2S/11, S=250mm; c) L=S/3, S=250mm; d) L=S/3, S=200mm; e) L=S/3, S=150mm; f) L=S/3, S=100mm

All the necessary tests were carried out using the visual correlation program Visual Image Correlation (VIC) to monitor mid-span deflection (Fig.1). This program analyses the changes on the pictures taken during the test by mapping and tracking pixels. These are created by painting the photographed side of the specimens with black and white patterns.

## Results and Discussion

### Bending Stiffness Test

It is observable that method 5) presents the highest stiffness values with a relative error for this method of 2.5%, revealing a good uniformity and agreement between results.

It is apparent that a good correlation was obtained with this plot, being $R^2$>0,9 the acceptance criterion used. The only test that diverge from the others is the first one for S=100, where a slightly higher deflection was obtained, in relation to what the result was supposed to be. This phenomenon, common to the three specimens, could be justified by the closer distance between rollers in this assay, making it similar to a three-point bending test and applying a lower bending moment to the specimen. Furthermore, due to the smaller moment applied in this span, is there less deflection due to bending, making the crushing of cork more pronounced and interfering with the results. This way, it isn't possible to use this method with smaller support spans, being a test constraint.

## Conclusions

Considering the obtained results with the different referred methodologies, as well as the assumptions and approximations made, it is proved that the best method for the determination and characterization of the stiffness of each specimen is the "Linear regression from stiffness as a function of the support span" method. This method allows the standardization of the results and the elimination of variations of the method's "Flexural stiffness calculation from the ASTM-standard D7250" equations, depending on the chosen loading type. It is the method that presents greater accuracy on experimental results and it corresponds to the method that uses less simplifications from the theoretical point of view (simplifications that this sandwich doesn't follow).

Thus, the "Linear regression from stiffness as a function of the support span" method may be used for the determination and characterization of the flexural stiffness of asymmetrical and unconventional sandwiches structures.

## Acknowledgments

The authors acknowledge the support from Galrão, SA and Urmal, SA for providing the raw materials. Funding: This study was developed by Frontwave, SA with the support of Instituto Superior Técnico from Lisbon University. The results presented in this paper were obtained in the frame of the project 10.472 STORK, funded by the European Regional Development Fund (FEDER) through the Alentejo Regional Operational Programme (PO Alentejo).

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## About the author(s)

Madalena Barata Garcia

Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. madalena.barata.garcia@tecnico.ulisboa.pt

João Pedro Sequeira Ribeiro

Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. joao.pedro.ribeiro@tecnico.ulisboa.pt

Virgínia Isabel Monteiro Nabais Infante, Prof.ª

LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. virginia.infante@tecnico.ulisboa.pt

Pedro Miguel Gomes Abrunhosa Amaral, Prof.

LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. pedro.amaral@tecnico.ulisboa.pt

GLOBALSTONE CONGRESS2018
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# Technological characterization and mineral composition correlation of silica ornamental rocks

**Rômulo Furtado Faria, Bruno do Vale Miotto, Viviane Viana Coelho, Juliano Tessinari Zagôto, Cyntia Laurete Caldeira, Roberta Vidotto Rocon**

**Synopsis**

Ornamental rocks sector in the world always seeks the understanding of scenarios increasingly complex and specific. This work is case study exploratory research. The methodology consists on bibliographical review and laboratory tests according to the norms ABNT NBR 12042 and ABNT NBR 15845. This study aims to correlate the results of the technological tests for each sampled lithology. The correlation was based on variables like petrographic aspects; hardness of the present minerals, texture (arrangement and grain size of minerals), content and size of quartz crystals, anisotropy of the rock, state and degree of mineral alteration due to Amsler abrasion test.

**Keywords:** Petrography, abrasion, correlation.

## Introduction

The international scenery of ornamental rocks has become increasingly competitive over the years. According to IMM, 2015, Brazil in this decade has been gaining positions in the international markets, both in terms of the representativeness of physical export volume and in the variability of rocks. It currently ranks 5th behind China, Italy, Turkey and India. According to ABIROCHAS (2017), exports more than tripled in the last 10 years.

In order to face this competitive scenario, it is necessary to invest in technical studies, which involves evaluating the degree of relationship between two or more variables in order to find out precisely how much one variable interferes with the result of another (TAGGART, 2013). The techniques associated to Correlation Analysis represent a fundamental application tool in the behavior of Engineering and Natural Sciences phenomena. Therefore the work had an applied practical character.

## Materials and methods

The work is characterized as exploratory research and is classified as a case study due to the collection of lithological data generated from the sampling to be performed in situ. The methodology consists of stages: documentary research based on bibliographic review and compilation of theoretical reference, practical and applied in laboratory tests according to the standards ABNT NBR 12042 and ABNT NBR 15845 and then to trace the correlation of the mineralogical properties with the Amsler abrasion. Three materials, AM-01; AM-02 and AM-03, were sampled.

## Results and Discussion

The mineralogy, structure, texture, types of alteration were determined from figures 1, 2 and 3, after determining these parameters, thin sections photomicrographs were obtained, which are important in the description process.

The first analyzed rock is a leucocratic, holocrystalline, unequigranular and hipidiomorphic texture Garnet-Muscovite-Biotite-Monzogranite igneous rock (Fig. 1).

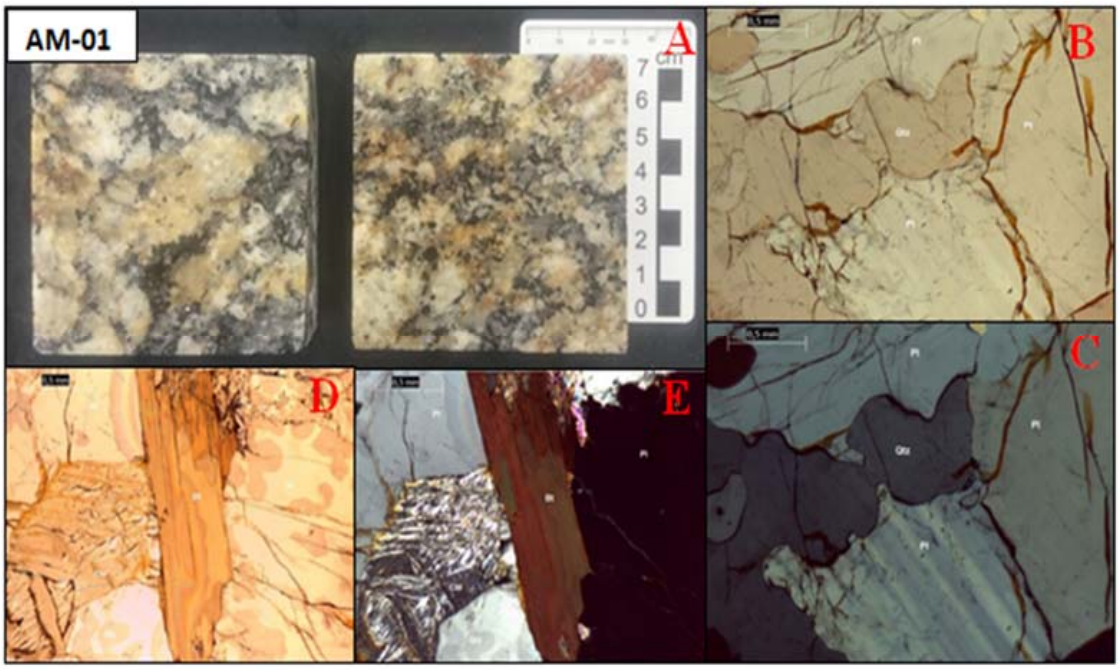


Fig. 1. **A)** AM-01 rock sample used for the Amsler abrasion test and macroscopic description; **B)** Natural Light_5x_ and **C)** Plane Polarized Light_5x_showing the predominance of quartz in the thin section; **D)** Natural Light_5x_ and **E)** Plane Polarized Light_5x_ showing the presence of Biotite and Chlorite. *Pl*→ Plagioclase; *Qtz*→ Quartz; *Bt*→Biotite e *Chl*→ Chlorite.

The second analysed rock is a fine grain Biotite-Plagioclase-Quartz-Schist metamorphic rock with textures ranging from granolepidoblastic to small portions of polygonal granoblastic texture, presents intensely sericitized plagioclases (Fig. 2).

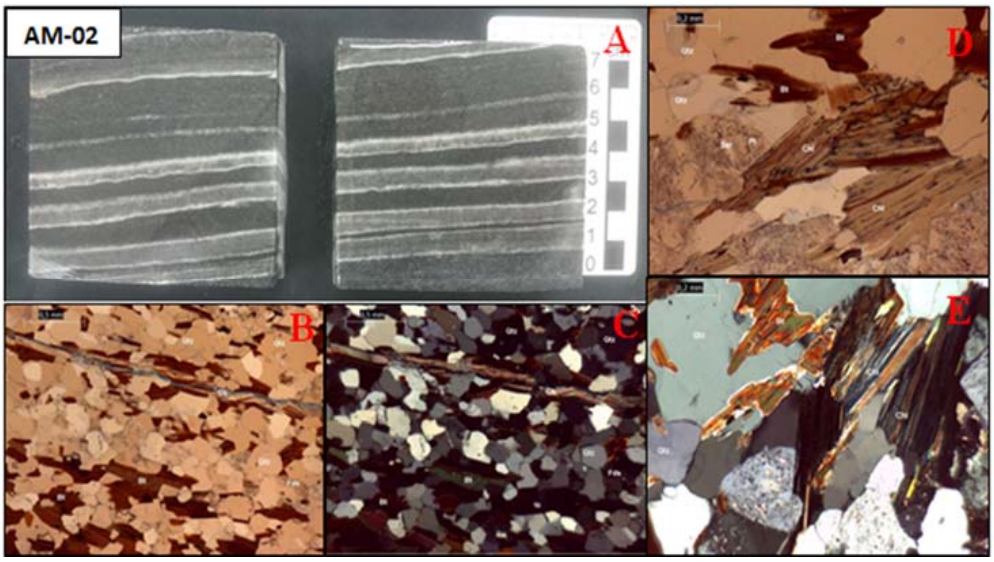


Fig. 2. **A)** AM-02 specimen for Amsler abrasion test and macroscopic description; **B)** Natural Light_5x_ e **C)** Plane Polarized Light_5x_showing lepdoblastic texture; **D)** Natural Light_10x_ and **E)** Plane Polarized Light_10x_showing the presence of Fe-Mg-Chlorite.*Pl*→ Plagioclase; *Qtz*→ Quartz; *Bt*→Biotite;*Fds*→Feldspar; *Cb*→ Carbonate; *Ser*→Sericite e *Chl*→ Chlorite.

The third tested rock is a medium grain size quartzite with granoblastic texture and predominantly interlocked contact between quartz grains that exhibits the characteristic undulatory extinction.

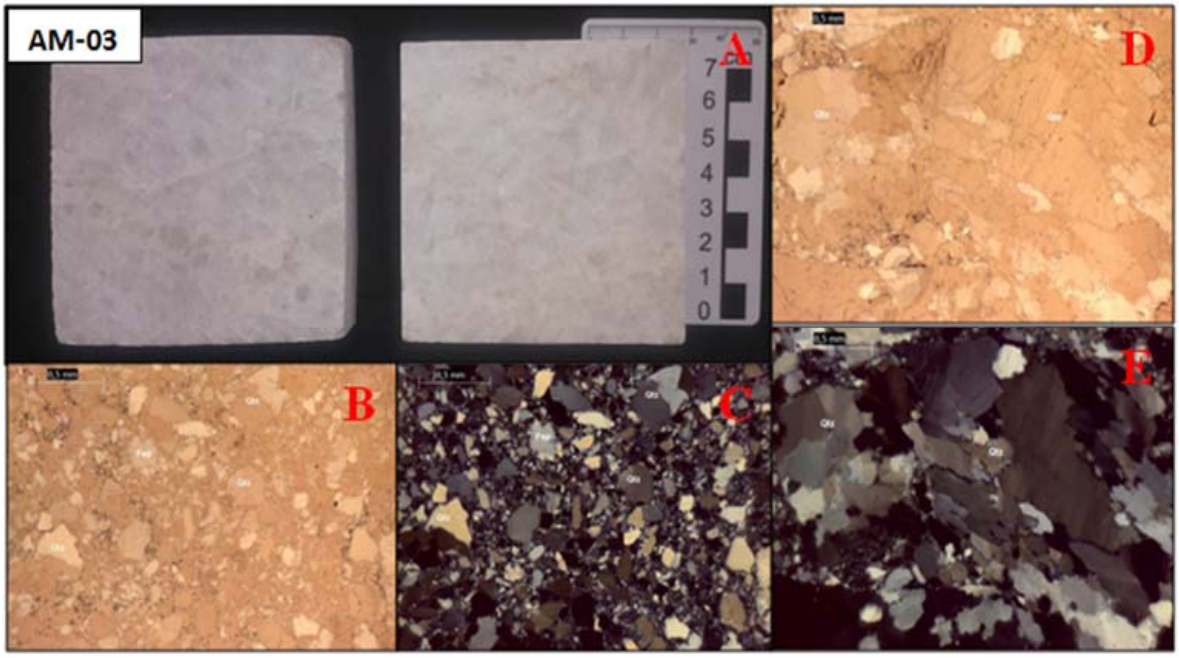


Fig. 3. **A)** AM-03 specimen for the Amsler abrasion test and macroscopic description; **B)** Natural Light_5x_ e **C)** Plane Polarized Light_5x_Showing the great predominance of quartz; **D)** Natural Light_5x_ e **E)** Plane Polarized Light_5x_Characteristic undulatory extinction of quartz that is a feature of this lithology. *Qtz*→ Quartz; *Fds*→ Feldspar (Pl e Kfs).

The correlation of the Amsler abrasion results with quartz mineralogical percentage of the samples AM-01, AM-02 and AM-03 is show in Fig. 4. In a brief analysis of this correlation, it can be identified that the AM-03, because it is composed of 95% quartz, it was the least abrasion result in relation to the other samples, as already could be foreseen in the mineralogical description. The AM-01 sample is composed by a relatively low percentage of quartz (22%), but it must be considered that it is an igneous rock, integrated and extremely cohesive with a large percentage of plagioclase (30%) and alkali feldspar (20%). In AM-02, despite the higher percentage of quartz (37%) than sample AM-01, predominantly presents a granolepidoblastic texture and higher percentage of biotite (25%), besides a considerable amount of sericite, white mica, and chlorite replacing biotite, so these factors reduce the hardness of this sample and this clearly explains the high result of 1,811 mm in the Amsler abrasion test. It completely impedes the use of this stone for floor of paving as it regulates the standard ABNT NBR 12042.

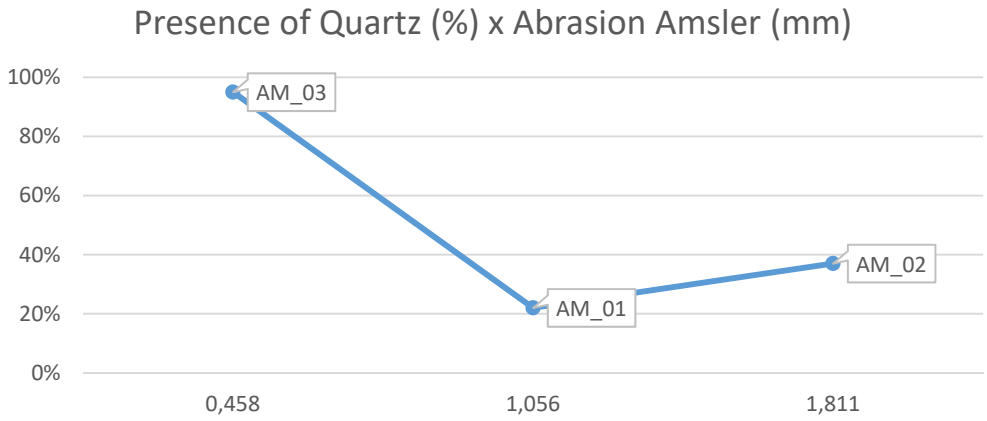


Fig. 4. Results of Amsler abrasion tests for sampled rocks.

## Conclusions

The obtained results concentrate positive aspects of academic nature, since it derives from a research project. The most important is a technical bias, based on knowledge that can serve as a basis for the mineral processing industry, which is a very important sector in the economy of several states of the federation, especially the state of Espírito Santo and Bahia.

The analysis consisted of the percentage of quartz and Amsler abrasion results: the samples whose quartz percentage was higher the abrasion in millimeters was smaller except for AM-02 that presented greater variability of filossilicato minerals according to figure 2. It is noteworthy that, in future works, other parameters besides mineralogy must be considered for correlation with Amsler abrasion test.

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## About the authors

FARIA, R.F.

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. romulo.faria@ifes.edu.br.

MIOTTO, B.V.

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. bruno.miotto@ifes.edu.br.

COELHO, V.V.

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. viviane.coelho@ifes.edu.br.

ZAGÔTO, J.T.

Federal Institute of Espírito Santo, Mining Department, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. tessinari@ifes.edu.br.

CALDEIRA, C.L.

Federal Institute of Espírito Santo, Mining Student, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. cbermontd@gmail.com.

ROCON, R.V.

Federal Institute of Espírito Santo, Mining Student, Rodovia Miguel Curry Carneiro, 799 - Santa Luzia, Nova Venécia - ES, 29830-000, Brazil. robertavr2016@hotmail.com.

# SUSTAINABILITY TECHNICAL SESSION

Marble (Exido - MAG BAN Companies). Photo: Maria Heloisa Barros de Oliveira Frascá (2018)

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CONNECTING MINDS IN THE WORLD OF STONE

# How can Dimension Stone Industry meet the fundamental values of Geoethics?

**Nicola Careddu, Giuseppe Di Capua, Giampaolo Siotto**

**Synopsis**

Geoethics is an emerging field in geosciences. Its main purpose is to identify values and practices to adopt when dealing with the most critical environmental issues of modern times and to base a more sustainable interaction between humans and the Earth system. Geoethics encourages a critical analysis of the use of geo-resources and the development of environmentally and socio-friendly technologies. Geoethics aims at finding solutions that are compatible with natural dynamics and the preservation of landscape. Geoethics enhances the social role of geoscientists and promotes the geological heritage as a scientific, cultural, educational and social value. Geoethics supports the adoption of ethical guidelines in the geoscience community and the industrial sector to favour appropriate behaviours when dealing with issues impacting the environment and human life. This paper argues that geoethical values, as stated in the Cape Town Statement on Geoethics, are necessary even in the Dimension Stone Industry, by presenting also some case studies from Sardinia (Italy). This region has a long history of production of ornamental stones.

**Keywords**

Geoethics, dimension stone, quarrying, sustainable development, geoheritage.

## What Geoethics is?

Geoethics is defined by the IAPG – International Association for Promoting Geoethics as the "*research and reflection on the values which underpin appropriate behaviours and practices, wherever human activities interact with the Earth system. Geoethics deals with the ethical, social and cultural implications of geoscience education, research and practice, and with the social role and responsibility of geoscientists in conducting their activities.*" (Cape Town Statement on Geoethics).

## Thoughts on the application of values of geoethics to the dimension stone industry

Professionals working in the dimension stone industry are expected to be competent in this field. They should follow regular training activities and a life-long learning. A degree in geology or mining engineering is a strategic option, which may be further enhanced by a Ph.D.

Technical and scientific knowledge (including information about probabilities and uncertainties of analyses) and theoretical and practical experience achieved through various studies must be shared at all levels. Sharing knowledge can be carried out by publishing each own study in journals subject to a peer-review process. An objective and unbiased peer-review process should always be applied to technical and scientific publications on dimension stone. Nonetheless, a lot of people working in the dimension stone sector have published top-notch studies and articles only in commercial journals (especially in the years 1970-2010), that lack of any kind of peers' check. Unethical practice which should be stopped includes the re-publishing of academic research after a mere change of the editing,

or of numbers. The public presentation of research results at congresses or conferences should be highly encouraged. The principle of research integrity has to be applied also to the dimension stone sector, too, in order to guarantee excellent working results and the adoption of best practices.

## Environmental implications of the dimension stone sector in Sardinia

Since ancient times, the life of Sardinian people have been strongly linked to stone, which turned out useful once humans found a way to transform and use it to organize their life. Stone was used for building tombs, “nuraghi” (typical constructions of the bronze age), places of worship, roads and cathedrals. Sardinian stones currently are undergoing a new phase of industrial use in the production of street furniture and decorative parts used for public and private buildings (e.g. in the restoration of several civic centres).

The sardinian landscape offers a remarkable geological diversity, that has to be preserved as an essential element sustaining local biodiversity and favouring cultural and social diversity. The law n.31/1989 by the Sardinian Regional Government recognizes 24 “geologic monuments” which constitute a tangible and intangible “resource”, capable to comply with the idea of the sustainable development. The geological history of Sardinia covers a wide geological time of the Earth history: there are many outcrops showing lithological and paleontological peculiarities that are important for both studying and teaching. Following a geoethical approach, these geological outcrops should be preserved and not ruined, for examples, by heavy sampling. Many Sardinian historical quarries for ornamental purposes should be protected and recovered as touristic sites showing an industrial archaeology heritage, as done for example, from 1997, with the geopark “Parco Geominerario della Sardegna”, now included in the UNESCO Global Geoparks network.

On the other side, the promotion of positive examples in the way quarries operate should be undertaken more effectively, in order to make local communities aware that in those cases operations fulfill all the sustainable development criteria and practices and are respectful of the environment. For example, in the case of the marble quarries of Orosei (East Sardinia), fossils found during the excavation process have been preserved.

In this perspective, geotourism representing an “added value” to the local economy of communities, can play an important role in the enhancement of a geoethical culture in society. Geotourism is strictly linked to the concept of “Geoheritage” and has clear geoethical implications: the geoheritage, as well as all scientific and cultural factors, has an intrinsic social and economic value, and strengthens the sense of belonging that communities feel for the local environment in which they live.

## Role and responsibilities in the dimension stone sector

Whenever possible, professionals in the dimension stone sector have to consider that the setting-up of a quarry for ornamental stone has an important impact on the geosphere and ecosystems. Negative past experiences in Sardinia show many examples of avid and unethical exploitation of stone deposits (known also as “robbery mining”) and brought to wide damages to the environment. Such quarrying methods prevented further working activities and the excavation of other portions of the deposit of economic interest. Landfills

must be designed in the perspective of a circular economy development, favouring the reuse of waste/scrap materials as secondary raw materials. Finally, the opening of a quarry and/or a stone-processing plant have to be carefully evaluated and assessed in comparison with other alternative activities which could be more interesting from an economic and social point of view. Responsible mining is a new way to develop socio-environmentally respectful mining activities. In this perspective, all actors involved in mining projects have duties toward the environment and human communities, such as: 1) Professionals have to support decision-makers with environmentally and socio-friendly solutions able to guarantee adequate levels of safety for the environment and people; 2) Politicians should not prevent quarrying only on the basis of environmental claims or in support of irresponsible opportunistic slogans: they should base their decisions on mining activities by evaluating their socio-economic benefits for local residents, and the impact on ecosystems and landscape; 3) Mass-media should not create sensationalistic warning every time there is the possibility to start mining activities by open a quarry: mass media should inform citizens in a transparent way, by sharing information that have a solid scientific and technical basis; 4) Citizens have the right to receive an adequate level of information on pro and cons about a mining project and to be involved in the decision-making process, but at the same time they have the duty to evaluate information based on reliable scientific and technical data. They should avoid to turn down a project only on the base of irrational and groundless fears; 5) Universities have to create geoscience and engineering curricula in which ethical problems and dilemmas related to mining activities are adequately treated. A strong cooperation among these actors is necessary to guarantee a geoethical approach to mining. Geoethics values applied in dimension stone industry are not a limit to the freedom of action but a new opportunity for geoscientists to contribute to determining the best way forward for society.

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## About the authors

Nicola Careddu, senior researcher

University of Cagliari, Department of Civil, Environmental Engineering and Architecture (DICAAr). Address: via Marengo 2, 09123 Cagliari, Italy. E-mail: ncareddu@unica.it. Phone n.: +390706755561.

Giuseppe Di Capua, geologist

Istituto Nazionale di Geofisica e Vulcanologia. IAPG – International Association for Promoting Geoethics. Address: via di Vigna Murata 605, 00143 Roma, Italy. E-mail: giuseppe.dicapua@ingv.it. Phone n.: +390651860806.

Giampaolo Siotto, mining engineer

Mediterranea Progetti e Finanza s.r.l. Address: via Tola 30, 09128 Cagliari, Italy. E-mail: studiosiotto@gmail.com. Phone n.: +390704560893.

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL
April 26-29, 2018
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# Portugal Mineral Resources Cluster Collective strategy for sectorial recognition and sustainable development

**Marta Peres, Luís Lopes, Miguel Goulão, Luís Martins**

**Synopsis**

The Mineral Resources Economic Sector (MR) can only be properly considered as a potential factor in the development of a Country if there is an integrated strategy transversal to all activities related to it. Contributions from different areas, such as geology, territorial planning, environmental protection, socioeconomic sustainability of populations where MR is exploited, associated with market policies, among others, should be analyzed together in an integrated way. Therefore, the proposal as a strategic economic cluster and subsequent recognition of the Cluster of MR of Portugal constitutes a milestone and an important step for its rational management.

As an evolution of the Portuguese Stone Cluster, where the clustering strategy demonstrated positive results during the Portuguese economic crisis, the main goal of the "Associação Cluster Portugal Mineral Resources" (ACPMR) is to spread the experience acquired in the stone sector to the Mineral Resources Economic Sector.

**Keywords**

Mineral Resources, Cluster Association, Dimension Stone Industry, ACPMR.

## Portugal Mineral Resources Cluster Association: a short story

The Portuguese Mineral Resources Cluster application and recognition emerges as a natural evolution of the Natural Stone Cluster. In 2009, the Natural Stone Cluster of Portugal had its governmental recognition and from the beginning of its activities, on the 17th of July of that year, three anchor projects and several complementary ones were developed. In total, there was an investment of almost 58 million euros. Effectively, the government support was € 38,246,879.00 and the participation of the promoters was € 19,584,923.00. As a result, and in general, the ornamental rock sector grew in contrast with the economy, for example, it showed a growth of 28% in 2013. This was only possible due to the promotion and marketing strategies that have been carried out in major trade fairs helded each year, for example: Xiamen (China), Verona (Italy), Vitória (Brazil), Orlando (Batalha, Madrid, Carrara, Cachoeiro de Itapemirim, Izmir, etc.). This strategy has continued to this day with several projects, of which we highlight the creation of the brand Stone.PT, the project "First Stone" and others submitted and awaiting approval.

However, the eligibility criteria for an economic activity sector to be recognized as "Cluster" were modified and to continue with the recognition of strategic sector, ornamental rocks alone would not have sufficient economic dimension. Therefore, the management of Valorpedra (management body for the Natural Stone Cluster) took the initiative to promote a broad discussion to all Mineral Resources, in order to discuss the theme and raise companies and entities so that the synergy thus created reached a dimension that would fall within the new eligibility parameters.

Nowadays, the Cluster of Mineral Resources has a membership of 38 associates and other partners with the following distribution: 29 Companies; 4 Entities of the Research and

Innovation System; 2 Business Associations; 2 Other Associates and 10 other relevant partners. As new projects are submitted and new contacts being made, new partners have been integrated into the Partnership for Mineral Resources of Portugal.

Reporting to 2013, the associated companies presented a turnover of € 69,141,790.00 with exports of € 53,305,210.00 being extra European Community exports € 41,087,040.00.

The importance of non-European Community markets in the volume of exports was 77.08%, which is a percentage considered very high in relation to the average national performance of the two macroeconomic aggregates, whose national average for that year was 32%. None of the member companies in the cluster has identified the presence of assets or jobs abroad; internationalization will also be a goal to be achieved.

Considering the entire business universe of the Cluster, i.e., companies associated with core and support activities, there is a turnover variation between 2010 and 2013 of 2.20%, much higher than the national average growth rate, which was - 2.97%.

In 2013, the degree of coverage of imports by exports, measured by the quotient between the value of exports and the value of imports of companies associated with core activities, was 1,261.46%, thus showing a behavior far above the national average ratio, which was 104.5%.

Until 2020 the Cluster aims to achieve the following goals: Turnover growth rate of 26.5%; Exports growth rate of 26.5% and substantially increase the growth rate of investment in R & D and innovation.

Among others, the elements listed above contributed to the recognition of the Portugal Mineral Cluster.

In the extended version of this work, an updated version of the above mentioned economic parameters will be present as well as more detailed objectives, framework, strategic proposals, and ongoing actions to be developed in the short and medium term within the scope of the Cluster of Mineral Resources of Portugal.

We also intend to disseminate the experience and attract potential interested parties to this strategy of collective efficiency relevant to Portugal. Moreover, this also constitutes an opportunity for cooperation and internationalization of the companies and entities of the Community of Portuguese Speaking Countries.

## Projects:

### On going

- Internationalization of Portuguese Stone Brand – STONE.PT (ACPMR, ASSIMAGRA, UE); it would be detailed.
- Inovstone 4.0 – Advanced technologies and software for natural stone (Consortium with 24 partners. Leader: CEI – Companhia de Equipamentos Industriais Lda); it would be detailed.
- Stone.pt Lab – (ACPMR, ASSIMAGRA, lab partners); it would be detailed.

### To be prepared

- New approaches in exploring and research of Mineral Resources;
- Qualify, safeguard and potentiate mineral resources;
- Transforming Environmental liabilities into raw materials;
- Circular Economy in Natural Stones.

## Acknowledgments

This study is co-financed by the European Union through the European Regional Development Fund, included in the COMPETE 2020 (Operational Programme Competitiveness and Internationalization) through the ICT project (UID/GEO/04683/2013) with reference POCI-01-0145-FEDER-007690 and the European Union through the System for Supporting Collective Actions - Networks and other forms of partnership and cooperation, Project POCI-01-0248-FEDER-027550.

## About the authors:

Marta Peres, Dr.

ACPMR – Associação Cluster Portugal Mineral Resources. Praça Luís de Camões, nº 38, 7100-512 Estremoz, Portugal. E-mail: marta.peres@clustermineralresources.pt

Luís Lopes, Prof.

Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: lopes@uevora.pt. ICT (Instituto de Ciências da Terra, Portugal; Earth Sciences Institute, FCT) and Associação Cluster Portugal Mineral Resources

Miguel Goulão, Dr.

ASSIMAGRA – Mineral Resources Association of Portugal. Rua Aristides de Sousa Mendes, 3b 1600-412 Lisboa. E-mail: mgoulao@assimagra.pt. ACPMR – Associação Cluster Portugal Mineral Resources

Luís Martins, Dr.

ACPMR – Associação Cluster Portugal Mineral Resources. Praça Luís de Camões, nº 38, 7100-512 Estremoz, Portugal. E-mail: lmartins@clustermineralresources.pt; ASSIMAGRA – Mineral Resources Association of Portugal (lmartins@assimagra.pt)

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Health and Safety overview related to dimension stone sector: Italian context

**Graziella Marras, Augusto Bortolussi, Nicola Careddu**

**Synopsis**

When it comes to human health and safety, the dimension stone industry represents one of the most hazardous activities. When accidents occur in quarries or dimension stone processing plants, consequences are usually very serious. A general description of Italy's state of the art is made herein, with a special focus on occupational injuries occurred during the last five years and fatal injuries of the last three years. Based on the outlined data, the study aims to assess the main safety risks linked with the dimension stone industry and, in particular, it analyzes the diamond wire sawing process in more detail. Suggestions and ideas are offered to mitigate risks.

**Keywords**

Dimension stone, health and safety, occupational injuries, risk assessment, diamond wire sawing.

## Introduction

The dimension stone sector is a very important part of the global economy. The 2016 gross quarrying production is estimated to account for 296 million tons with a total turnover of about 22 billion dollars [1]. Italy is a state of the art Country with regard to mining and quarrying technologies, and it has been reported to have the world's finest extractable and processing plants technologies. The number of workers involved in the sector is about 33,000 units in Italy, a data which raises questions and concerns about occupational health and safety. Even if fatality is a very limited risk - due to the widespread culture which regards the wellbeing and safety of workers as top priority - efforts should be made to reduce that risk to zero.

Unfortunately, one of the industry characteristics is the safety risk directly connected with the activity [2]. In Tab. 1, the Accident Frequency Index (AFI) is reported for construction, transportation and mining and quarrying sectors, considering Permanent Disabilities and Fatalities [3]. The data show that in the case of mining and quarrying sector the AFI for Permanent Disabilities is lower than the corresponding values of construction and transportation sectors, while the AFI for Fatalities of mining and quarrying is the highest.

Table 1. Italian Accident Frequency Index of different industrial activities.

| ACCIDENT FREQUENCY INDEX | | |
|---|---|---|
| INDUSTRY | PERMANENT DISABILITY | FATALITY |
| Construction | 3.78 | 0.10 |
| Transportation | 2.37 | 0.08 |
| Mining and quarrying | 1.87 | 0.11 |

Note. Accident Frequency Index: number of indemnified injures/1,000 workers/year

With the objective to reduce the number of casualties to zero, it is fundamentally important to assess risk [4]. The productive chain must be analyzed, different phases need to be specified, risks identified and safety measures applied to reduce such risks, in order to obtain a specific product, for instance rock blocks, with a level of efficiency that allows the maximum safety for workers [5, 6]. In this study, highest safety risks during extraction are indicated and statistics data about work injuries in the past five years in Italy are reported and evaluated. One of the most recurring fatalities of the past year is analyzed in detail, the cause of the accident identified and technical reduction solutions are examined.

## Italian overview of quarrying and mining health and safety

Italy's crux text on health and safety protection of employees in the workplace is Legislative Decree No. 81 dated 9 April 2008. This *Code* can be applied to all kinds of activities and risks, as well as to all workers. Unfortunately, it is still unclear which regulatory references apply to the quarrying and mining safety. Current specific rules are too dated: these are Italian Royal Decree No. 1443 dated 29 July 1927 and Decree issued by the President of the Republic of Italy No. 128 dated 9 April 1959. At his stage, significant interpretation problems emerge and it would be advisable to deepen, improve and unequivocally determine the roles, functions and competence of those who carry out specific tasks in the companies.

With regard to the economic activity coded B *Mining and Quarrying*, as classified by Statistical Classification of Economic Activities in the European Community, an overview of data, published by the National Institute for Insurance Against Industrial Injuries and elaborated for this treatise, this is summarized hereinafter. The occupational injuries per type of economic activity B is calculated at 685, a figure which refers to the mean value in the past five years (2012 - 2016), of which the average of fatalities is identified in 6.5 [7]. The most affected subsector is *Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate* with a mean value of 6.4. The main causes of fatal accidents in Mining and Quarrying can be reassumed in six major classifications: cutting wire rupture, traffic accident, machinery or men fall from bench crest, rock fall, electric shock due to worn out cables and blasting induced damage [8]. An *excursus* of the Italian outlined occupational fatalities along with accident causes occurred in the past three years is listed in Tab.2 [9].

### Diamond wire sawing: health and safety considerations

The diamond wire saw is one of the most important technologies adopted in carbonate and silicate ornamental stones sectors. Due to the spread of that technology the chance to have accidents connected with its application is increased. Beside the risks associated with the system power units (both Diesel or electric), the hazard part of the technology is mainly related to the diamond wire moving in a closed loop, with a tangential speed that can easily reach 40 m/s in common applications, and subject to a traction that depends on the kind of rock cut (normally in marble is about 1.5 kN) [10]. The sudden rupture of the wire causes a whiplash and the projections of the free diamond beads both in the same plane of the cutting area. The risk of such an event can be diminished by reducing hazard levels and/or any possible damage [8]. In the first case, the chance of wire rupture should be decreased, for instance by improving the rope quality, by limiting the rope operative stress conditions, by controlling the effectiveness of junctions. In the second case, the damage caused should be minimized, for instance by protecting the wire with a belt with the purpose of mitigating

the whiplash effect, with the use of a plastic coated diamond wire to secure the beads to the rope and avoid their projection.

Table 2. Quarrying fatal accidents causes in the past three years

| YEAR | DATE | WORKPLACE ACCIDENTS |
|---|---|---|
| 2014 | 6 September 2014 | Truck driver died with his truck after a closed road gave way |
| 2015 | 29 August 2015 | Quarryman died after falling from above while sawing blocks from a bank |
| 2015 | 23 November 2015 | Quarryman died after his head is hit by a diamond bead chain |
| 2015 | 11 December 2015 | Worker in charge of marble stocking area is run over by a marble slab during loading |
| 2016 | 14 April 2016 | Accident chain involving two quarrymen who are first hit and then dragged down in a landslide - the accident included the under-construction passageway |
| 2016 | 28 November 2016 | Quarryman is run over on the quarry pit by a marble slab detached from a block during production phase |

Note. Economic activity coded B0811: Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate

## Result and discussion

As previously pointed out, the hazards present in mineral-extracting operations make them unique in the field of industrial safety and health. Safety risks can be controlled by applying a proper policy. In this perspective, the role of human behavioral factors on safety is decisive. The education expertise and the observance of safety measures are important to prevent and minimize quarrying and mining accidents. A feasible solution to improve working conditions and the application of adequate preventive and safety measures seems to be leading towards the creation of a management system which can be certified (e.g.: BS-OHSAS 18001; ISO 14001). Moreover, it becomes necessary to identify an unambiguous regulation to prevent serious legal cases, such as the ones occurring in those Italian regional authorities where the administrative bodies in charge of the territory come up with different risk mitigation solutions. This kind of attitude results in unequal economic outcomes, with subsequent aggravations for companies which have to comply with more restrictive provisions.

## Conclusion

Occupational health and safety is becoming a social responsibility, people need to be made aware of *safety and safety culture must be created*. It would be worth thinking about a new perspective of risk assessment, where risks can be identified and analyzed from the very beginning so that safety measures can be applied to eliminate or minimize them. This could be achieved by providing a further Code of Best Practice and Recommendations. Further actions must be taken to prevent additional occupational injuries and fatalities. Furthermore, it is necessary to support Italy's leading technology and *know-how* to regard the safety of the dimension stone industry as a top priority, and create the right environment to *Connect mind to the world of stone.*

## Acknowledgments

The authors are thankful to Autonomous Region of Sardinia for the financial support (L.R. of 7th August 2007 nr.7).

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## About the authors

Graziella Marras, researcher

University of Cagliari, Department of Civil and Environmental Engineering and Architecture, via Marengo 2, Cagliari 09123, Italy. graziellamarras@gmail.com

Augusto Bortolussi, senior researcher

National Research Council of Italy, Institute of Environmental Geology and Geo-Engineering, via Marengo 2, Cagliari 09123, Italy. bortolussi@unica.it

Nicola Careddu, senior researcher

University of Cagliari, Department of Civil and Environmental Engineering and Architecture, via Marengo 2, Cagliari 09123, Italy. ncareddu@unica.it

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# Life Cycle Inventory of Brazilian natural stones

**Monica Castoldi Borlini Gadioli, Nuria Fernández Castro, Carlos Eduardo Ribeiro Wandermurem**

**Synopsis**

Brazil is one of the main producers and exporters of natural stones in the world. Aiming to contribute to environmental improvements, the life cycle inventory of Brazilian natural stones – LCI Stones was elaborated. This paper intends to present the results obtained along the LCI Stones project. The project was carried out according to the Brazilian methodology for the elaboration of inventories and to the 14040 and 14044 ISO standards. The study consists of two product systems: quarrying and processing (which is divided in two others systems: sawing and polishing), being the last one the main system of study. The product considered is the polished slab. The data were collected within companies, comprising a representative time period for the inventory validation. All inputs and outputs of mass, water and energy as well as products and emissions, within the boundaries, were identified and quantified. The main difficulty found in the data collection was the lack of data control in the companies, mainly the water and energy consumption and polishing inputs. The results of the study showed that, among the stones production processes, gang saw cutting was the one with the most relevant impacts.

**Keywords**

Life cycle inventory, natural stones, LCI Stones, polished slab, environment.

## Introduction

Life-Cycle Assessment (LCA) is a technique to assess environmental aspects and potential impacts inherent to the life cycle of a product or service, as it makes a detailed analysis of its whole life-cycle, *i.e*. from the acquisition of raw material (cradle) to its final disposal (grave). A LCA study is performed through four stages: goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment and life-cycle interpretation. LCA also supports product marketing and decision-making in the industry, aiming, *i.e,* strategic planning, priorities setting and design or redesign of products or processes [1]. LCA is also an important tool to elaborate environmental reports such as Carbon Footprint, Water footprint or Energetic Efficiency and accepted to achieve LEED and other environmental certifications. The project entitled "Technology, Energy and Environmental Improvements of Ornamental Stones Production through Product Life-Cycle Assessment, LCI – Stones" was one of the pilot studies of Life-Cycle Inventories (LCI) from the Brazilian Life-Cycle Assessment Program – PBACV (from Portuguese *Programa Brasileiro de Avaliação do Ciclo de Vida*) that establishes guidelines under the National System of Metrology, Standardization and Industrial Quality (SINMETRO) to provide continuity and sustainability to the actions of LCA in Brazil. It was one of the preliminary studies carried out to validate the LCI methodology developed in Brazil and the data collection methodology was adapted to the specific case of the stones supply chain, according to the technological representativeness and peculiarities of this industry in Brazil. The project was funded by the National Council for Scientific and Technological Development (CNPq).

This paper intends to present the results obtained along the LCI Stones project, from the blocks extraction in the quarries to the slab processing.

## Materials and Methods

The inventory – LCI Stones was carried out according to the Brazilian methodology for the elaboration of inventories [2] and to the 14040 and 14044 ISO standards [1][3]. The goal of the present LCI study was to contribute to the improvement of the productive processes of the natural stone´s industry in Brazil, and it's competitiveness from the environmental point of view. The LCI – Stones included all processes from the blocks quarrying to the slabs polishing, therefore it was limited, concerning to completeness, to the approach of "cradle to factory gate". Two product systems were considered: quarrying (auxiliary system) and processing (main system) . The product was the standard polished slab. Being the quarried blocks the raw material for the slabs production, quarrying was included in the study as auxiliary system. The main product system boundaries encompassed two subsystems, the blocks cutting (primary-processing) and the polishing of the obtained slabs (secondary-processing) and included the transportation of the blocks from the quarries to the processing plants. The function defined was providing 5.5 $m^2$ (slab standard size: 2.90 m x 1.90 m) of polished stone and the functional unit (minimum individual amount of inventoried product to this function) was one square meter of polished slab. Figure 1 shows the boundaries defined for the main system.

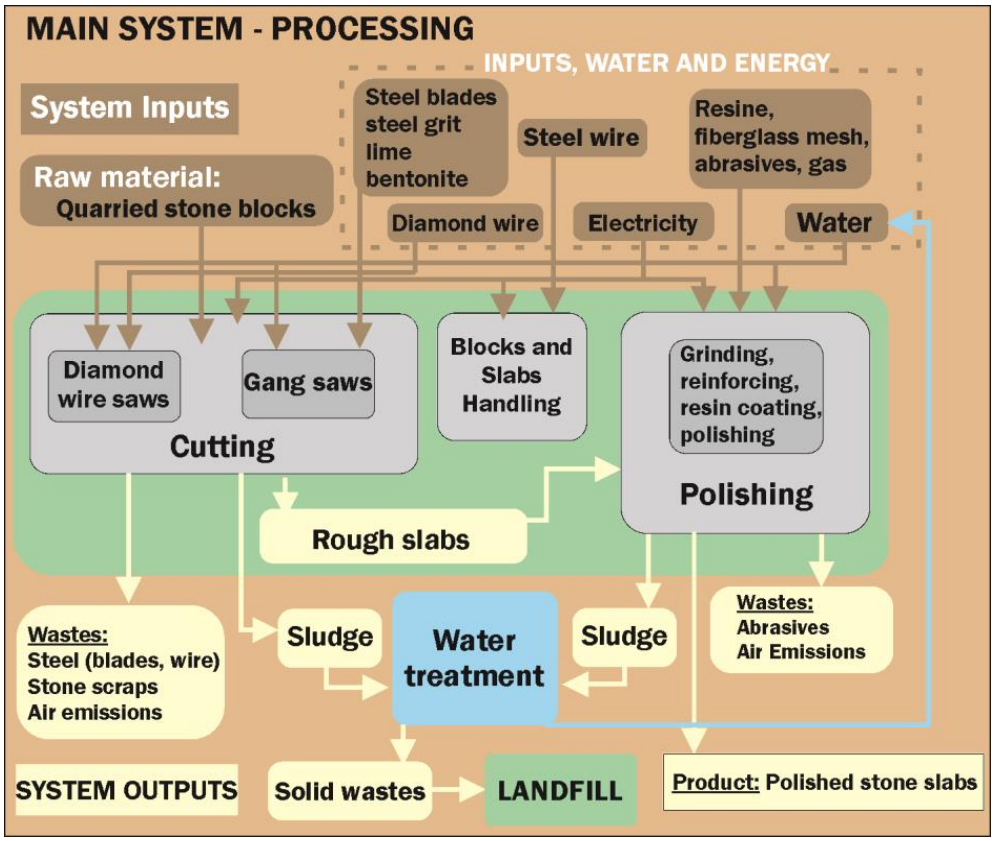


Fig. 1 Boundaries of the slabs production system (Main Product System).

The study was carried out within the context of the State of Espírito Santo, the most representative to the Brazilian natural stones sector and the main producer and exporter of

the country. Primary data, from 2011-2012, were collected in the companies. All inputs and outputs of mass, water and energy as well as products and emissions, within the boundaries, were identified and quantified. The teamwork gathered and measured this inventory data *in situ*, at the companies facilities, which grants their reliability.

## Results and Discussion

Table 1 shows the consumption of the main quarrying inputs. Energy and water are the most relevant in terms of consumption and, considering the mass representativeness, water stands out with 99.4%.

Table 1 Consumption of main inputs in extraction.

| Inputs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diesel | Diamond Wire | Detonating Cord | Wedge | Rod | Black Podwer | ANFO | Bit | Steel cable | Electricity (kWh/m³) | Water (L/m³) | Lubricant (L/m³) |
| (kg/m³) | | | | | | | | | | | |
| 9.99 | 0.06 | 0.04 | 0.03 | 0.21 | 0.14 | 0.22 | 0.05 | 0.62 | 50.88 | 2000 | 0.08 |

Within the LCI-Stones time frame, 2011-12, in Brazil, stone blocks were mainly cut in gang saws (traditional technology with steel blades) and just 20% of the Brazilian slabs were cut by the diamond wire saws. Thus it was considered in this study a four to one contribution of gang saw to diamond wire technology in the overall results. Comparing both cutting technologies, tables 2 and 3 show that energy consumption of blocks' cutting by diamond wire saws is around half of that of the gang saws (48.65%).

Also the water consumption per square meter cut is much lower for the diamond saws (29.92 L/m²) than for the gang saws (57.70 L/m²). On top of that, gang saws use more inputs (lime or bentonite, steel grit) than diamond saws. Nowadays, more than a half of the Brazilian slabs are produced by diamond wire saws, technology whose use is still growing. This can be seen as an improvement not only in production rates but also from the environmental point of view, especially in reference to water and energy consumption.

Table 2 Inputs consumption of stone blocks cutting in gang saws.

| Blade (kg/m²) | Grit (kg/m²) | Lime (kg/m²) | Bentonite (kg/m²) | Steel cable (kg/m²) | Electricity (Kwh/m²) | Water (L/m²) |
|---|---|---|---|---|---|---|
| 0.61 | 1.11 | 0.55 | 0.26 | 0.0002 | 7.79 | 57.70 |

Table 3 Inputs consumption of stone blocks cutting in diamond wire saws

| Electricity (Kwh/m²) | Water (L/m²) | Diamond Wire (Kg/m²) |
|---|---|---|
| 4.00 | 29.92 | 0.015 |

Regarding the polishing step, the abrasives and resins consumption is directly dependent on the processed material. In example, some very well-known Brazilian exotic stones need more resin than traditional materials in order to be cut and polished, as they

are naturally more fragile. Table 4 shows the measured values for the polishing inputs consumption in this study, where mostly commercial granites were processed.

The obtained results clearly show that the gang saw cutting of blocks is the process that consumes more water and energy.

Table 4 Consumption of inputs in polishing

| Silicon carbide abrasive ($kg/m^2$) | Resin Bonded abrasive ($kg/m^2$) | Diamond abrasive ($kg/m^2$) | Resin ($kg/m^2$) | Catalyst ($kg/m^2$) | Fiberglass mesh ($kg/m^2$) | Natural Gas ($kg/m^2$) | Electricity ($Kwh/m^2$) | Water ($L/m^2$) |
|---|---|---|---|---|---|---|---|---|
| 0.05 | 0.005 | 0.003 | 0.08 | 0.03 | 0.43 | 0.03 | 3.45 | 18.77 |

The LCI – Stones was validated and the LCA completed by specialists. The results showed that, among all the processes of the natural stones production chain in Brazil, the gang saw cutting of blocks was the one that presented the most relevant impacts. Taking into account all the processes and inputs in general, the imported inputs were the ones that influenced most on the impact categories considered.

## Conclusions

The substitution of the traditional blocks cutting technology, the gang saws, by the diamond wire saws, which is already happening in Brazil, represents an improvement of the natural stones industry, productively and environmentally. Other improvement appointed by this study results could be reducing the use of imported inputs. The Brazilian LCI-Stones was elaborated with primary data, reliable and representative of the natural stones production in Brazil. The generated valuable information can contribute to improve productive processes and products competitiveness from the environmental point of view, and also is the first step to obtain Environmental Products Declarations (EPD) and certifications such as the Leadership in Energy and Environmental Design – LEED by stones producers, because it is valid for the whole sector.

## Acknowledgments

The authors thank CNPq (proc. 555723/2009-7) for supporting this research and companies where the data were collected.

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## About the authors

Monica Castoldi Borlini Gadioli, D.Sc.; Nuria Fernandez Castro, M.Sc.;Carlos Eduardo Ribeiro Wandermurem, technician.

Centre for Mineral Technology - CETEM/MCTIC, Espírito Santo Regional Unit, Rodovia Cachoeiro-Alegre, km 5, Morro Grande, Cachoeiro de Itapemirim, Espírito Santo, 29311-970, Brazil

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Ecological fickerts used in the polishing of dimension stones

**Wana Favero Gaburo Dorigo, Leonardo Luiz Lyrio da Silveira, Phillipe Fernandes de Almeida**

**Synopsis**

The processing stages of the dimension stones industry use inputs mainly from petroleum-derived chemicals that can cause damages to the environment and to the human health. Therefore, there is a need to develop technologies more ecological and sustainable aiming to replace the conventional inputs actually used by less aggressive ones. From this, fickert made from polyurethane castor oil resin, Silicon Carbide (SiC), and silica from rice hull ash (RHA) and synthetic diamond is developed in order to compare them with the epoxy resin fickerts currently used in industry. Each half of an ornamental stone slab was polished with one type of fickert and the results obtained of the gloss measures were compared. It was found that the part that was polished with the abrasive made by polyurethane castor oil resin presented brightness about 10 Gloss Units (GU) greater than the other part that was polished with the conventional abrasives, in addition to presenting low values of mass loss. These results allow concluding that the ecological abrasive fickert is as a good alternative to the polishing of ornamental stones considering eco-efficiency and sustainability aspects.

**Keywords**

Abrasive, polishing, stones, ecological, RHA.

## Introduction

A few decades ago, the generation of pollutants by companies was perceived as an inevitable consequence of industrial processes, causing a marked degree of environmental deterioration in many regions of the world (CIMM, 2016). The industrial processing of dimension stones embraces a succession of steps from the primary processing, where the sawing of the blocks from the quarries occurs, transforming them into rough slabs, until the secondary processing, in which the finishing phase takes place. In this step, these slabs pass through polishing machines with polishing heads where abrasive tools (fickerts) are arranged in sequence in the heads, from the coarsed to the finest grain. The fickerts perform a circular movement on the slab, with constant water flow for waste removal and surface cooling. This process aims to reduce the roughness of the material and increase its brightness values, configuring the polishing step that will produce ready-to-sell slabs. The types of fickerts used in the polishing of dimension stones can be divided into: Magnesians, in which the matrix is composed by Sorel cement, having as abrasive element the silicon carbide (SiC); resinoid, that are immersed either in epoxy resin or sintered metallic matrix, having diamond grains as the cutting elements. Among the above mentioned fickerts, the ones made from epoxy resin are the most used in the industry over the world. However, these tools are those that can present greater potential of environmental damages and risk to human health, since they contain toxic substances such as Bisphenol A and Epichlorohydrin in its composition (BESERRA *et al.*, 2012). Based on this, it is sought to develop new technologies with a view to replace such inputs with others that are more ecological and pose minimum risk. Dorigo and Silveira (2016) performed abrasion tests with the aid of *Taber Test* machine in samples made using castor oil polyurethane resin and reinforced with silicon carbide (SiC) and silica from

rice hull ash (RHA). The results of the abrasive tests were promising in relation to the abrasion resistance, which are lower than the minimum wear value proposed by the dimension stone fickert industries (0,5%).

From the works already developed, and seeking greater efficiency without losing the sustainable bias in the production of inputs for the processing of dimension stones, it was proposed to use the most resistant composition formula found in previous research (Dorigo and Silveira, 2016), and with the addition of synthetic diamond as cutting element, ecological fickerts were produced on industrial scale to be compared with conventional fickerts based on epoxy resin in order to analyze which one obtained the best final gloss result in the polishing of a granite slab.

## Objectives

The objective of this work is to compare the gloss results on a sienogranite slab polished with the fickert made from polyurethane castor resin and with the conventional fickerts used in the industry, in order to verify the cutting efficiency and the performance of this input made with ecological matrix.

## Methodology

### Materials

For this research, it was polished a rock slab commercially known as Yellow Fiorite, which is classified as a porphyritic sienogranite composed by phenocrysts of potassium feldspar, quartz, biotite and little amount of plagioclase feldspar. In the preparation of the fickert, the polyurethane resin was used in the proportions of 1: 1.2 polyol and prepolymer, respectively. As an abrasive extenders, the formula corresponding to the sample represented by the proportions of 50% of Rice Hull Ash (RHA) and 45% of Silicon Carbide (SiC) in grain size 1200 mesh, and as a cutting element, 13.3g of synthetic diamond was added in the 600 *mesh* granulometry for each fickert produced (Figure 1). The polishing test was carried out in the Dimension Stones Processing Laboratory of the Federal Institute of Espírito Santo (IFES) in a semiautomatic polishing machine, which has one polishing head and capacity for 6 fickerts (Figure 2). The brightness measurements were performed using a micro-tri-gloss glossmeter.


Fig. 1. Sample of the yellow sienogranite (A); Extenders of RHA and SiC (B) and synthetic diamond (C).

Fig. 2. Polishing running test of the dimension stone slab in semi-automatic polishing machine.

## Methods

The granulometry chosen to the fickert was 600 mesh, due to the fact that this stage constitutes an important transition phase between the roughing and the polishing itself. The procedure for making the fickerts was started by weighing the castor oil polyurethane resin components (polyol and prepolymer), the RHA and SiC extenders and the diamond particles. After this, the polyol and the prepolymer were homogenized and it was necessary to use a vacuum system to remove the $CO_2$ generated, this process took approximately 12 minutes. Subsequently, the loads of RHA and SiC and the diamond were added to the blend, homogenized and arranged in molds suitable for dimension stone fickerts (Figure 3). After being ready, the fickerts went through 15 days of curing before being unmolded and subjected to the polishing test.

Fig. 3. Main steps for the production of ecological fickerts.

## Results and Discussion

The polishing tests presented very satisfactory results concerning to the values of gloss and mass loss obtained. In the graph of Figure 4, it can be seen that the polish done with the castor oil abrasives presented a mean value for the gloss values approximately 10 GU (Gloss Unit) greater than the average gloss obtained on the part of the slab polished with the fickerts of epoxy alloy.

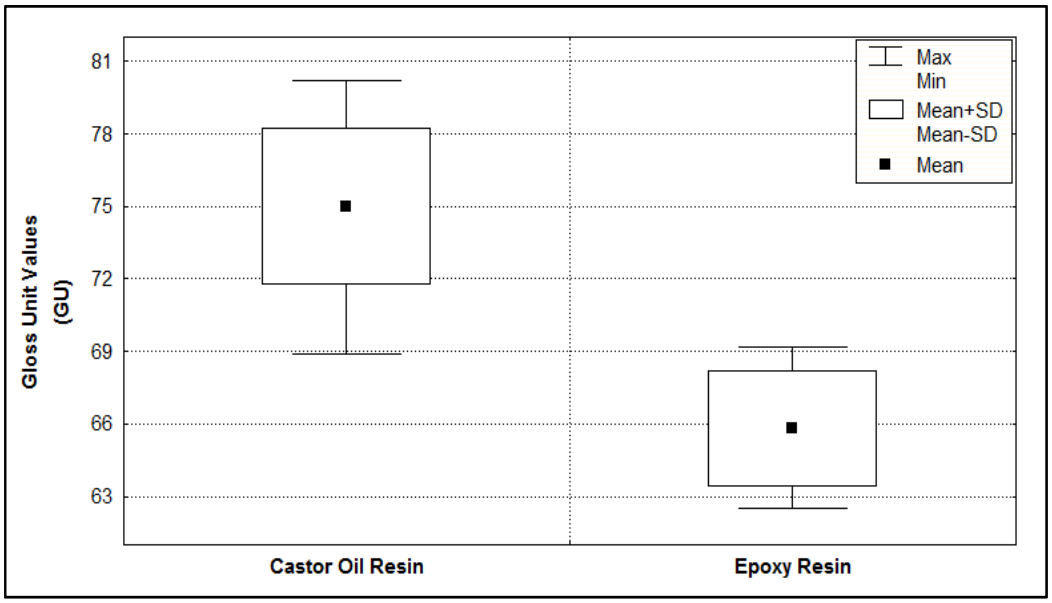


Fig. 4. Brightness results obtained in the polishing with the two types of fickerts.

## Conclusions

From the comparison of the polishing results obtained with the castor fickerts and with the epoxy fickert, it was possible to verify how efficient the ecological fickerts were in the polishing of the granite in question. The side of the slab polished with the castor fickert presented excellent results regarding to the gloss and low values of wear when compared to the conventional fickert used by the dimension stone industry.

## Ackowledgments

To the company Cobral Abrasivo and Minérios Ltda for providing the molds and to Rodrigo Abrasivos Ltda for the technical orientations. To the PhD candidate Phillipe Almeida for the assistance during the entire research and to the CNPq for the scientific initiation scholarship granted.

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## About the author(s)

Wana Favero Gaburo Dorigo, Mining Engineer

Federal Institute of Espirito Santo State, Department of Mining Engineering, Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code29.311-970, Brazil. E-mail. wanadorigo@gmail.com

Leonardo Luiz Lyrio da Silveira, PhD

Centro de Tecnologia Mineral – Núcleo Regional do Espírito Santo (NR-ES/CETEM-MCTIC), Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code29.311-970, Brazil. E-mail. leolysil@cetem.gov.br

Phillipe Fernandes de Almeida, M.Sc.

University of Sao Paulo, Department of Architecture and Urbanism, Avenida Trabalhador São Carlense, 400, São Carlos-SP, Zip Code 13.566-590, Brazil. E-mail. Phillipe.prudente@gmail.com

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# Environmental impact of new sandwich-structured stone composite

**Rodrigo Sequeira, Joel Pinheiro, José Silvestre, Pedro Amaral**

**Synopsis**

In the last few years, the use of sandwich composite solution in architectural projects has grown exponentially. Combining fragile materials such as natural stone with other reinforcement materials has the potential to create a new composite structure with improved characteristics to those presented by the individuals. The need to use materials that enable maximum performance when installed induced the development of sandwich-type materials, which can combine rigidity and mechanical strength, while maintaining the low weight. The present work was conducted in partnership with the engineering company Frontwave SA in the framework of an R&D project that aimed the development, production and experimental characterization of a new sandwich-structured composite material based in natural materials including stone and cork. The sandwich composite combines natural stone and cork bonded by natural fibers and bio based resins. Experimental characterization included bending tests. In the case of asymmetrical sandwiches structures, the existing standards for composite materials are not fully suitable and special testing methodologies had to be developed based on digital image correlation for stiffness and strain analysis. A comparison of various outcomes was carried out. The environmental impact was measured using the Life Cycle Assessment (LCA) analysis and costs were assessed for comparison purposes with other current solutions. The three studied parameters: mechanical performance, life cycle assessment and costs were studied in a multi criteria analysis, which leaded to a global decision maker indicator.

**Keywords**

Composite Material; Sandwich Structure; Natural Fibres; Bio-based Resins; Life Cycle Assessment.

## Introduction

The construction sector consumes yearly about half of all natural resources extracted in Europe and their transformation into building products has huge energy demands. Therefore, the focus of today's environmental policy is to be on the building end-of-life scenarios and material efficiency. Here waste prevention and recycling /reuse play a key role by providing huge energy, water and material savings. These issues are also specifically addressed in the Construction Products Regulation1 (CPR 2011), where health and safety aspects related to use of construction products cover of the entire lifecycle. Meanwhile the building sector is moving from new buildings towards maintenance and renovation.

In engineering the contribution involves the research and development of systems that consume energy and other resources at a rate that does not compromise the environment, focusing on objectives such as waste, materials management, pollution prevention and product improvement.

Natural materials have been used to try to respond to the above problems and composite materials, by their nature, are usually the focus of the studies and developments towards evidencing less and less reliance on synthetic materials with high environmental impact. The natural fibres and bio-based resins have been the target of extensive study in

recent years that have already discovered some applications to integrate, both structural and non-structural. The use of these materials involves a whole analysis that focuses not only environmental issues but also the technical capabilities and financial benefits or consequences in their employability.

This work produced and studied different types of sandwich-structured composites with natural stone and cork using natural reinforcement and bonding materials. Glass fibre and epoxy resin were compared with the flax fibre (natural) and a bio-based resin regarding: bending mechanical performance, life cycle and cost that in a multi-criteria analysis suggest a more suitable solution in view all these factors.

Preliminary works included concept and specification development of this new and innovative solution and all material options. Literature review was focused on the state of the art of natural fibers and bio-based resins as well as the sandwich structure and life cycle assessment technique. Are presented in the following points the production methods used, the experimental characterization and results, Life Cycle Assessment (LCA), costs, the multi-criteria analysis and finally the conclusions and recommendations.

## Sandwich-structured stone composite concept and specification

Stone and cork sandwich-structured composite is based on a concept that comprise a laminated composite material built in layers that combines different characteristics from their main constituents: stone and cork. The adhesion of the two materials is based on resins, and the strength is given by biaxial fibers (syntactic or natural). This concept stands for an innovative solution of low weight, high strength and long-lasting service life allowing a large range of applications comparatively to a natural stone product due to its improved mechanical and physical properties.

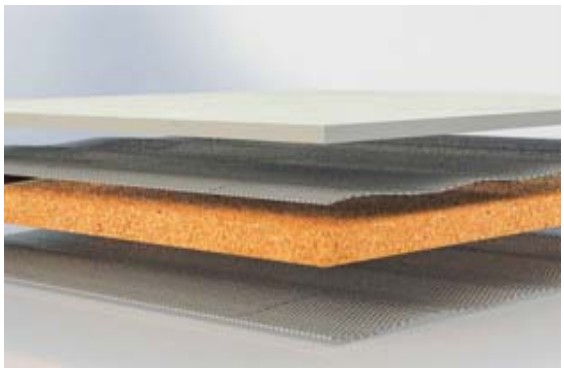

Fig. 1 Stone and cork sandwich-structured composites schematic representation.

In the sandwich structure, the fibers embedded in resin give stiffness to the system as well they promote the adhesion between the stone and cork layers. The stone layer at the top gives has an aesthetic function, however gives to the stone composite panel an asymmetry.

## Production method

Specimens were produced through hand lay-up (lamination). The composite layers are unified through the quantity of resin assessed per the type of fiber and its weight, as well as the type of other layer than fiber, stone or cork, since the latter absorbs resin through its pores. A curing process follows the above procedure.

Specimens were produced with dimensions: 300 x 300 $mm^2$ and 10 mm thick, and then sawn cut to size with the dimensions required for the experimental characterization. Six

different combinations were produced as shown in the Table 1, with the layers of stone and cork remaining constant.

The first “weight” value represents the fiber weight for the layer between the stone and cork and the second weight value concerns the last layer, adhering to the cork. The glass fiber is biaxial as well as the flax BD (standing for bidirectional). The flax UD fibers are unidirectional which are perpendicularly arranged in the production of the composite. Both resins are epoxy however one is 37% bio-based and the other is a conventional bi-component resin.

Table 1 Different fibers and resins studied in the sandwich structured composite.

| Series | Fibre | Weight ($g/m^2$) | Resin |
|---|---|---|---|
| 1 | Flax UD | 430/430 | Epoxy |
| 2 | Flax UD | 430/430 | Bio |
| 3 | Glass | 600/300 | Bio |
| 4 | Flax BD | 500/400 | Epoxy |
| 5 | Flax BD | 500/400 | Bio |
| 6 | Glass | 600/300 | Epoxy |

## Mechanical Characterization

### Specimen dimensions

Specimens’ dimensions met ASTM C393 (Standard Test Method for Flexural Properties of Sandwich Constructions). The length was somewhat limited by the available stone tiles (300 mm) and the thickness by the application itself. This standard specifies that the specimens should have a rectangular cross-section, the thickness must equal the sandwich structure and the width should be greater than twice the thickness and three times the core thickness and less than half the distance between supports. Note that specimen length was imposed by the standard as the distance between supports plus 50 mm, so the distance between supports was defined as 250 mm.

### Bending tests

Currently, the standard methods for flexural tests on sandwich structures assume specimen’s longitudinal symmetry. In this study, the stone composite specimens do not show symmetry. ASTM C393 standard contains a flexural stiffness calculation method for sandwich structures with different materials on both sides, but this method would require testing tensile strength to determine the Young's modulus which could become lengthy and avoidable since the goal is to compare different composition of the same composite solution. Thus, the calculation of the mechanical properties did not follow an existing methodology.

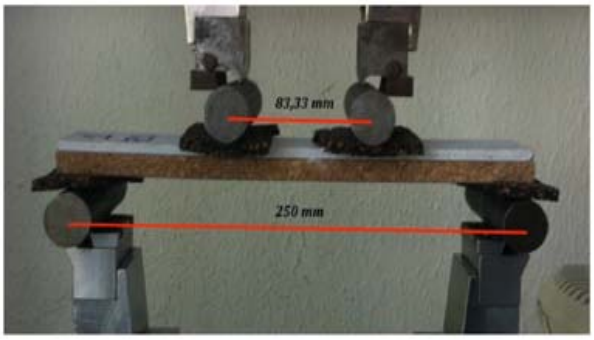


Fig. 2 Distance between supports for the bending test.

The selected test method was the four-point bending, wherein the specimen is supported by two supports spaced by 250 mm. Load is applied at two points equidistant from the supports, separated by a distance equal to one third of the distance between supports, the third point loading procedure, therefore 83.33 mm. Figure 2 depicts de experimental set up for the four-point bending tests.

## Environmental life cycles analysis (LCA)

LCA assessment was based on the standard ISO 14040-2006. Starting with the definition of the functional unit, which suits the need to quantify the product functionality by measuring its performance when executing the function associated with it, it is a reference to which the inputs and outputs are related.

Measuring the consumption of materials and emissions of unit processes associated with each product life cycle as well as its environmental impact, the functional unit was defined as "The production of raw materials and installing a panel 1 m2 ".

Having defined the functional unit, it was then compare the environmental efficiency associated with the supply of a 1 m2 panel for all the alternatives presented. After this setting, it was possible to estimate the amount of material required to fulfil this function.

The boundaries of the LCA were defined from cradle to gate, adding in the end the transport phase of the finished product.

## Cost analysis

Relatively to cost analysis, the price of each material involved in all production series developed in this work was estimated then, price range for each square meter of composite itself.

## Multicriteria analysis

Multicriteria analysis was performed as a tool to support decision making, since it can create choice indicators considering all necessary parameters. In the economic aspect, incorporated costs and carbon footprint were considered and, in the mechanical aspect flexural strength and apparent stiffness. Since each parameter has a unit, all parameters had to be properly non-dimensional to allow an assignment of weights depending on their importance, and finally compared in an overall analysis to address the best solution.

## Conclusions

The best mechanical performance was found on the sandwich-structured stone composite with glass fiber due to its considerably higher mechanical properties, indisputable

fact and which the flax fibers are not able to compete. The replacement of the synthetic epoxy resin by the bio based, allowed the maintenance of the mechanical performance in both cases of the natural and synthetic fibers. It should be stressed out the good score of the natural fibres in the composite material sandwich structure composite material studied in this work; it has been proven that their joint utilization with the biological based resin resulted in a 18% reduction in the apparent stiffness and with the synthetic epoxy resulted in a 22% reduction in the maximum strength, when compared with the series involving glass fiber.

The lower ecological footprint was found for the glass fiber series with the bio based resin. Bio based showed a clear reduction on the environmental impact in relation to the epoxy. The natural fibers, even though presenting a similar impact to the glass fibers, lose ground to the latter due to higher resin absorption in the production process, leading to a higher impact.

The two sandwich composites series with flax fibers (natural) showed a 1.5 absorption coefficient, showing a 50% increase in resin consumption comparatively to the same case with glass fibers.

The worst ecological footprint was found for the sandwich composites series with flax fibers UD (unidirectional) with an absorption coefficient of 2.

This study main conclusions focused that the natural fibers, being technically inferior to the synthetic ones, will hardly replace them for structural applications, even though this replacement is possible if the project requirements met, even though presently they show an inferior performance in terms of cost and ecological footprint.

## Acknowledgments

The authors acknowledge the support from Galrão, SA and Urmal, SA for providing the raw materials. Funding: This study was developed by Frontwave, SA with the support of Instituto Superior Técnico from Lisbon University.

The results presented in this paper were obtained in the frame of the project 10.472 STORK, funded by the European Regional Development Fund (FEDER) through the Alentejo Regional Operational Programme (PO Alentejo).

This work was also supported by “Fundação para a Ciência e a Tecnologia” (FCT), through the Institute of Mechanical Engineering (IDMEC) under the Associated Laboratory for Energy, Transports and Aeronautics (LAETA), Project UID/EMS/50022/2013.

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## About the author(s)

Rodrigo Pinto Machado Portugal de Sequeira

Instituto Superior Técnico, Universidade de Lisboa, Department of Civil engineering, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. rodrigo.sequeira@tecnico.ulisboa.pt

Joel Roque Pinheiro

Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. joel.pinheiro@tecnico.ulisboa.pt

José Dinis Silvestre

Instituto Superior Técnico, Universidade de Lisboa, Department of Civil engineering, Av. Rovisco Pais, 1049-001 Lisboa, Portugal.

jose.silvestre@tecnico.ulisboa.pt

Pedro Miguel Gomes Abrunhosa Amaral, Prof.

LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. pedro.amaral@tecnico.ulisboa.pt

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# The Padua natural stone: from the corrals to the Olympic Boulevard

**Carlos Cesar Peiter, Maria Martha de M. Gameiro**

**Synopsis**

The Santo Antonio de Padua natural stone quarrying cluster in Rio de Janeiro state is considered one of the more well succeeded in Brazil reaching 150 small and medium companies operating quarries and sawmills for slabs and tiles production. There has been a continuous development from the initial stone use as corral flooring material, until the massive use in the Porto Maravilha , the project to modernize the Rio de Janeiro old port urban area. Such step forward was made possible by simultaneous political, social and economic factors that came out from the intensive and persistent work undertaken by the local SMEs representatives, together with government agencies, private institutions and other public authorities that supported a regional development plan on which the natural stone production was set as a priority. In this paper are described some parts of the Padua stone cluster past and more recent events that may offer suggestions and practical examples for future similar initiatives in other places and with other stone materials.

**Keywords**

Natural stone cluster, Santo Antonio de Padua cluster, Olympic Boulevard flooring

## Introduction

The history of the Padua natural stone cluster started almost 40 years before the present stone materials massive production. The geological formation of the Northwestern region of Rio de Janeiro State favored the beginning of the quarrying artisanal operations. During the late sixties and seventies of the previous century, local gneiss stone was used as the " Pedra de Curral", or as a cattle stone flooring. The availability of outcrop volumes of gneiss rock with two different colors (gray and yellowish) available almost at the surface of the two regional hills formation (Serra do Bonfim e Serra do Catete) helped to promote artisanal quarrying to extract small stone blocks followed by the splitting into smaller slabs (40x40 cm ) useful for corral floors. The typical Padua tiles (11,5 x 23 x 2 cm) production started when a diamond disk saw made by a small local mechanical workshop was introduced to quarry owners. From that time on, dozens of small quarries and small sawmills began to supply the Southeast market of Brasil . The "Pedra Miracema"(first brand for the Padua stone) the grey more common type , and the "Pedra Madeira" , the yellow , white and rose colors type of gneiss, became in a few years well known for the building contractors and architects. By that time, in the years 1990, almost all of the stone quarries and stone sawmills operate without legal permits, not only the mining, but out of environmental and safety regulation. The damage to the local environment forced the Forestry Police of Rio de Janeiro to make a blitz in 1996 in order to stop most of quarries operations. (DEPARTAMENTO DE RECURSOS MINERAIS DO ESTADO DO RIO DE JANEIRO, 2012)

## From informality to legal operation

The police blitz started an extensive consultation to all regional and state political stakeholders, as well to government agencies and to justice authorities who, together with the quarry owners' representatives, promoted a long process of negotiation to give opportunity to all quarries and stone processing sawmills to fulfil legal requirements (PEITER, 2000). Many governmental and private institutions took part to support, being the more important : the quarry owners association ,SINDGNAISSE, the Mineral Resources Department of Rio de Janeiro – DRM RJ, and the environmental agency , FEEMA ( now INEA), the Centre for Mineral Tecnology, CETEM, the National Institute for Technology, INT, the Brazilian Agency for Small and Medium Enterprises , SEBRAE, and the technology institution connected to the Rio de Janeiro Industry Federation, SENAI . The Federal Public Prosecutor (Ministério Público Federal) was involved due to federal regulations. Funds for technical R&D projects came from the Rio de Janeiro State Science Agency, FAPERJ, and from the Mineral Technology R&D Fund of the Ministry for Science and Technology – CT MINERAL. The stakeholders consultation ran very well and, in 2002, the TACs, a special legal agreement, was signed by the federal prosecutor and miners to provide a time schedule to quarry owners to correct wrong environmental, safety and health procedures. DRM RJ, INEA, CETEM, SENAI and the SINDIGNAISSES worked together to provide technical solutions the agreement requested

## Solutions to environmental problems

Among the environmental problems, the pollution of brooks and water resources with mud coming from sawmills was considered very serious causing many conflicts between small farmers and miners, sawmill owners. A simple and not expensive process to clean and reuse water was developed by CETEM and INT including solid /liquid flocculation settlers for recycling of water to sawmill and separating fine stone solids to be used in industrial mortar composition. Most of sawmill owners followed the patented project offered by CETEM and INT (INSTITUTO NACIONAL DE PROPRIEDADE INDUSTRIAL, 2017) to build saw tailings treatment settlers to get their operation licenses. After that, a mortar industrial plant was built by the company Pedreira São Sebastião that received subsidies from the municipal and state governments to locate at Santo Antonio de Padua municipality consuming most of the available tailings.

## From corral to the Olympic Boulevard

After 2003, Brazil underwent about eleven years of economic prosperity and civil construction market boom. The Padua quarry SMEs were invited by Brazilian Association of Natural Stones, ABIROCHAS, to participate in international stone fairs and had the opportunity to get in touch to international trade, products quality and natural stone technology. Such a world market view pushed them to go further, with the support of DRM RJ and SEBRAE, to ask for the geographic indication (sourcing) an international accreditation for three materials: Pedra Carijó, Pedra Cinza and Pedra Madeira. An extraordinary development of the Padua stone cluster happened from 2011 to 2014 due to Rio de Janeiro City urbanistic plan for the 2016 Olympics. The huge Rio de Janeiro old port modernization project, known as Porto Maravilha (COMPANHIA DE DESENVOLVIMENTO URBANO DA

REGIÃO DO PORTO DO RIO DE JANEIRO, 2017), was a 2.5 billion dollars private/public investment multipurpose project, focusing new housing and business buildings construction, urbanistic modernization, cultural and historical places and monuments repairs and rehabilitation works and implementing of modern means of public transportation. The Padua stones were chosen as flooring material for the Olympic Boulevard, a new sidewalk by the old port sea side, and for other public squares like the Praça Maua (Maua Square), where two new museums were inaugurated : the Museu de Arte do Rio , MAR, and the futuristic Museu do Amanha (Tomorrow´s Museum) (Figure 1) , matching a large demand of about 650 thousand squares meters (Fig. 2) and in the museums square , Praça Mauá (Fig. 2).

Fig. 1 The Olympic Boulevard with grey Padua stones flooring near the Tomorrow´s Museum (www.portomaravilha.com.br)

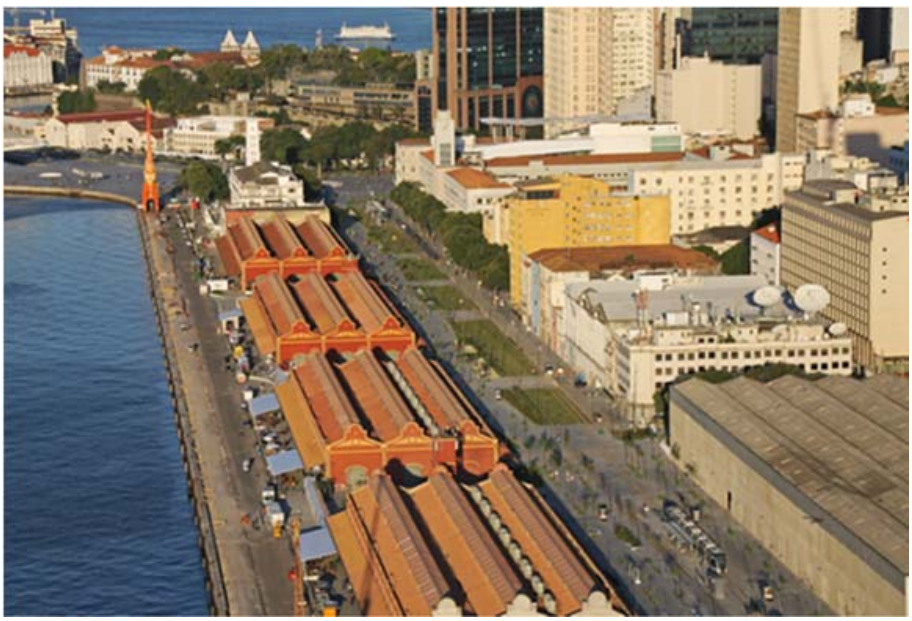

Fig. 2 View of the Olympic Boulevard (www.portomaravilha.com.br)

## Conclusion

The Padua natural Stone Cluster has been considered nationally one of the well-succeeded stakeholders initiatives planned and performed by private / public organizations and SMEs. Most of objectives have been reached and the northwestern region of Rio de Janeiro State received such an important support regarding its peculiar mineral endowment. The environment in the region is subject to permanent surveillance and inadequate quarrying and stone processing practices have been changed to a lower level of impact operations. Although the present economic crisis caused a large drop on stone output , the main social, political and industrial cluster participants are now updated and well prepared for domestic and international market competition and future prosperity times.

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## About the author(s)

Carlos Cesar Peiter, Senior Technologist. PhD Mineral Eng. Sciences.

Centro de Tecnologia Mineral, CETEM. Rio de Janeiro, Brazil, Av.Pedro Calmon,900, 21941-908. cpeiter@cetem.gov.br

Maria Marta de M. Gameiro, Mining Engineer, MSc. Geology.

Departamento de Recursos Minerais do Estado do Rio de Janeiro. R. Marechal Deodoro, 351, Niterói, Brasil, 24030-060. mgameiro@drm.rj.gov.br

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL
April 26-29, 2018
CONNECTING MINDS IN THE WORLD OF STONE

# Nature conservation, land use planning and exploitation of ornamental stones

**Jorge M. F. Carvalho, João Meira, Célia Marques, Susana Machado, Lia M. Mergulhão, Jorge Cancela**

**Synopsis**

Cabeça Veada is the name of a relatively small exploitation cluster for ornamental limestones occupying an area of 98 ha in the Portuguese Natural Park of Serra de Aire e Candeeiros, which is also a Natura 2000 Network protected area. Supported by comprehensive geological, mining and environmental studies, a specific methodology was developed in order to address the compatibility between the long term sustainability of this industry with the preservation of existing protected natural values. The obtained land use map should allow the Cabeça Veada mineral resources to be adequately included in the municipal land use planning process.

**Keywords**

Nature Conservation, Land Use Planning, Ornamental Limestones, Portugal.

## Introduction

The exploitation of mineral resources can only take place where they occur and their long-term availability and exploitation depends on geological, technological and market conditions, but also on the constraints imposed by land use policies and practices. Nevertheless, despite their importance, they are often overlooked in land use plans, thus limiting their access by the mining industry. Concerted efforts by the Portuguese authorities and the industry have allowed the implementation of several good practices seeking the integration of mineral resources in land use planning policies and tools. We present an example of such good practice in a specific mining site known as Cabeça Veada, located in the Natural Park of Serra de Aire e Candeeiros (NPSAC), Portugal, where the main issue was to find the best way to make the mining activity compatible with nature conservation.

## Setting

The NPSAC is also a designated Site of Community Importance (SCI) of the Natura 2000 Network since 2000 (Ref. PTCON0015). It is located in an uplifted limestone massif of the Lusitanian Basin, Portugal (Wilson et al., 1989) (Fig. 1), where several lithostratigraphic sections of Jurassic formations outcrop in extensive areas. The sections of Middle Jurassic age mainly consist of light cream-coloured limestones formed under very specific palaeo environmental conditions, leading to their occurrence as massive limestone bodies (Azerêdo, 1998). These are exploited as 2 $m^3$ to 6 $m^3$ blocks for ornamental/high-value applications in about 100 open pits (Carvalho, 2012).

Quarrying in NPSAC is one of the fundamental economic activities with local and regional impact, supporting one thousand direct jobs and generating wealth of over €100 million. Ornamental limestones exploited and transformed here are exported all over the world. The quarries are not dispersed; instead, they are clustered in five main exploitation areas of suitable stone quality, being the Cabeça Veada site one of them.

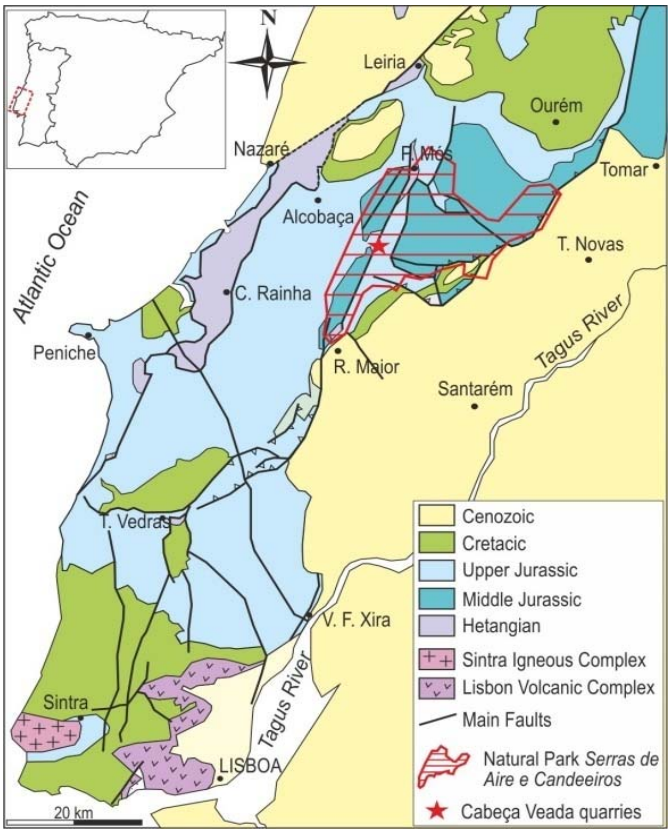


Fig. 1 Geological setting of the Cabeça Veada quarrying site and NPSAC in the Lusitanian Basin (adapted from the Portuguese Geological Map, 1:1,000,000, edited by LNEG-LGM).

## Methodology and results

According to the legal management rules of the NPSAC, the Cabeça Veada site should be subjected to detailed land use planning at the municipal level aimed at the establishment of compatibility measures between rational mining activity, the environmental restoration of degraded areas and the conservation of existing natural values. Taking into account these objectives, the adopted methodology was based on comprehensive geological, mining and environmental studies.

The first working phase consisted of the acquisition of geological, mining and environmental data for characterization and diagnostics. The geological and environmental studies were carried out at a 1:2.000 scale, as legally required for this type of land use planning maps. The geological studies comprised: i) thematic geological mapping oriented to ornamental limestones, ii) fracturing studies, iii) hydrogeological studies, and iv) diamond drilling.

The environmental studies consisted of: i) characterization and mapping of vegetation units, giving particular emphasis to the survey of flora species more relevant for conservation within the NPSAC, ii) identification of fauna species, iii) identification, characterization and mapping of biotopes and habitats, and iv) identification of geological heritage sites.

Natural value maps were produced for flora, fauna and habitats. They resulted from the valuation of criteria such as the occurrence of species and habitats listed in the birds and habitats directives. The relevance of each natural value in the produced maps was expressed on an ecological relevance scale, from Low to Exceptional.

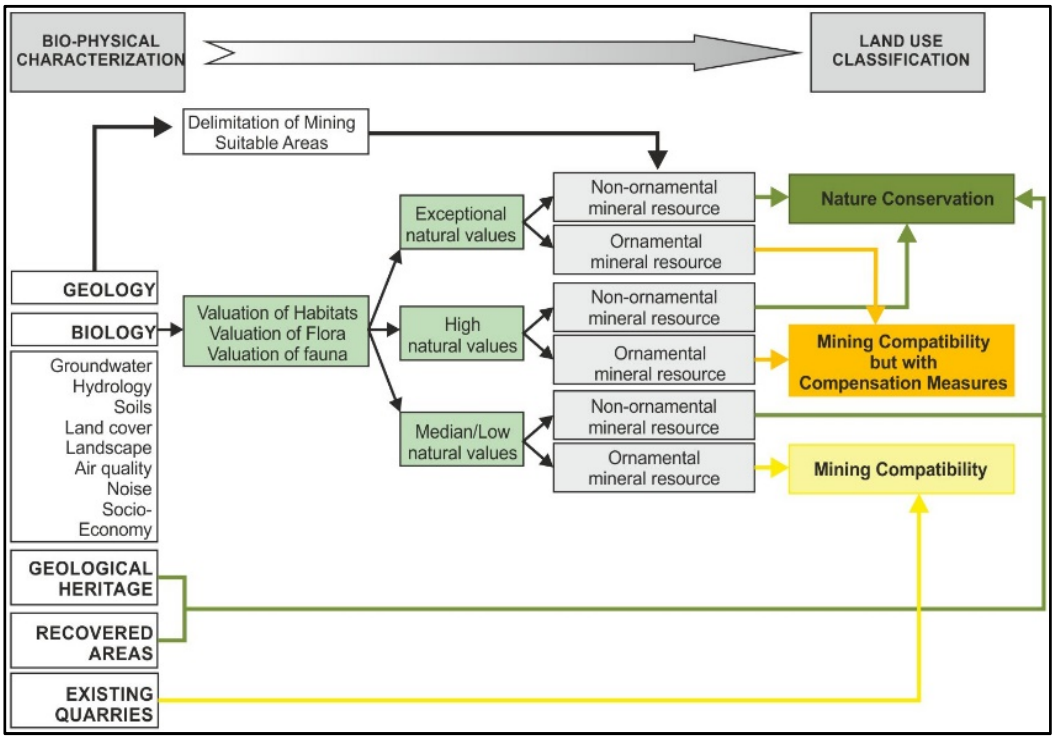


Fig. 2 Methodology for the compatibility between quarrying and nature conservation on land use planning.

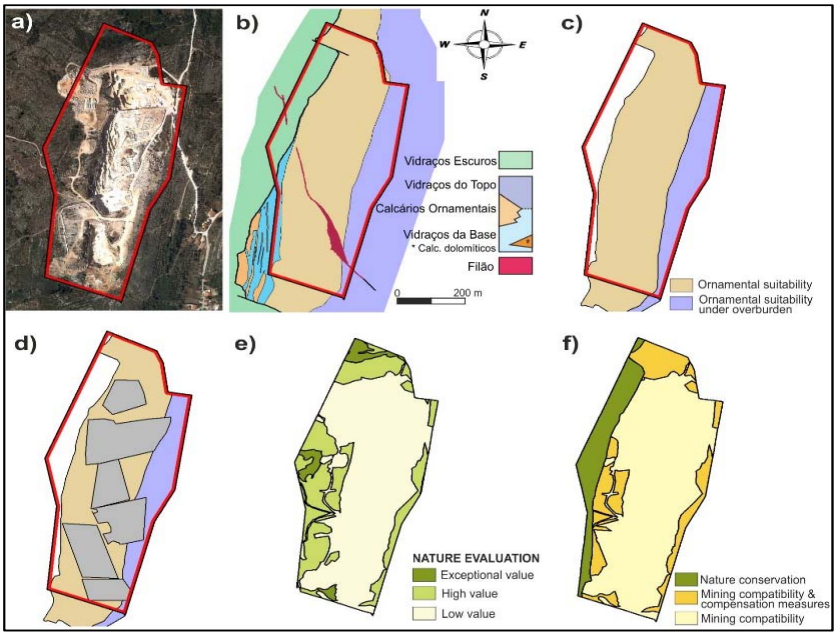


Fig. 3 Results from the geological and environmental studies carried out at the Cabeça Veada site: a) aerial view of the quarrying site; b) geological thematic mapping; c) delimitation of the suitable areas for limestone quarrying; d) existing licensed quarries; e) GIS integration of the natural values evaluation process; and f) land use spatial planning proposal for the Cabeça Veada site.

The second working phase was directed to the integration of all spatial data, making use of GIS support. The main focus was the coexistence of limestones suitable for ornamental purposes and other natural assets previously valued by means of qualitative and/or quantitative criteria, as presented in Fig.2. The main intermediate results achieved through this methodology as well as the final land use planning proposal for the Cabeça Veada site are presented in Fig.3.

## Final remarks and conclusions

The planning map proposal yielded for the Cabeça Veada area is just one step of the whole process of including its mineral resources in the formal municipal land use planning. Nevertheless, it is extremely relevant as a scientifically based support for the political decision. It represents also a turning point in the relationship between mining industry stakeholders and environmental protection authorities after more than 20 years of land use conflicts. Working in a collaborative way, it was possible to accomplish a balance between nature conservation policies and the mining industry. Furthermore, it demonstrates how crucial geological knowledge is for the suitable practice of land use planning, achieving supporting solutions that prevent the sterilisation of mineral resources, thus contributing to the sustainable supply of mineral raw materials to Europe from domestic sources.

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## About the authors

Jorge Manuel Ferreira de Carvalho, PhD Geol.
Laboratório Nacional de Energia e Geologia, IP.Estrada da Portela, Bairro do Zambujal, Apartado 7586 – Alfragide, 2610-999 AMADORA, Portugal. Jorge.carvalho@lneg.pt.

João Meira, MScGeol.
Visa Consultores, SA., Rua Alto da Terrugem 2, 2770-012 Paço de Arcos, Portugal. jmeira@visaconsultores.com

Célia Marques, Eng.Environm.
ASSIMAGRA - Assoc. Portug. dos Industriais de Mármores, Granitos e Ramos Afins. Rua Aristides de Sousa Mendes, 3-B, 1600-412 Lisboa, Portugal. cmarques@assimagra.pt

Susana Machado, MSc. Geol.
Laboratório Nacional de Energia e Geologia, IP.Estrada da Portela, Bairro do Zambujal, Apartado 7586 – Alfragide, 2610-999 AMADORA, Portuga. Susana.machado@lneg.pt

Lia Morais Mergulhão, Eng. Geol.
Instituto da Conservação da Natureza e das Florestas. Avenida Barão Almeida dos Santos, n.º 10/12, 2710-525 SINTRA, Portugal. Lia.mergulhao@icnf.pt

Jorge Manuel Frazão Cancela, PhD.Arq.
Biodesign - Arquitetura Paisagista, Planeamento e Consultadoria Ambiental, Lda. Rua de Timor n.º12, 1.º, 1170-372 LISBOA, Portugal. Cancela.jorge@biodesign.pt

GLOBALSTONE CONGRESS2018
ILHEUS (BAHIA) BRAZIL
April 26-29, 2018
CONNECTING MINDS IN THE WORLD OF STONE

# StonePT – Certification trust and quality excellence of Portuguese dimension stones

**Luís Lopes; Célia Marques; Miguel Goulão, Marta Peres, Nelson Cristo**

**Synopsis**

The main objective of the StonePT – Portuguese Stone Brand, is to certify the Natural Stone product, so that StonePT companies can technically communicate their products, with customers and prescribers, being easily identified through its BRAND, its Identity – StonePT.

The StonePT brand is supported by a certification system, aiming at the international recognition of Portuguese natural stone construction products, not only for its physical and mechanical characteristics, but also for the Portuguese transformer knowledge. This certification system, based on technical specifications and harmonized European standards for construction products using natural stone, aims at fulfilling a market gap with regard to guarantee of origin and quality assurance associated with the processing and , not least, the suitability of using each type of stone for different applications.

The advantages of using STONEPT brand by the companies could be listed as follows: a) Increases customer acceptance of products; b) Makes the difference compared to competitors; c) Increases competitiveness by reducing the costs of non-quality; d) Reinforces the image of the company; e) Facilitates access to new markets and, f) Allows to demonstrate compliance with regulatory requirements.

**Keywords**

StonePT, stone certification, stone market, Portuguese Dimension Stones.

## Rationale for the creation of the StonePT brand

Natural stone, which can be used as ornamental rock, is an abundant geological feature in Portugal, although there is no complete knowledge of the potential and effectiveness of each type of stone explored. In order to fill this gap, a certification system was developed, aiming at the international recognition of Portuguese natural stone construction products, not only for their physical and mechanical characteristics, but also for the ancient Portuguese transformer know-how. This certification system, based on technical specifications and harmonized European standards for construction products using natural stone, is intended to fulfill a market gap with regard to guarantee of origin and quality assurance associated with processing and , not least, a suitability of use that each type of stone for different applications. All this process, based on an image of quality and trust, is been disseminated all over the World as the StonePT Brand.

## StonePT certification process

The StonePT Brand certification process, is based on qualification projects for Portuguese dimension stones companies, supported by COMPETE2020/PORTUGAL2020 program, and is conducted through four essential steps: i) implementation; (ii) evaluation; iii) management and, iv) certification. After the implementation of the specific StonePT requirements, companies undergo an evaluation process, which will lead to product

certification. After that, the company will have to maintain and manage the implemented process control mechanisms.

The certificate is voluntarily requested by companies that must demonstrate to accomplish the requirements based in the following scope:

- Guarantee of origin for Portuguese stone products
- Product Quality requirements
- Quality assurance associated to the transformation processes
- Service Quality
- Time of Delivery;
- Complaint management
- Stones adequacy of use
- Stone material traceability

## Certifications

Product certification is an instrument for producers to demonstrate, in an impartial and credible manner, the quality, reliability and performance of their products at three levels:

**Certified** – The StonePT mark of certification (Fig. 1) intends to fulfil an existent void in natural stone market in what concerns the extraction locations and quality assurance associated to the transformation processes and, not less important, to the adequacy of use that each type of stone has for different applications, particularly those employed in the construction sector.


Fig. 1 StonePT Certified stamp.

The companies certified with StonePT demonstrate to accomplish the requirements based in three main pillars: origin of stone, skills to transform and control the final product, and knowledge related to the adequacy of use for each type of stone in each application (requirements for the end-user).

**Verified** – The environmental protection is a concern of any organization. The political discussions surrounding the subject and the consecutive increase in legislation imply a selection of suppliers that must have environmental awareness.

The StonePT Verified certification (Fig. 2) is the evidence concerning the social responsibility of the company in respect to general environmental concerns, from residues, water effluents to the impact of improving measurements in the surrounding environment.

This environmental certification is completely addressed towards the extractive and transformation industry dealing with natural stone.


Fig. 2 StonePT Verified stamp.

The StonePT Verified mark is granted to the companies that fulfil a system that commits with environmental requirements, properly adjusted to the activity leading to the transaction of Portuguese natural stone products showing also StonePT certification.

**DOC** – It is the CONTROL OF ORIGIN of Natural Stone (Fig. 3). It is assigned through the classification defined for each type of stone (the original raw material) that will be equivalent/tracked to those established through national or international institutions at the nomenclature level, and is granted to the quarry upon proof by the producer of the place of extraction, in particular at the level of geographical location and petrographic characterization. It has the advantage of accompanying the product, allowing manufacturing companies to acquire raw block while maintaining this distinctive Brand.


Fig. 2. StonePT DOC stamp.

## Advantages of using STONEPT brand by the companies

**StonePT** consists of a signature that distinguishes the Portuguese Stone from all products of the competition, using independent and credible stamps and certificates – internationally – for the recognition of Portuguese Stone as a contemporary quality product while:

1. Increases customer acceptance of products;
2. Makes the difference compared to competitors;
3. Increases competitiveness by reducing the costs of non-quality;
4. Reinforces the image of the company;
5. Facilitates access to new markets;
6. Allows to demonstrate compliance with regulatory requirements.

## Achievements (until now…) and concluding remarks

In the first phase of the project 20 pilot companies covering 52 stones were enrolled in the certification process. 18 quarries were certified with the DOC Stone PT subsystem; and the Stone PT Verified (Environmental Stamp) was only assigned to 6 companies, which demonstrated compliance with the environmental requirements set out in the environmental product verification specifications. There's an up to date free to use directory were the Stone PT companies are listed in the following address: http://stone-pt.com/en/documents/

What does it mean to be **Stone PT**? It represents a National value. Or better still, it represents national values. This is why we have captured the Portuguese soul to show what it means to be the hallmark of the Portuguese ornamental stone. The Portuguese Stone Brand presents itself with an international communication strategy, inspired by Portugal. Allusive to the slogan "We offer the Best (from Portugal to the World)", which is a declaration of Portuguese singularity, values and Portuguese raw material. Fado, football, sea and wine, ambassadors of the Portuguese name on the planet, meet the most varied types of national ornamental stones for a true celebration of what is Portuguese and are use together in outdoors publicity panels to promote Portuguese Stones.

Taking the old memories written in stone we can stated that "If you want to do something to last long, just do it in stone!"

## Acknowledgments

This study was co-financed by the European Union through the European Regional Development Fund, included in the COMPETE 2020 (Operational Program Competitiveness and Internationalization) through the ICT project (UID/GEO/04683/2013) with reference POCI-01-0145-FEDER-007690 and the European Union through the System for Supporting Collective Actions (Internationalization), which is part of PORTUGAL 2020 through the projects "Internationalization of the Portuguese Stone Mark - 2nd Edition" with reference POCI-02-0752-FEDER- 014739 and "Project StonePT" of the Business Incentive System (Qualification) with a reference POCI-02-0853-FEDER-000045.

## About the authors

Luís Lopes, Prof.

Universidade de Évora, Escola de Ciências e Tecnologia, Departamento de Geociências. Colégio Luís António Verney, Rua Romão Ramalho 59, 7000-671 Évora. E-mail: lopes@uevora.pt; ICT (Instituto de Ciências da Terra, Portugal; Earth Sciences Institute, FCT) and Associação Cluster Portugal Mineral Resources

Célia Marques, Eng.

ASSIMAGRA – Associação Portuguesa dos Industriais dos Mármores, Granitos e Ramos Afins. Rua Aristides de Sousa Mendes, 3b 1600-412 Lisboa. E-mail: cmarques@assimagra.pt

Miguel Goulão, Dr.

ASSIMAGRA – Associação Portuguesa dos Industriais dos Mármores, Granitos e Ramos Afins. Rua Aristides de Sousa Mendes, 3b 1600-412 Lisboa. E-mail: mgoulao@assimagra.pt; ACPMR – Associação Cluster Portugal Mineral Resources

Marta Peres, Dr.

ACPMR – Associação Cluster Portugal Mineral Resources. Praça Luís de Camões, nº 38, 7100-512 Estremoz, Portugal. E-mail: marta.peres@clustermineralresources.pt

Nelson Cristo, Eng.

ASSIMAGRA – Associação Portuguesa dos Industriais dos Mármores, Granitos e Ramos Afins. Rua Aristides de Sousa Mendes, 3b 1600-412 Lisboa. E-mail: ncristo@clustermineralresources.pt

GLOBALSTONE CONGRESS2018
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# Lithological and commercial diversity of the natural stones of the State of Espírito Santo

**Hieres Vettorazzi da Silva; Nuria Fernández Castro**

**Synopsis**

The State of Espírito Santo is the main producer of Natural Stones in Brazil. More than a half of the Brazilian quarries production comes from this state, with some marble and large reserves of igneous and variable metamorphic rocks. The complexity and unique geotectonic evolution of this region have provided migmatites, gneisses, granites, norites, monzosyenites, deformed granitoids and high-grade marbles. The lithological assemblages exhibit different mineralogical composition and structural-textural behaviour depending on the genetic characteristics according to the evolutionary geotectonic stage. Four production poles are identified in the state of Espírito Santo. Two of them in the northwest where yellow, white and green granites from Carlos Chagas, Ataléia, and Aimorés Suites, and other late-collisional leucogranites are extracted. In the central region green charnockites and black norites from Aimorés and Espírito Santo Suites, respectively, are quarried and, in the South, migmatitic gneisses and marbles from the crystal basement and also tonalitic-monzogranitic granitoids of the pre-collisional stage and post-collisional zoned igneous plutons, give grey monzogranites, diorite-gabbros and brown monzonite-syenite rocks.

**Keywords**

Espírito Santo State, Natural Stone, Geotectonic, Lithological assemblage.

## Introduction

The State of Espírito Santo is known worldwide for the great production of granites and marbles. However, granites and marbles aren't the only ones making up the lithological framework of the state. Due to the peculiar tectonic evolution of the region, several lithologies are recorded. High-grade metamorphic rocks predominate in spatial distribution and natural stones production. Igneous rocks like monzogranites, charnockites, norites, gabbros, syenites, and monzonites have, also, a significant spatial and natural stones production distribution. In the state of Espírito Santo, the production of natural stones is concentrated in four main poles. In the northwest area of the state, there is one pole where are quarried yellowish and white granitoids from the Carlos Chagas and Ataléia Suites and another pole with gabbros, syenites, and charnockites from the Aimorés Suite with black, brown and green colours. Other late-collisional leucogranites are exploited too in this area (Silva & Castro, 2012).

In the central area of the state, green charnockites of the Aimorés Suite, black norites of the Espírito Santo Suite and migmatitic gneisses of the Nova Venécia Complex are the dominant natural stones produced. The third pole and the main natural stones' production centre of the country is located in the South, around the municipality of Cachoeiro de Itapemirim. With many quarries and processing industries, which started with the marbles from the Itaóca Ridge in the middle of the 20$^{th}$ Century, has today a quite diversified stones production, processing stones from all around the country. Yet, in this area, are also quarried high-grade marbles of the Itaóca Ridge, from the Italva Complex, monzogranites and gabbros of the Santa Angélica Suite, black diorites from Juiz de Fora and kingizites from São Fidelix Complex (Silva & Castro, *op. cit*.).

## Regional Geology

The administrative boundaries of the state of Espírito Santo are fully inserted in the northern part of the Mantiqueira Structural Province (Almeida, 1977 *apud* Pedrosa-Soares, 2007). More precisely, within a lithodemic unit called the Araçuaí Orogen (Pedrosa- Soares *et al*. 20015) from Neoproterozoic age with Northeast-North-Northwest structural vergence and limited to the West and North by the São Francisco Craton.

The tectonic subdivision of the region is very complex. In the literature, two models are shown with different interpretations. The first, proposed by several authors (Uhlein, 1991; Pedrosa-Soares & Weidmann-Leonardos, 2000; Heilbron *et al.* 2004 *apud* CPRM, 2015), defines three zones with distinct ambience, being the deformed covers of the Craton, representative of foreland area basin. The outer zone would be characterized by thrusts and folds towards the craton and marked by low-grade metamorphic paragenesis, whilst the inner zone stands out by the occurrence of high-grade metamorphic rocks and intense generation of granitic magmas with different compositions.

The second proposed model (Alckmin, 2006) presents a subdivision in structural domains, based on the regional kinematic analysis. Among these structural domains, the zones of high metamorphic degree, representative of the orogenic nucleus, are coincident with the geographic territory of the state of Espírito Santo. It can be divided into two subdomains: one in the north of the state, which would be represented by rocks of the middle crust, while the other, in the southern part, is represented by rocks that reached depths of the infra-crust, showing gneiss and mylonitic fabrics.

In the second subdomain, in the south and central parts of the state of Espírito Santo, it is common that the outcrops present kinematics related to shear with thrusting faults and folding phases during the main deformation period, with west vergence and presence of late dextral transcurrent to thrusting faults in the syn-collisional period. Already in the northern subdomain, coincident with north portion of Espírito Santo State, extreme northeast of Minas Gerais and extreme south of Bahia, there are minor transcurrent faults, predominating thrusts of medium to low angle, with main vergence in the western portion to the west with the Craton as a shield, while the eastern portion has east vergence, towards the Congo Craton. This change of tectonic vergence occurs north of the parallel 20 ° S, near the capital Vitória.

### Evolutionary model

Alkmin and others (2003), based on these kinematic interpretations, and inspired by the tectonic scenario that resulted in the formation of Western Gondwana, proposed a genetic model of the Araçuaí Orogen still unknown in the literature, where the subduction of an oceanic crust restricted by a cratonic bridge is induced by distant collisions, similar to the mechanism of a *"Nutcracker".*

Briefly, four evolutionary stages are defined for the Orogen. The first, when the opening of the Macaúbas Basin occurred, is indicated by the ophiolitic remains with isochronic ages by Sm-Nd dating of 816 +/- 21 Ma (Pedrosa-Soares *et al.* 1998, 2001; Suita *et al.* 2004; Queiroga *et al.* 2006 *apud* CPRM, 2015). The second happened between 630 Ma and 580 Ma and is highlighted by the processes of subduction and formation of the magmatic arc, culminated with the convergent interaction of the paleo-plates of São Francisco, Congo, Amazonas,

Paraná-Paranápanema-Rio de la Plata, and Kalahari, forming the supercontinent Western Gondwana. The third stage was syn-collisional, with intense deformation, regional metamorphism and intensive generation of anatectic magmas. The fourth stage was initially marked by intense kinematic tangential motion to the South, towards the Ribeira Orogen. In the end, the gravitational collapse of the Orogen occurred, particularly in the central portion, with the formation of normal shear zones and intense generation of plutonic bodies in three different stages (CPRM, 2015).

With the stabilization of the South American shield in the Paleozoic and the construction of a continental platform free of large deformations, a magmatism in Paleocene (last 56 Ma), associated with Abrolhos Vulcanism in the state of Bahia still happened and it can be seen in the state of Espirito Santo as small rhyolitic spills and diabase dikes that structurally cut older rocks along the entire length of the Araçuaí Orogen (Salino, 2013).

### Geological units

All geological units and commercial lithotypes presented in this paper are subdivided by (CPRM, 2015) into four main lithological domains, classified by age, genesis and tectonic environment.

• Bottom crust fragments: Paleoproterozoic rocks (2,3 Ga to 2,0 Ga), which are remnants of crustal roots, predominantly charnockites, diorites, and para-derived rocks, represented by the complexes of Caparaó, Serra do Valentim, Juiz de Fora, and Ipanema. One example is the dioritic gneiss *"Black Stype"* from the Juiz de Fora Complex.

• Neoproterozoic sedimentary basins (1,0 Ga to 0,6 Ga): basal portion of the orogen, representative rocks of the sedimentary fill of the Macaúbas Basin, a precursor to the beginning of the magmatic arc. The representative units are called Rio Doce Group, Nova Venécia Complex, Italva Group, Rio Negro Complex, São Fidélis Group, Jequitinhonha Kinzigito Complex, and Bom Jesus do Itabapoana Group. Generally, they are para-derived rocks, composed by quartzites, peraluminous gneisses, marbles, pyroclastic and volcano-sedimentary rocks. Kingizites from the São Fidelis Complex like *"Black Indian"* and *"Blue Fantasy"*, syenogranitic gneiss *"Blue Jaguar"* from Nova Venécia Complex and marble *"Cristalita"* from the Italva Group in Cachoeiro de Itapemirim are the most produced;

• Granite-genesis of Araçuaí Orogen (Neoproterozoic to Phanerozoic):

- Pre-collisional stage (630 Ma to 590 Ma), with the subduction of the oceanic crust and the beginning of the magmatic arc formation and acidic plutons generation, corresponding to the mesocratic type I granites, found in the south of the state. Representatives of this stage are leuco-mesocratic tonalitic-monzogranitic granitoids like *"Cinza Imperial"* and *"Cinza Andorinha"*.
- Sin-collisional to the late-collisional stage (590 Ma to 575 Ma), represented by softly or high deformed anatectic granites S-type. Representative of this stage are the rocks of the Ataléia and Carlos Chagas Suites, mostly located in the north of the State and commercialized as the renowned yellow and white granites: *"Giallo Ornamental"*, *"Giallo Veneziano"* and *"Yellow Santa Celícia"*;

and late-orogenic leucogranites with small grenades, as *"White Dallas"* and *"White Siena"* as intrusive apophysis on gneisses of Nova Venecia Complex;

- Post-collisional stage (575 Ma to 490 Ma) is composed by igneous rocks which represent the gravitational collapse of the mountain ridge, positioned in most cases, in regional transcurrent structures. Three stages of magmatism are recognized during this period. The first one represented by plutons of granitic to dioritic/noritic composition, who receive the designation of Espírito Santo Intrusive Suite and are represented by norites *"Black São Gabriel"* and *"Black Aracruz"*. The second magmatic stage is represented by the Santa Angélica Intrusive Suite, predominant in the southern region of the State and is composed by zoned batholith plutons with granitic edges and mafic cores, represented by *"Grey Corumbá"* and *"Black Santa Angélica"* and minor bodies with alkaline composition like the brown monzo-syenite *"Ocher"*. The third is characterized by the occurrence of rocky bodies of metaluminous composition, noritic, gabbroic and charno-enderbitic, denominated Aimorés Intrusive Suite, dominant from the central portion of the state of Espirito Santo to the border with state of Minas Gerais, where the city of Aimorés is and its bodies give rocks predominantly charnockitic like *"Green Butterfly"* and *"Green Labrador"*.

• Cenozoic Covers, represented by Espírito Santo Group haven't commercial interest and no lithotypes of this hedge are produced. Initially represented by the Abrolhos Formation (60 Ma), occurring in the oceanic platform cost. Novais *et al.* (2007 *apud* CPRM, 2015) describe the existence of ignimbrites and pyroclastic rocks with rhyolitic to dacitic compositions along São Mateus River in an aulacogen structure. That Formation is correlated by Ar-Ar dating methods with an igneous province called Abrolhos Volcanic Complex, associated to the continuity of the Vitória-Trindade chain and connected to many oceanic fault zones and which has an extension equivalent to a meso-oceanic chain.

The Rio Doce Formation (56 Ma to 34 ma) represents the sedimentation of the paleodelta of Rio Doce and is composed of sandstone, shale, and limestone. The Barreiras Group (23 Ma) in the state of Espírito Santo covers the crystalline basement. It is composed of white, yellow and reddish sandstones; fine and coarse-grained argillites with a ferruginous matrix. It occurs as coastal boards that form the cliffs.

• Surface covers (2,6 Ma to recent): At the end of the Pleistocene, the coastline extended 27 km east of the current line. From then on, the exposed surface of the Barreiras Group began to erode, favoured by a marine regression that aided in the excavation of deep valleys along the Doce, Barra Seca, and São Mateus Rivers and some of their tributaries. After a new transgressive cycle between 25,000 and 5,000 years ago, the coastline began to form one similar to the current one, where the valleys excavated by the regressive cycle begun to be filled by fluvial and marine sediments.

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## About the authors

Hieres Vettorazzi da Silva, Geologist

External Consultant at the Centre for Mineral Technology (CETEM)
Rodovia Cachoeiro x Alegre - km 5 - Morro Grande - 29.300-970 Cachoeiro de Itapemirim, Brazil.
Currículo Lattes | hvettorazzi@gmail.com | +55 28 999244059

Graduated in Geology at the Federal University of Espírito Santo (2014). He has experience in the following areas: petrography, mineral aggregates and sustainable development.

Nuria Fernandez Castro, Mining Engineer, MsC.

Technologist at the Centre for Mineral Technology (CETEM)
Av. Pedro Calmon, 900 – Cidade Universitária – 21941-908 Rio de Janeiro – RJ (Brasil)
Currículo Lattes | ncastro@cetem.gov.br | +55 21 38657336

Graduated in Mining Engineering at the Technical University of Madrid, Spain (1994), specialized in Geology by the Federal University of Ouro Preto (1995), specialized in Technology and Valuation of Dimension Stones by Federal University of Rio de Janeiro (2006) and Master of Science in Geology by the Federal University of Rio de Janeiro (2009). Technologist at the Centre for Mineral Technology (CETEM/MCTIC) being Head of the Regional Unit of Espírito Santo, in Cachoeiro do Itapemirim, the CETEM's branch for natural stones research and development, from 2009 to 2018. Has experience in the following areas: dimension stones, local production clusters (APLs), mining (quarrying), sustainable development and scientific dissemination.

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# Technological characterization of granites from Espírito Santo – a dimension stones pole in Brazil.

**Leonardo Monjardim Amarante, Paulo Arcângelo, Flávio Faucão, Bruno Lempe Veiga, Filipe dos Santos Machado, José Ignácio Zambrano Giraldo**

**Synopsis**

The state of Espírito Santo is the main producer of ornamental stones in Brazil, in addition to the volume extracted and processed; there is a huge variety of materials available in the market. The present article compares 130 types of granites identified in technical publications, demonstrating the physical-mechanical differences between them, in order to develop a chart, displaying the most distinct values (positives and negatives) for each characteristic assessed. The references for the classification were the requirements foreseen by the normalizing organs. Finally, it is suggested specific uses for the distinct types of ornamental stones studied, aiming to guide different projects.

**Keywords**

Granite, ornamental stones, physical-mechanical characterization, application.

## Introduction

Espírito Santo accounted for 75% of the physical volume and 81% of total revenues from Brazilian ornamental rocks exports, becoming the largest producer, processor and exporter in the country, with more than 90% of the investments in the sector's industrial park (ABIROCHAS, 2016). Reference entities have published guidelines for the application, use and maintenance of commercial rocks, as the Manual of Ornamental Stones and Atlas of Dimensions of the State of Espírito Santo.

The commercial value of ornamental stones is a direct consequence of their technical characteristics and aesthetics (color, texture and composition) or the market conditions and trends. The best technical, aesthetic and commercial value, are determinants criteria for the choice of the rock's application. Therefore, the knowledge of the physical-mechanical characteristics of the ornamental rocks can affect the price of the product, the options of use and the valuation of the material by the market requirements (MOURA, 2000).

According to Frascá (2001), cladding technology currently covers characterization and alteration technology tests, obtaining chemical, physical, mechanical and petrographic parameters that will guide the choice and use of these materials in civil construction.

## Materials and Methods

The granite-type ornamental stones are lithologically diverse and include several kinds of rocks. In Manual of Characterization, Application, Use and Maintenance of the Main Commercial Rocks of Espírito Santo and Atlas of the State of Espírito Santo are available the physic-mechanical characteristics of 130 lithotypes.

This research discusses correlations between lithotypes with distinct physical and mechanical characteristics, which influences positively and negatively in the applicability of technological production. The physical and mechanical properties' information has enabled

the improvement of the ornamental rocks' application and maintenance in different environments. Figure 1 shows the methodological flow used to carry out this study.

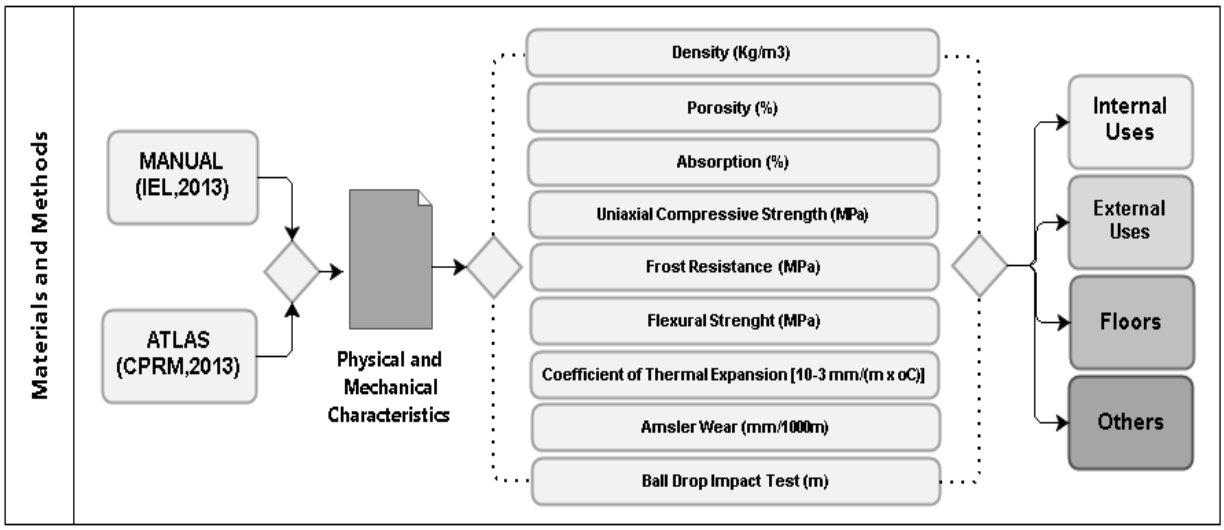


Fig.1 Methodological flow.

## Results and Discussion

The results of the tests presented in the atlas and manual are within the limits proposed by regulatory agencies (ABNT – Brazil; ASTM - USA). For some characteristics, such as apparent density, water absorption and porosity, uniaxial compression, flexural resistance, linear thermal expansion coefficient and amsler wear, to support decisions on the best application of the type of stones.

American Society for Testing and Materials (ASTM), and European Committee for Standardization (ECS) provide specific parameters, revised and updated in Brazilian Association of Technical Standards (ABNT) through the NBR 15844: 2010 standard. The review verifies 130 types of granite, identifying the three highest and lowest ranked values, in addition to standardization, as the research subjects.

### Density (Kg/m3)

The Black Diamond, Black White Eagle and Black Aracruz rocks present higher bulk density [Figure 2], while the Giallita, Gold Sun and Golden Fantasy granites had the lowest values, as the results indicate. All the rocks analyzed had an apparent density higher than the specified by the ASTM C-615 (≥ 2560 kg / m3), or by ABNT NBR 15844 (> 2550 kg / m3) [Figure 2] for silica rocks, showing that they fit the established standards.

According to Kalix (2011), mineralogical composition, the existence of microcracks, contact relations between the mineral grains, granulation, structural aspects, among others, must be observed, since they influence the porosity, density and absorption of 'rock water directly, being extremely important elements in the evaluation of durability and mechanical resistance over time.

### Porosity and Water Absorption (%)

The granites Sucuri Brown and Golden Fantasy showed porosity [Figure 3] and absorption [Figure 4] values greater than the one suggested by Brazilian Association of Technical Standards in NBR 15844, standing out positively among the other lithotypes in this feature. The black granites, followed by the green granites, obtained lower values of porosity than the others, indicating the absence of intercommunicating pores; therefore, the lower the water absorption of the rock, the greater is the probability of high mechanical strength. The yellow granites presented the highest porosity and water absorption values, indicating the need of waterproofing of the stone tiles when applying in humid environments. The density suggest low porosity and absorption values, and high compressive strength. The less emptiness, the denser the rock, and therefore less likely it is to absorb water.

### Uniaxial Compressive Strength (MPa)

The Himalaya White, Bressan Gray and Black Diamond granites present considerable resistance to uniaxial compression [Figure 6]. Therefore, these lithotypes are recommended in situations of compressive stresses (internal and external coatings, floors and walls, dry or wet areas). Although high values of compressive strength indicate denser rocks with lower porosity and water absorption, their mineralogical composition and texture should be considered when deciding their application, mainly in external and humid areas. Yellow granites, (Yellow Atacama, San Francisco Cristal and Santa Cecilia Gold) showed compressive strength below than NBR 15844 standard; thus, it should be used with restrictions, especially in wet areas such as bathrooms, kitchens, lavatories and outdoor areas.

### Coefficient of Thermal Expansion ($10^{-3}$ mm/°C)

Given that the rocks expand and compress when exposed to substantial temperature changes, it is important to characterize the stone performance in this parameter (coefficient of linear thermal expansion [Figure 7]), as it will define the spacing that should be used during the laying procedures. According to NBR 15844, the maximum value of thermal expansion coefficient, for ornamental granites, is 8.0 x $10^{-3}$ mm/°C.

It can be noticed that the studied lithotypes presented expansion values similar to the maximum considered. The Yellow Cachoeiro, Black Aracruz and Black Santa Angélica granites have the highest values of expansion coefficients. On the other hand, the Ocre Itabira, White Primate and Yellow Gold Brazil granites present the lowest values.

### Flexural Strength (MPa)

The flexural strengths of the black granites (Black Diamond, Absolute Black, and Black Santa Angélica) varied between 21.68 MPa and 33.50 MPa [Figure 8], while the yellow granites (Giallita, Yellow River, Soft Yellow) were between 5.95 MPa and 6.00 MPa. Comparing to the NBR 15844 and ASTM C615 ranges, the black granites are resistant and the yellow granites presents unsatisfactory results. Therefore, black granites are indicated for external coatings use, applied with metallic "inserts" constituting ventilated or aerated facades.

As the studied yellow granites, the Cachoeiro, Veneziano and Ornamental yellow granites [not in the chart] revealed to be satisfactory as far as the resistance to the flexion [Figure 8]. However, due to its coloration, indicative of its minerals transformation processes, it should only be applied in indoor environments, where there is no excessive humidity, avoiding further deterioration. Yellow River, Giallita and Soft Yellow granites have low flexural strength, therefore contraindicated in aerated and ventilated facades and wet areas, and indicated for indoor flooring. Figures 2 to 9 show the results that stood out positively and negatively when compared to established norms.

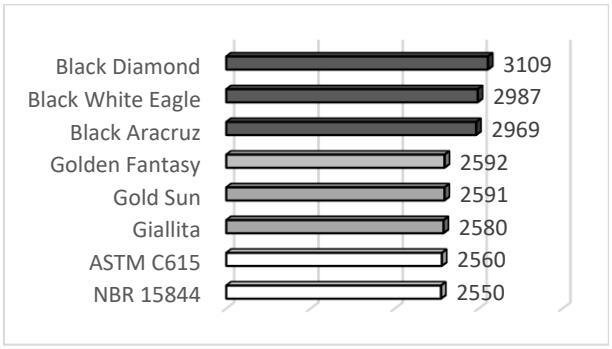


Fig. 2 Densities (MPa).

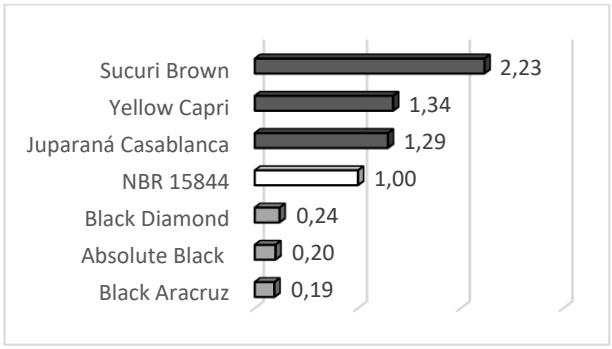


Fig. 3 Porosity (%).

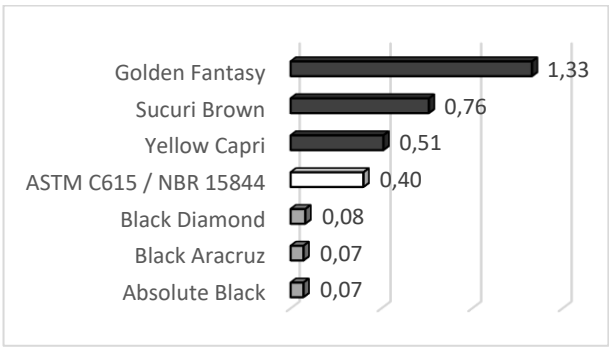


Fig. 4 Absorption (%).

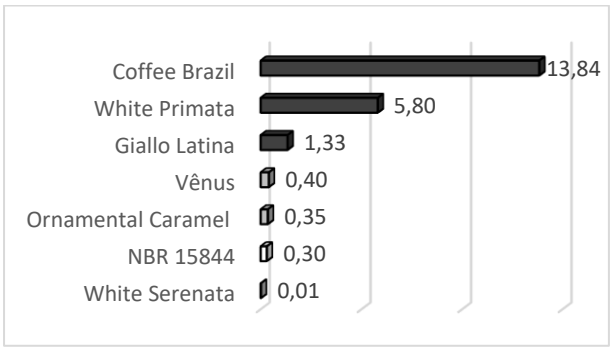


Fig.5 Drop ball test (m).

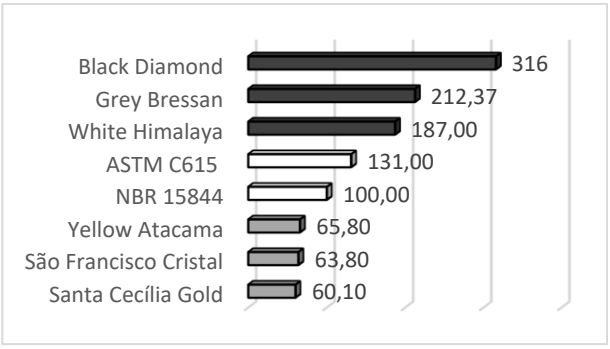


Fig. 6 Uniaxial compressive strenght (MPa).

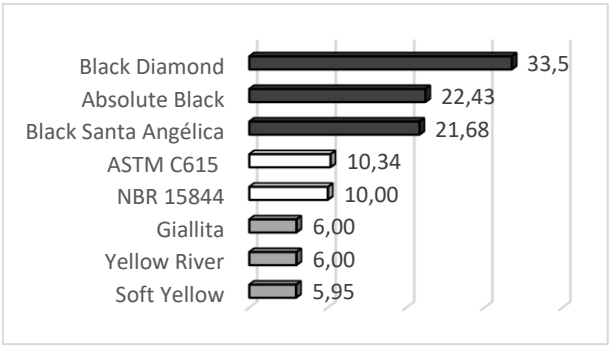


Fig. 8 Flexural strengths resistence (MPa).

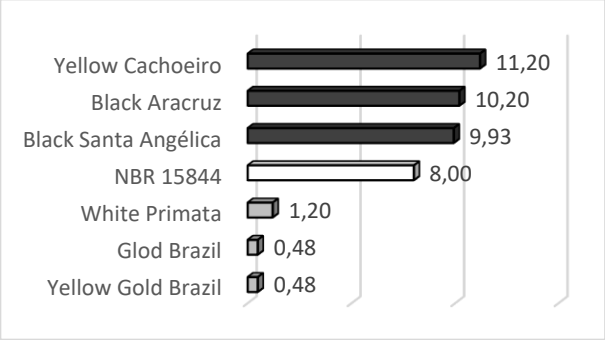


Fig. 7 Thermal Expansion ($10^{-3}$ mm/°C).

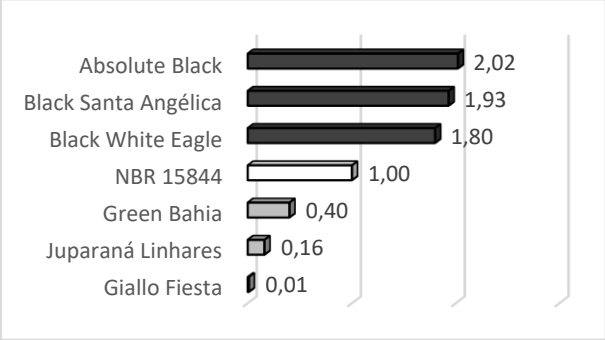


Fig. 9 Amsler wear (mm/1000m).

Normalized values. Minimum values. Maximum values

### Amsler Wear (mm/1000m)

The results for the Amsler wear of the studied lithotypes are described [Figure 9], compared only with the NBR 15844 specification, since ASTM C615 does not specify this limit. The abrasion resistance of the black granites was above the NBR value, which indicates the use for environments with intense trampling. The resistance to abrasive wear of some materials can be explained by the high quartz concentration. In relation to the other granites, the abrasive wear of Green Bahia, Juparaná Linhares and Giallo Fiesta, were below 1.00 mm. Consequently, the latter should be avoided in places where there are intense and aggressive traffic.

### Impact Resistance (m)

All granites presented satisfactory values, except White Serenata [Figure 5], for impact resistance parameter. Coffee Brazil granite presented the highest resistance to hard body impact; and can be used without restrictions to cover places where there are impacts.

## Conclusions

There is a great variety of possibilities for the application of the granites of Espírito Santo, it is up to the designer, architect or engineer to select with suitable criteria the best option to assist the needs of the project. Despite the presentation of the data, the references do not fit the standards established internationally. Except for the density, the studied granites have rates and coefficients above and below the normalized values, requiring well-established selection criteria.

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## About the author(s)

Leonardo Monjardim Amarante, master's degree in Engineering and Sustainable Development in progress.

Federal University of Espírito Santo, Vitória/ES, Brazil. leonardo@monjardim.com

Bruno Veiga, bachelor of Business Administration.

TAFE Queensland Brisbane, South Brisbane, Australia. brunolv@gmail.com

Paulo Arcângelo; Flavio de Souza Gomes Faucao; Filipe dos Santos Machado; José Ignácio Zambrano Giraldo; graduating in Civil Engineering.

Pitágoras College, Guarapari/ES, Brazil. paulo.menezes@pitagoras.com.br

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# Comparison between cutting technologies for ornamental stones: diamond wire and water jet

**Rita de Cássia Pedrosa Santos, Victor Hugo Ataíde Borges, Walter Albergaria Junior, Flávio Augusto Santos e Sousa**

**Synopsis**

The search of ornamental rocks cutting technology to meet the market and efficiently together economic, environmental and safety parameters is increasingly requested in the mineral realm. This study tried to compare two cutting technologies with respect to their technical-operational aspects: diamond wire and water jet. The methodology used consists of a bibliographical research raising data of both technologies and organizing them in graphs and tables for the best comparison. The diamond wire offers significant economic advantages over water jet, which limits the use thereof. Regarding the environmental aspects, the two techniques proved to be equivalent, with optimum performance in this parameter. The water jet has advantage in safety factor in relation to the diamond wire, due to its ability to cut by computerized system.

**Keywords**

Diamond wire, water jet, ornamental stone, granite.

## Introduction

The extraction technologies, also called cutting technologies, understand the procedures for release of large volumes of outcropping rocks. This method is used in primary, secondary and squaring blocks, usually through combined techniques. The definition of the cutting methodology should take into account environmental factors, collaborating on environmental protection and rational use of mineral resources. Operational cutting alternatives have been offered by the sector in order to reach the level of productivity and clean production required by the public (NOBRE, 2017).

### Diamond wire

According to Costa (2009), the basic principle of cutting with diamond wire is to pull a handle of diamond wire, entwined in the rock by two coplanar and perpendicular holes, which intersect at the ends. The wire is inserted into such holes with the aid of a nylon wire carried by compressed air and then the two ends are mended, forming a closed circuit, and then wire is supported on a drive pulley of the cutting equipment.

The technique is now widespread throughout the world, and continues to be development and improvement object. The advances made in this technique have provided higher cutting speed, the best result in the cut interface and an optimization of the own diamond wire constituent components (REGADAS, 2006).

### Water-jet

Water jet is a process that uses a jet of high pressure water to cut the rock. A device called a monitor forms the jet and controls its direction. The water jet has output speeds of 300 to 500 m/s and pressure variable between 150 and 300 MPa. It may work with pure or

mixed water with abrasive (CHIODI, 1995). Normally the distance between the jet nozzle and the rock is 2 - 3 cm (BORTOLUSSI et al., 1996).

The cutting system of this technology consists of a set of hydraulic pumps and a high pressure feed motor, a rod that supports the injector nozzle, as well as a support and handling structure. The support structure also serves as a guide for the rod, exerting control of the movements to be executed, to generate continuous and repetitive movements, since successive passes of the equipment generate the cut (ALENCAR et al., 1996).

## Justification

Raising the technological level of the production chain is not only about achieving higher profits, but also offering the market a product in accordance with international standards, reducing the environmental damage associated with mining practices and reducing the waste of raw material in the mining. Therefore, cutting technologies that are more accurate and faster are increasingly requested (NOBRE, 2017). The comparison between search in cutting technology that offers the best performance in cutting processes of ornamental increasingly becomes necessary to meet the market demands and environmental.

## Methodology

He referred to various literature as a form of literature, including articles, papers, dissertations and ornamental stone sector organizations to collect data on the various cutting technologies, allowing further comparison between the methods in the form of graphs and tables, facilitating the comparative examination. The works consulted were obtained through electronic media, public and particular libraries and conference proceedings.

## Results and discussions

According to the studied literatures, the main operating parameters relevant in assessing the choice of cutting technology have been synthesized in Tab. 1.

Table 1 Comparison of operational parameters of the diamond wire and water jet.

| TECHNOLOGY | COMPARISON OF OPERATIONAL PARAMETERS | | | | | | |
|---|---|---|---|---|---|---|---|
| | Investment cost | Operating costs/m² | Production rate | Flexibility of operation | Waste generation | Noise level | Safety factor |
| Diamond wire | 3 | 4 | 4 | 4 | 4 | 4 | 3 |
| Water jet | 2 | 2 | 2 | 4 | 4 | 4 | 4 |

Legend: relative performance (4-Great, 3-Good, 2-Bad, 1-Limit). Note: Adapted from Nobre, 2017, Vidal et al., 2013, Wilson et al., 1997.

Analyzing the presented data, observes that the diamond wire has excellent performance as regards operating costs and production rate while the water jet has poor performance. Costs related to investment and maintenance of equipment to obtaining the necessary pressures for cutting make the water jet process expensive, limiting their use.

The diamond wire or equivalent has advantages in relation to the water jet in all parameters except the safety factor. The diamond technique, when in operation, performs the rotational movement without any protection for workers, providing greater scratch the accidents when compared to the water jet technique. In this technique, the adoption of computerized equipment without the need for operators to perform the cutting process, guarantees greater advantage as regards the safety factor.

Regarding environmental parameters, both technologies showed great performance as waste generation and noise level. Both of them can be favor the application of the methods in the face of increasingly stringent legislation on the environmental impacts is generated by the mining ventures.

Fig. 1 is some technical and operational parameters of the studied technologies.

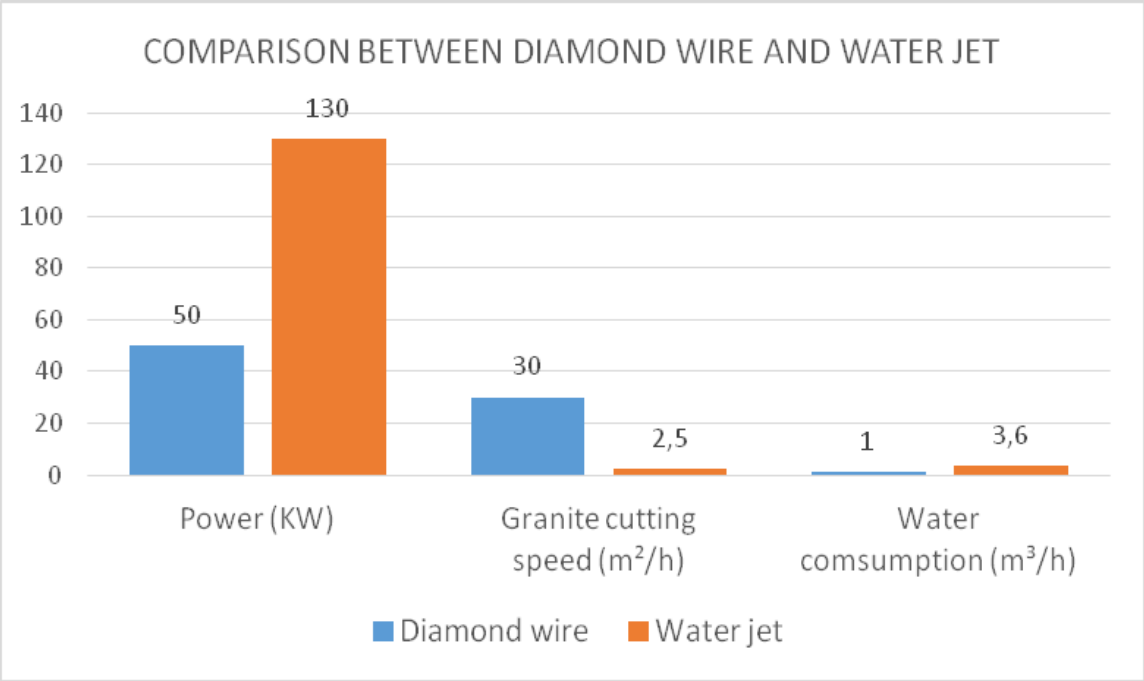


Fig.1 Graph comparing technical and operational parameters of diamond wire and water jet in granite cuttings. Note: adapted from Alencar et. al. 1996 and Vidal et al. 2013.

To construct the graph in Fig. 1, was admitted to the upper limit found in the literature, considering therefore the highest value obtained. The diamond wire is outstanding in all observed parameters, obtaining better efficiency energy, higher cutting speed and lower water consumption. In contrast to water jet technology, the diamond wire has a 62% less installed power, which promotes greater energy savings in its use. The productivity of the diamond wire is significantly higher, with a cutting speed twelve times higher than that achieved by water jet.

As for water consumption, the diamond wire is in advantage when compared to water jet, having a consumption of 72% less. Therefore, the diamond technique has less impact to the water resources of the enterprise, promoting a more sustainable environment as the use of water in the cutting process.

## Conclusions

Although both technologies analyzed present environmental benefits, the diamond wire is obtained highlight the economic point of view and as productivity. In addition, there are currently several options for diamond wire, allowing the choice of the most appropriate for each type of lithology, which also generates gains in performance and consequently lowering the cost of operation.

The advantage about the safety factor presented in water jet technology counts as only positive difference to the diamond wire which, despite its importance, does not pay its economic and operational disadvantage, limiting their use.

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## About the authors

Rita de Cássia Pedrosa Santos, Master in Mineral Economy – Mining Engineer

Federal University of Goias, Department of Mining Engineer, Av. Dr. Lamartine Pinto de Avelar, 1120, Setor Universitário, Catalão, 75704-020, Brazil. E-mail: rita.pedrosa@ufg.br.

Victor Hugo Ataíde Borges, Mining Engineer graduating

Federal University of Goias, Special Academic Unit of Engineering, R. Bélgica, 203, Loteamento Vila Chaud, Catalão, 75704-090, Brazil. victor.ataide@outlook.com.br.

Walter Albergaria Junior, B. Sc. Information Systems

Plural Treinamentos e Soluções, R. Domingos Rodrigues Borges, 735, Catalão, 75713-265, Brazil. Walter.albergaria@gmail.com

Flávio Augusto Santos e Sousa, Mining Engineer graduating

Federal University of Goias, Special Unit of Engineering, Av. Gérson Barbosa de Melo, 782, Santa Cruz, Catalão, 75706-600, Brazil. fl_augusto@yahoo.com.br.

GLOBALSTONE CONGRESS2018
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April 26-29, 2018
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# Insertion of silicon carbide as cutting element in ecological fickerts for dimension stone polishing

**Phillipe Fernandes de Almeida, Victor Moza Ponciano, Leonardo Luiz Lyrio da Silveira, Eduvaldo Paulo Sichieri**

**Synopsis**

The dimension stone polishing consists of eliminating the surface roughness of the slabs with the use of fickerts. The main tools used for this activity are composed of epoxy resin, derived from petroleum, which contains chemical elements with potential harmful to the environment and human health. To overcome this problem, it is necessary to develop new technologies with the lowest environmental impact in their life cycle, from the raw material acquisition, the use until the waste disposal. This study aims to contribute to the improvement of the ecological fickert, based on castor polyurethane resin, developed by the Centro de Tecnologia Mineral (CETEM). The fickerts presented here are composed of castor oil resin, silicon carbide and silica from rice hull ash. Two compositional formulas were used for the development of the pieces and they were submitted to an industrial polishing machine. The results showed that the formulas with higher percentage of extenders presented better performance, expressed by the relation between the loss of mass of the pieces and the gain of gloss on the surface of the slab. This fact allows to infer that this line of research presents great potential of applicability in the market of dimension stones.

**Keywords**

Polishing, Abrasive, SiC, RHA.

## Introduction

The dimension stone polishing consists of eliminating the roughness of the slabs that come from the sawing process through an abrasive process that occurs in the contact between the diamond tools and the surface to be polished. The wear is performed by fickerts arranged in descending order on the polishing heads, from the coarse grain to the finest one. These polishing heads perform the rotational movement and are applied under pressure on the slab surface, which gradually decrease the roughness and increase the brightness intensity on it. The main fickerts used for the polishing of dimension stones can be divided into two types: the magnesia bond fickert and diamond bond fickert. The magnesia bond fickert is composed of a sorel cement (magnesium chloride and magnesium oxide) and Silicon Carbide (SiC). The diamond bond fickert is composed of an epoxy or synthetic metal matrix and the diamond as abrasive element. Epoxy fickerts are the most used by the polishing industry, and although they are more technologically advanced, they are composed of non-renewable materials and contain bisphenol A and epichlorohydrin, substances that may present a potential harmful to human health (BESERRA et al., 2012). From this observation, some studies were developed to test the potential of a polyurethane resin based on castor oil as a matrix of fickerts for stone polishing, as it can be seen at Dorigo & Silveira (2016), Almeida et al. (2017), among others. The present study proposes the preparation of a fickert composed of the polyurethane castor oil resin, extenders and green silicon carbide (Green SiC) for experimental tests in an industrial polishing machine. The tool is presented as a sustainable alternative for the dimension stone polishing process once it is a non-toxic product from renewable resources.

## Objective

The objective of this study is to test the potential of a tool for the dimension stones polishing, which is consisted of a matrix composed of polyurethane castor resin, silicon carbide and rice hull ash, with the addition of green silicon carbide as cutting element. The research proposes to develop an ecological fickert that has a higher techinical eficience than the magnesia bond fickert and is cheaper than the diamond bond fickert, besides that, offer a sustainable alternative for the stone polishing process.

## Methodology

### Materials

The materials used to prepare the matrix of the fickerts were the bicomponent polyurethane resin composed of 1.2:1 ratio of polyol and prepolymer, respectively, and the silicon carbide (SiC) and the silica of the rice hull ash (RHA), both in grain size 1200 mesh. This matrix was used to formulate two sets of fickerts with different cutting elements. In the first set was incorporated the green SiC in the grain size 60 mesh and in the second the green SiC in the grain size 120 mesh. All the extenders used for making the fickerts are shown in Fig. 1A. The stone chosen for the polishing test was a porphyritic sienogranite composed by phenocrysts of potassium feldspar, quartz, biotite and little amount of plagioclase feldspar (Fig. 1B). A micro-tri-gloss glossmeter was utilized for the brightness measurements (Fig 1C).

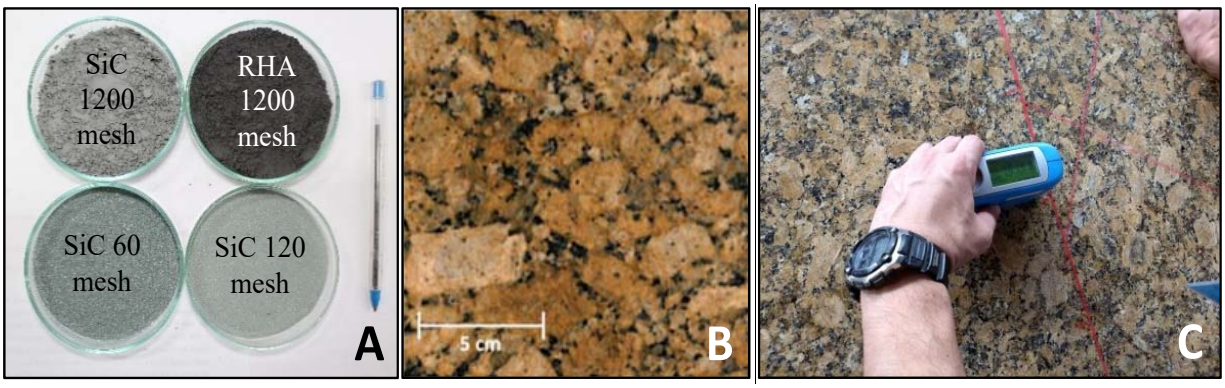


Fig. 1 Materials used: Compounds (A), stone sample (B) and glossmeter (C).

### Methods

First of all, two formulas (T1 and T2), presented in Table 1, were obtained from Taber Test assays generated in the study done by Dorigo and Silveira (2016). For the preparation of the samples, the resin components were first mixed for 2 minutes and subjected to a vacuum system for another 15 minutes to remove the $CO_2$ released during the polymerization reaction. After this step, the extenders of SiC and RHA and the abrasive element green SiC, previously submitted to oven drying, were homogenized with the resin and deposited in molds (Fig. 2A). The pieces were removed from the molds on the third day after molding and they went through a cure process for another 15 days before being subjected to the polishing process. The fickert samples and the polishing process itself are shown at Fig. 2B and C.

Table 1. Proportions of the compounds used in the experimental tests.

| Formulas | Polyol (g) | Prepolymer (g) | RHA (g) | SiC 1200 mesh (g) | SiC 60 and 120 mesh (g) | Total weight (g) | % extenders | % resin |
|---|---|---|---|---|---|---|---|---|
| T1 | 58 | 48 | 53 | 32 | 30 | 221 | 52 | 48 |
| T2 | 58 | 48 | 53 | 43 | 30 | 232 | 54,3 | 45,7 |


Fig. 2 Fickert molding process (A), fickert samples (B) and polishing test (C).

The polishing was performed in the semi-automatic polishing machine belonging to the Federal Institute of Espírito Santo. The first step was the uniformization of the slab surface using a 24 mesh magnesia bond fickert. After this, the plate was divided into two equal area strips to test the two sets of ecological fickerts. Each strip was polished by a 60 mesh fickert for 36 minutes and then by a 120 mesh fickert for 54 minutes. After the tests, 1000 measurements of brightness were made at the interior of each strip and the fickerts mass loss was measured.

## Results and Discussion

The polishing tests showed a satisfactory performance of the ecological fickerts made with the castor polyurethane resin. From the analysis of the graphs (Fig. 3) it is possible to notice that the pieces formulated with a higher quantity of extenders (T2) presented a lower loss of mass in each piece, for both 60 mesh and 120 mesh granulometry, approximately 70% and 14% of difference, respectively.

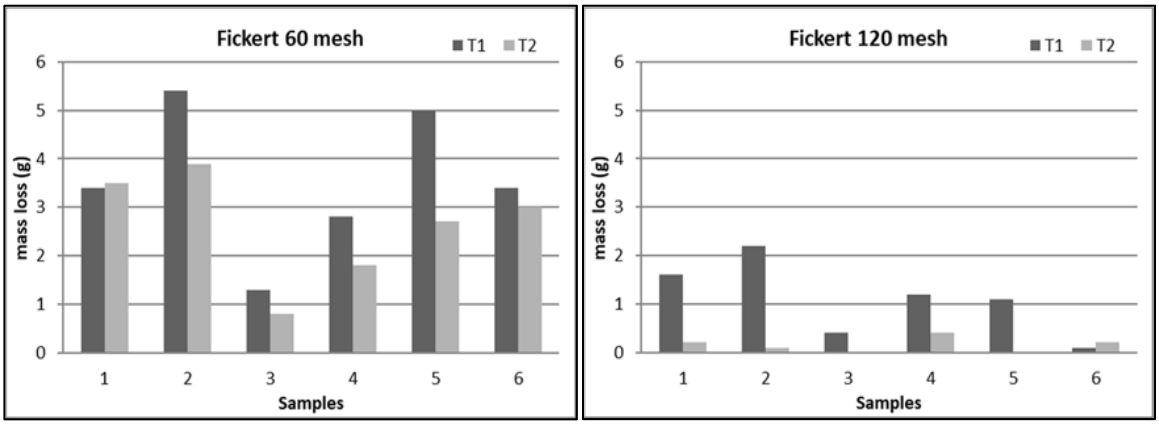


Fig. 3 Results of mass loss of the ecological fickerts after the polishing test.

Despite this fact, the measured values of gloss were 38.12 GU (Gloss Unit) for the two polished strips, which indicates that the formula T2 presented a better performance,

expressed by the relation between the mass loss of the pieces and the brightness gain on the slab surface. Some samples of the 120 mesh T2 fickert set showed a low mass loss, which was not possible to measure in the scale used to weight the samples.

## Conclusions

The performance of the polishing experiments with the ecological fickerts allows to infer that the insertion of the silicon carbide in the vegetal matrix was efficient with great possibility of application in the polishing industry. Nevertheless, it is still necessary to study the relationship between the abrasion resistence of the matrix and the cutting element, by adopting different proportions of the components or even the addition of new elements.

## Ackowledgments

To the Brazilian Association of Dimension Stone Industry for the financial support, to the company Cobral Abrasivos and Minérios Ltda, to Imperveg Polímeros Indústria e Comércio Ltda and to the Saint-Gobain Brazil for provinding the materials used in the research.

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## About the author(s)

Phillipe Fernandes de Almeida, M.Sc.

University of Sao Paulo, Department of Architecture and Urbanism, Avenida Trabalhador São Carlense, 400, São Carlos-SP, Zip Code 13.566-590, Brazil. E-mail: palmeida@sc.usp.br

Victor Moza Ponciano, Mining Engineer

Federal Institute of Espirito Santo State, Department of Mining Engineering, Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code 29.311-970, Brazil. E-mail: victor.moza@gmail.com.

Leonardo Luiz Lyrio da Silveira, PhD

Centro de Tecnologia Mineral – Núcleo Regional do Espírito Santo (NR-ES/CETEM-MCTIC), Rodovia Cachoeiro – Alegre Km 05, Cachoeiro de Itapemirim-ES, Zip Code 29.311-970, Brazil. E-mail: leolysil@cetem.gov.br

Eduvaldo Paulo Sichieri, PhD.

University of Sao Paulo, Department of Architecture and Urbanism, Avenida Trabalhador São Carlense, 400, São Carlos-SP, Zip Code 13.566-590, Brazil. E-mail: dusichi@hotmail.com

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# Reduction of marble waste landfills through the enhancement of $CaCO_3$

**Graziella Marras, Nicola Careddu, Giampaolo Siotto, Roberto Peretti, Augusto Bortolussi, Marco Surracco, Orietta Masala**

**Synopsis**

The research is aimed to the reduction of amount of marble waste/scraps placed to landfill through the recovery and enhancement of carbonate microfine sawdust, mainly resulting from the sawing and processing of carbonate dimension stones. Going through a regulatory framework in order to make the identification between waste, by-product and end of waste status clearer, the ultimate goal of this research is to identify alternative uses, which have a high added value, rather than landfilling, solution so far preferred but not more well-matched with the concept of sustainable development.

**Keywords**

Marble, carbonate dimension stone waste, extractive waste recovery, sustainability.

## Introduction / State of art

The use of natural resources leads to a massive waste production. Waste from extraction and mineral resources processing is one of the largest waste stream in the world. For the dimension stone sector, main data of waste production of the last year are shown in Tab. 1.

Table 1 Quarry production and waste (Montani data processing) [kt].

| World Stone industry: 2016 NET PRODUCTION | | |
|---|---|---|
| RAW PRODUCTION | QUARRYING WASTE | PROCESSING WASTE |
| 145,000 | 151,400 | 59,400 |

Note. Waste materials destined for granules, powders and similar users is included.

Extractive waste recovery is central for boosting the efficiency in recovering rock waste, residues and fines from each exploitation steps.

In the optic of sustainable use of natural resources, on 21st December 2005 the European Commission planned a Thematic Strategy, having as objective the reduction of the environmental impacts associated with resource use and doing so in a growing economy.

In this context, the project is based on a general analysis of the unclear condition between *waste, by-product* and *end of waste status* in Europe, clarifying the legislative framework and proposes some application solutions to convert an extractive industry waste into a useful by-product.

Once classified, the waste materials from the exploitation and processing of geomaterials, the parameters of applicability of the European legislation have been defined, and a recognition of the potential areas of interest for marble microfine sawdust has been carried out.

The proposed work is a summary of a project carried out by the team of authors around the reduction of marble waste landfills through the enhancement of $CaCO_3$, looking at the materials that are not being recycled or recovered despite the clear environmental benefit.

## Materials and Methods

Quarrying engages the production of significant amount of waste. The types of wastes generated from extraction activities of natural stones can be classified in four main categories based on their characteristics that condition the possibility of recovery:

- Defective or "third choice" blocks with regular dimensions but either with poor technical-aesthetical properties or, more commonly, not the correct size for further processing
- unshaped blocks of large or small size (unsuitable to block cutter sawing) and rubble (*pezzame*);
- scraps deriving from both block sawing and slab/strip cutting (*cocciame*, such as broken slabs, strips, tiles);
- sawdust deposited downstream the filter presses of water-treatment plants.

The material object of the research is the sawdust recovered from two wastewater treatment plants (Factory 1 and 2), at the exit of the filter-press section, currently classified as waste. This is coded in the European List of Waste (Commission Decision 2000/532/EC) with the reference nomenclature EWC 01.04.13 "*wastes from stone cutting and sawing other than those mentioned in 01.04.07*".

## Results and Discussion

After a complete characterization (Marras et al., 2017), the marble slurry can be reused and marketed for a number of industrial applications that employ micronized calcium carbonate, as a new material. Product specifications for the calcium carbonate vary depending on the application.

During the early years the research focused on the building industry, thinking to a massive use of the marble slurry, but the material is considered as poor one. Currently the aim is giving economic value to a waste. Thus, a summary of the investigated application, with high added value, is reported in the following Tabs. (2-4):

Table 2 Comparison between values for $CaCO_3$ filler requirements in paper industry and marble slurries data. [WGCC: wet ground calcium carbonate]

| PARAMETERS | VALUE | FACTORY 1 | FACTORY 2 |
|---|---|---|---|
| $CaCO_3$ [%] | > 95 | 99.11 | 99.18 |
| Brightness ISO [%] | 80 - 96 | 81.04 | 85.21 |
| Average particles size [μm] | < 3 | 3.92 | 3.64 |
| Particle size below 2 μm [%] | 2 - 20 | 21.8 | 26.7 |
| WGCC solids content [%] | 75 - 78 | 74.95 | 75.10 |

Table 3 Comparison between values for $CaCO_3$ filler requirements in rubber industry and marble slurries data.

| PARAMETERS | VALUE | FACTORY 1 | FACTORY 2 |
|---|---|---|---|
| $d_{50}$ [μm] | 0.7 - 5.0 | 3.94 | 3.72 |
| $CaCO_3$ [%] | 98.5 | 99.11 | 99.18 |
| $SiO_2$ [%] | 0.1- 0.4 | 0.14 | 0.16 |
| $Fe_2O_3$ [%] | < 0.08 | 0.03 | 0.04 |
| Specific gravity [g/cm$^3$] | 2.70 | 2.71 | 2.71 |
| Particles size < 10.5 μm [%] | 82 - 90 | 79.1 | 80.3 |

Table 4 Comparison between values for $CaCO_3$ filler requirements in tyre industry and marble slurries data.

| PARAMETERS | VALUE | FACTORY 1 | FACTORY 2 |
|---|---|---|---|
| Appearance | White to light grey powder | White | White |
| Specific gravity [g/cm$^3$] | 2.7 | 2.71 | 2.71 |
| Fineness - 150 μm [%] | 100 | 99.0 | 99.2 |
| Fineness - 45 μm [%] | > 95 | 97.8 | 97.8 |
| Fineness: residue at 40 microns [%] | < 0.5 | 2.7 | 2.6 |
| Loss in mass at 105 °C [%] | < 0.5 | 0.132 | 0.104 |
| Loss on ignition [%] | 43.50 ± 1.5 | 46.66 | 43.47 |
| $CaCO_3$ [%] | > 92 | 99.11 | 99.18 |
| Cu [%] | < 0.005 | 0.0002 | 0.0003 |
| Mn [%] | < 0.05 | < 0.01 | < 0.01 |

## Conclusion

The characteristics of the marble powder obtained as a waste in the two processing plants fulfill almost completely the requirements of the possible industrial reuse as filler.

To the benefit of $CaCO_3$ will achieve directly:

- larger revenue for the companies, linked to the sale of the new product;
- lower business costs currently linked to the dumping of landfills and the management of the waste;
- lesser volumes in landfills, restitution of areas to the community.

A positive repercussion, in addition to the economic and environmental ones, will be the employment growth also considering the development of new companies operating in the fields based on the reuse of marble powder.

At present the project is ongoing, new research fields being stone dusting and filler in the manufacture of various types of paint. It is clearly manifested that the main strategy is the prevention and the recycling of waste according with the concept of circular economy. What is required is evolution, seizing the opportunity to adapt waste policy to new conditions and new knowledge.

## Acknowledgments

Gratefully acknowledges Autonomous Region of Sardinia for the financial support (L.R. of 7th August 2007 nr. 7). The authors are thankful to S.I.M.G. and SARDEGNA MARMI for providing the materials for the project.

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## About the authors

Graziella Marras, researcher

University of Cagliari, Department of Civil and Environmental Engineering and Architecture, via Marengo 2, Cagliari 09123, Italy. graziellamarras@gmail.com

Nicola Careddu, senior researcher

University of Cagliari, Department of Civil and Environmental Engineering and Architecture, via Marengo 2, Cagliari 09123, Italy. ncareddu@unica.it

Giampaolo Siotto, professor

MPF - Mediterranea Progetti e Finanza srl, Via Pasquale Tola 30, Cagliari 09128, Italy. studio.siotto@gmail.com

Roberto Peretti, senior researcher

National Research Council of Italy, Institute of Environmental Geology and Geo-Engineering, via Marengo 2, Cagliari 09123, Italy. rperetti@unica.it

Augusto Bortolussi, senior researcher

National Research Council of Italy, Institute of Environmental Geology and Geo-Engineering, via Marengo 2, Cagliari 09123, Italy. bortolussi@unica.it

Marco Surracco, associate professor

University of Cagliari, Department of Civil and Environmental Engineering and Architecture, via Marengo 2, Cagliari 09123, Italy. surracco@unica.it

Orietta Masala, technician

National Research Council of Italy, Institute of Environmental Geology and Geo-Engineering, via Marengo 2, Cagliari 09123, Italy. omasala@unica.it

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# Characterization of slate waste powder

**Luciana B. Palhares, Claudio G. dos Santos, Tim N. Hunter**

**Synopsis**

In the slate extraction industries, there are several steps involved in processing from the extraction to the final products. During the development of that, many steps generate waste. The system of extracting rock blocks for the production of plates generates a significant amount of waste in the form of a mud composed mainly of water, lubricants and crushed rock. This waste with no defined destination accumulates in yards, reservoirs and streams, affecting the environment. Slate powder has great prospects for recovery, recycling and further applications. Therefore, it is important to execute the powder characterization. The aim here is the slate powder characterization related to XRD, SEM, EDS, G3 Morphology and thermal analysis.

**Keywords**

Slate, waste, characterization.

## Introduction

The majority of slate processes industries do not dispose their waste correctly turning their activities increasingly harmful to the local ecosystem. The waste generated by the extraction of slate and its processing can contribute to a series of impacts on the environment.

The waste produced annually by slate industries is nearly $1.5 \times 10^5$ tons (Abirochas, 2012). It is composed mainly of water, lubricants and crushed rock. The treatment and the use of it, is possible and some works have been developed to the characterization, recycling and ceramic processing (Palhares, L. et.al.; 2004; Palhares, L. et.al., 2011; Palhares, L. et.al., 2011; Palhares, L. et.al., 2005; Catarino, et.al., 2003; Cambronero, L., 2005, Palhares, L. et. al., 2013).

Identification, characterization and knowledge about the properties of different materials and wastes allow an evaluation about how it can be use and its attributes. Thus, the production of alternative materials can be achieved and reduced or even having the pollution eliminated in the extraction areas, besides promoting new opportunities for jobs what is essential to the progress and development of the country.

This paper describes the physic-chemical and thermal analysis characterization of the slate wastes for use in further research.

## Materials and Methods

The slate powder used in this work was generated by the process of stone calibration at Micapel Slate Company located in Pompeu, Minas Gerais State, Brazil.

In order to identify the powder crystallinity, X-ray diffraction tests were carried out in a diffractometer XRD Philips.

Particle size distribution was measured using the Malvern Mastersizer 2000 (Malvern Instruments Ltd., UK) and the thermal analysis was carried out using a Shimadzu Model TA-50 WSI instrument, temperature range from 30 to 1000$^o$C.

Particle density was measured using the Micrometrics Accu-Pyc 1330 helium pycnometer (Micromeritics Instrument Corporation, US).

Dry particle shape and size was characterized using a LEO/Zeisss 1530 scanning electron microscopy (SEM) (LEO Elektronmikroskope GmbH, Germany).

Morphology particles were analyzed by Morphologi G3, Automatic Particle Characterization System, Malvern Instruments, UK.

## Results

The density values found via helium pycnometry, and surface area analysis via nitrogen adsorption were, respectively, 2.76 g/cm$^3$ and 15.8 m$^2$/g.

Fig. 1 shows a typical diffractogram for the slate powder studied. By analyzing the obtained diffraction pattern the following minerals were identified: (Q) Quartz - $SiO_2$, (C) clinochlore, (M) muscovite, (A) albite, (H) hematite and (O) Orthoclase. The EDX analysis showed the qualitative percentage (%p/p) of the oxides presents in slate: $SiO_2$ – 60,5%; $Al_2O_3$ – 12,7; $Fe_2O_3$ – 7,9; $K_2O$ – 5,8; $Na_2O$ – 5,2 and others.

The muscovite identified is a potassium hydroxide aluminum silicate belonging to the class of micas; the clinochlore is a hydroxide, magnesium silicate, iron and aluminum, belonging to the chlorites group responsible for the green color of slates and shales; and albite and orthoclase are silicates belonging to the series of plagioclase feldspars. Feldspars act on the burning steps as fluxes increasing the strength of the parts. The hematite ($Fe_2O_3$) is the component responsible for the red color of the ceramics.

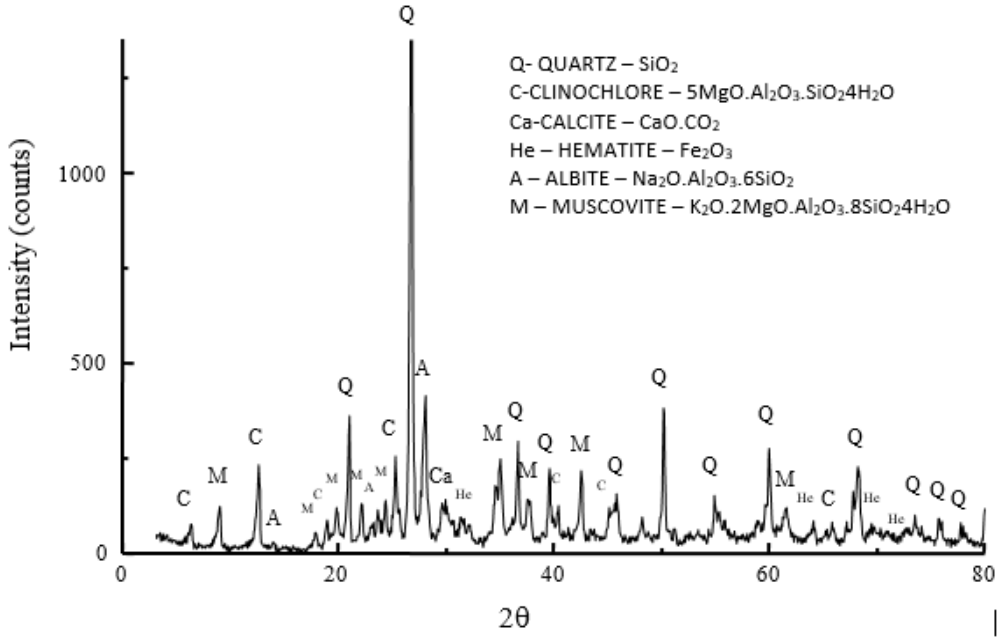


Fig. 1 Typical difractogram of slate powder: Albite (A), Quartz (Q), Moscovite(M), Clinochlore (C), Ortoclase (O) e Hematite (He).

Size distribution data in Fig. 2 shows an almost mono-modal curve. The slate powder sample has a major peak at a much larger size, closer to 5 μm and a minority closer to 1 μm.

The Fig. 3 shows the thermo-analysis curve. The first mass loss peak at about 250ºC and the second one at 350ºC correspond to free water adsorbed and water loss by hydroxide, respectively. The third event was assigned by the allotropic transformation of quartz and dehydroxylation of clinochlore constituent. Closer to 740ºC the constituents muscovite and clinochlore lost its lattice structure. To temperatures higher than 1000ºC there was an exothermic peak due to presence of liquid.

SEM images showed that particles has heterogeneous shape and size. The sample exhibits different sizes, and the presence of clusters. The results obtained via EDS (energy dispersive) show a higher percentage of quartz and alumina in both analyses due to presence of hydrated aluminum silicates in slate.

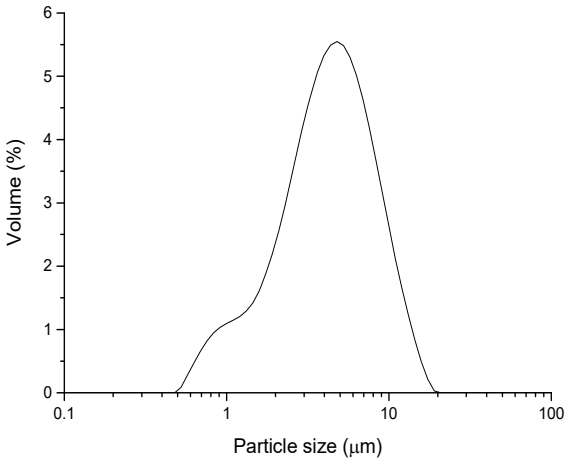


Fig. 2 Particle size distribution to slate powder.

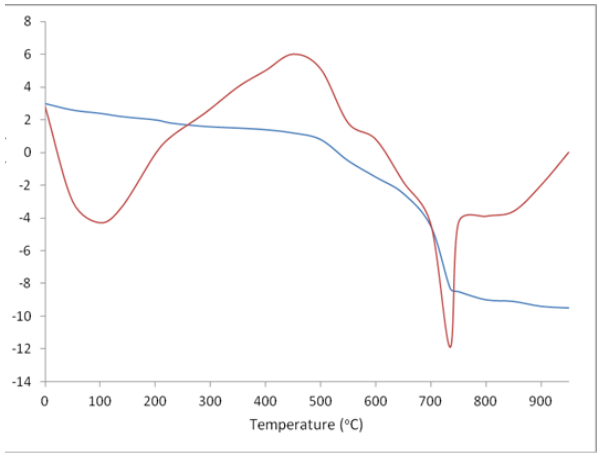


Fig. 3 Slate Powder Thermal Analysis.

The mapping of a determined sample region by EDS gives an idea of oxygen and silicon distribution in that area (Fig. 4). It was observed that the silicon and oxygen distribution in the same region are very similar and this fact suggest the silica ($SiO_2$) presence. In Fig. 5 it was observed aluminum presence that suggests a muscovite particle.

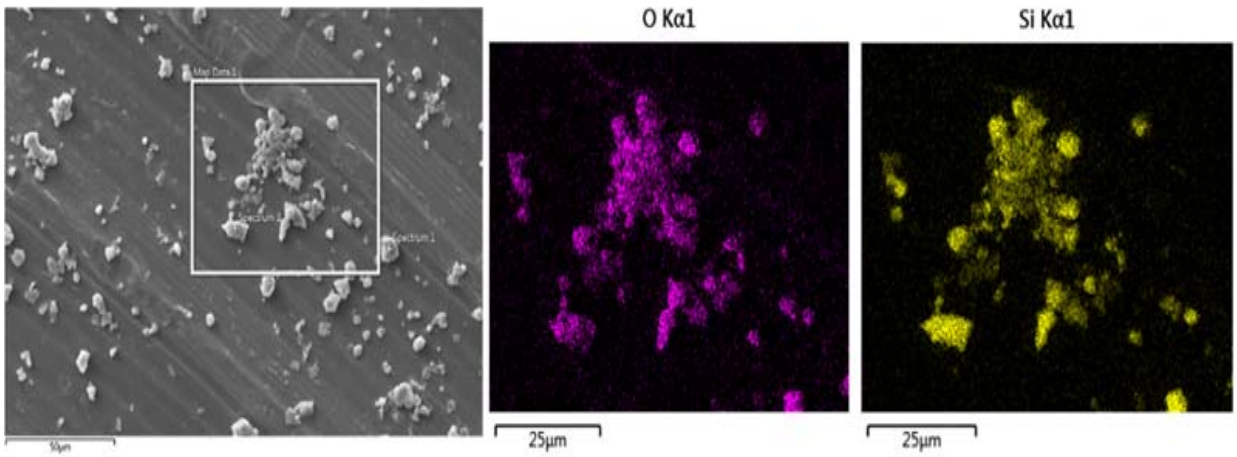


Fig. 4 EDS mapping of slate waste.

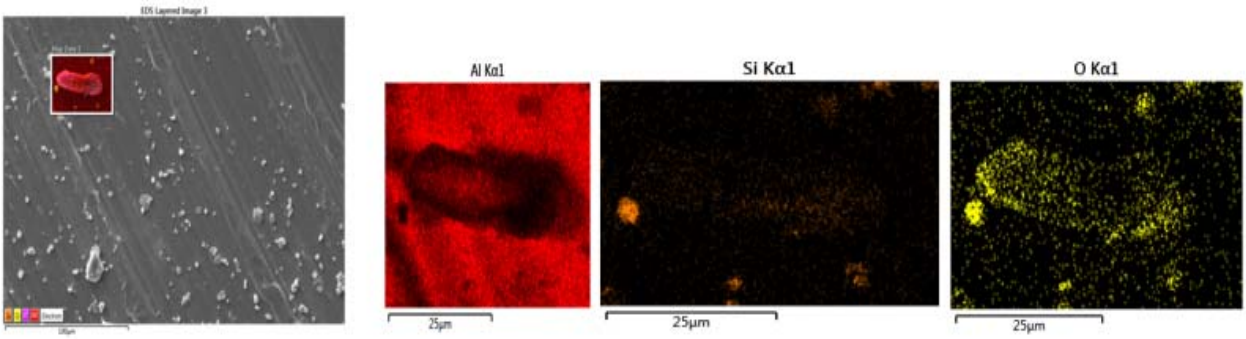


Fig. 5. EDS mapping of slate waste

Comparing the curves can be seen to higher value of circularity and aspect ratio more homogeneity particles (region 1) and to lower the presence of agglomerates (region 2). The identification of agglomerates is important because it can modify the properties of powder, such as flowability, surface area and dissolution rate.

## Conclusions

XRD, EDX and mineralogical analysis showed the main components of slate powder generated in extraction and beneficiation process are: (Q) Quartz - $SiO_2$, (C) clinochlore, (M) muscovite, (A) albite, (H) hematite and (O) Orthoclase.

Thermal analyses of slate powder in air atmosphere showed the allotropic transformation of quartz and dehydroxylation of clinochlore constituent. And changes in lattice structure in muscovite and clinochlore.

Particle distribution data indicates particles size between 0,89 and 24,8 µm. The higher values could be agglomerates as it can be seen in G3 morphological and SEM data.

The characterization of this waste is very important for its future application in several environmental research areas including ceramic processing.

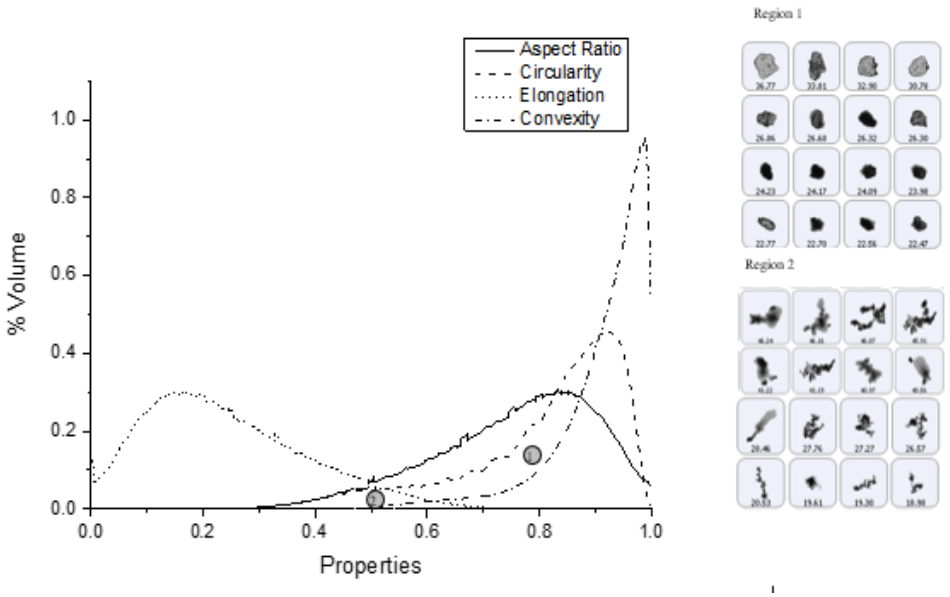


Fig. 6 Aspect ratio, Circularity, Elongation, Convexity X Number Distribution.

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## About the author(s)

Luciana Boaventura Palhares – Professor Dr. Materials Engineering
Centro Federal de Educação Tecnológica de Minas Gerais (CEFET). lbpalhares@hotmail.com

Claudio Gouvêa dos Santos - Professor DPhill Chemistry
Universidade Federal de Ouro Preto

Tim N. Hunter - Professor DPhill Chemical Engineering
University of Leeds – UK.

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# Concrete production using slate wastes

**Luciana B. Palhares, Paulo Renato P. de Paiva, Mateus A. D. Rodrigues, Victor C. Gonçalves, Sthéfany B. P. da Silva**

**Synopsis**

The system of slate extracting blocks and its final machining operations generate a large amount of waste (~ 75% of the extracted rock). The plate extraction system generates a significant amount of waste in the form of a sludge composed mainly of water, lubricants and crushed rock. This waste with no defined destination accumulates in yards, reservoirs and streams, affecting the ecosystems causing technical, economic, environmental and social problems. Due the physical and chemical properties of slate, the waste has great potential for recovery and recycling. In this paper showed the production of concrete with slate additions. The addiction of 15% showed that mechanical strength increased 38% compared to the reference concrete and water absorption approximately 20%. The works here developed has shown that all processing used need a control of slate particle size and others properties. The slate powder is promising for use in ceramic, concrete and new materials.

**Keywords**

Slate wastes, concrete, ceramic processing.

## Introduction

The dust-form slate sediments; which result from the extraction, cut and processing of the rock; have a significant and serious impact among the ecosystem nearby the mines. The processing of these powders by different techniques; so much as pressing, extrusion or collage; may be the solution for the recovery and recycling of the generated sediments.

According to Vidal (2003); the rock materials have their use dated back to 500 a.C., and initially only the surface used to be explored; however, with the coming of new demands, underground mining process began, leading to the appearance of clear sky and underground mining pits. Due to inadequate extraction technologies and the respective product quality, it did not take long for the disorderly extraction of the minerals to be perceived, issuing in high accumulation of waste laid out in clear sky (Fig. 1).

Fig. 1 Waste laid nearby the slate mines in Pompéu, state of Minas Gerais. (Source from the authors).

The main focus on slate extraction and processing in the state of Minas Gerais is the city of Papagaios, which holds 60% of the total production, conceived mostly by grey slate. The fields are explored out in clear sky, slopes and pits. The pits have regular and plain tread, due to the horizontalized cleavage (Chiodi Filho and Chiodi, 2014).

The study accomplished by Chiodi Filho and Chiodi (2014) managed to list 137 send-off piles, where almost 100 million tons of mineral-industrial waste is piled up.

The production of alternative materials throughout the rock-transforming industries waste may diminish – or even eliminate – the pollution in mining areas, besides promoting the appearance of new job and income opportunities, vital to the process of development of the country. It is worth emphasizing the indescribable environmental plead due to the use of materials classified as waste, generated in high amounts, being transformed in feedstock for other processes, even being able to reduce the spendings on waste disposal, generating income for the enterprises and meeting the environmental laws' requirements.

## Materials and Methods

The slate waste utilized was generated in the process of the rock extraction, in Micapel Slate Company, presented in Pompéu, MG. The rejects were dry sieving on a 2 mm sieve.

Mineralogycal and chemical analysis, along with X-ray diffraction tests, were conducted on the slate.

The obtained diffractogram allowed the identification of minerals present in the slate: quartz, muscovite, Clinoclhore, feldspar, hematite, among others; and together with the chemical analysis shown in Tab. 1, their quantitative evaluation (Table 2).

Table 1 Chemical analysis.

| | PF | $C_{total}$ | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MnO | CaO | MgO | $Na_2O$ | $K_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SLATE | 7,03 | 1,39 | 61,27 | 0,89 | 15,88 | 6,92 | 0,11 | 5,88 | 3,19 | 1,91 | 3,73 |

## Concrete production

For production of the specimens with slate waste, it was used the cement compound CP II-E-32, which is commonly applied in structural and conventional concrete, in pieces such as slabs, beams, columns, foundations and general mortars.

The proportion adopted was 1:2:3, which corresponds to *cement fraction (1): small aggregates (2): coarse aggregates (3)*, by weight. The water/cement ratio used was 0.55.Apart from the slate dust, washed sands, fine and coarse, with maximum grain sizes of 4.8mm and 5.53mm respectively, were used as fine aggregates, and nº 0 grit gneiss, as coarse aggregate.

In addition to the reference concrete, without addition of slate dust, test bodies were produced with 5%, 10% and 15% slate dust in replacement of sand, in weight. For each slate percentage and age break, four cylindrical specimens of 50mm in diameter and 100mm high were built, totalling 48 specimens. The production of the specimens was referenced by the NBR 5738 (ABNT, 2008, adapted).

Table 2 Mineralogical analysis

| Mineral | Slate |
|---|---|
| Quartz | 37,1 |
| Muscovite | 22,4 |
| Feldspar | 19,4 |
| Hematite | 6,5 |
| Clinoclhore | 11,0 |
| Calcite | 1,8 |
| Others | 1,4 |

To study the influence of slate in mechanical properties, it was determined the resistance of axial compression of the test bodies at 3, 7 and 28 days of age using assay universal machine Emic, DL-30000 model. The water absorption of the concrete was performed through immersion method, according to NBR 9778 (ABNT, 1987).

## Results and Discussions

It was observed that all concretes produced with slate presented, to all ages and all substitution levels, higher compressive strength compared to the reference concrete. This result indicates the benefit of incorporating the reject in relation to the mechanical performance of the concrete.

Fig. 2 holds graphical representation of the strength evolution with time. At the age of 3 days, the adding of 15% presented intermediate resistance related to 5% and 10% slate concrete. Since the resistance values of 10 and 15% additions were similar, it is believed that age was precocious for having a complete binder hydration, competing with the slate hydration and other reactions in concrete.

For the ages of 7 and 28 days, there was a progressive growth in resistance with the increasing slate content through time.

This gain in strength brings indicative of the pozzolanic activity and filler effect occurrence, as the dust used as aggregate possessed low particle size. The dust particle size was sufficient to promote pores refinement and higher densification of the concrete. Furthermore, the slate lamellar structure and its coarseness favoured full bonding strength with the concrete matrix because of the high surface area.

The through-immersion water absorption tests showed a decreasing trend of absorbed water mass with the growth of substitution aggregate content. All absorption levels are very close, leading to a considered average absorption of 7%. As the water/cement ratio was the same for all test bodies, this water absorption similarity was already expected. The higher w/c ratio, greater the resulting porosity of the excess water evaporation and, consequently, greater the quantity of absorbed water.

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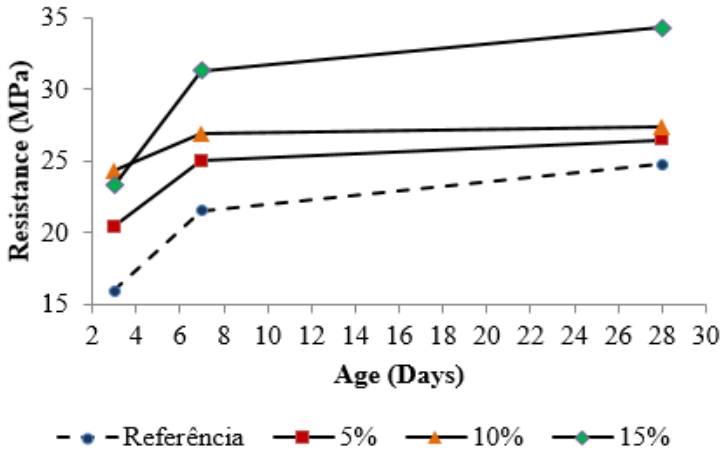


Fig. 2 Test bodies before breakage.

NBR-6136 (ABNT, 2007) requires a maximum water absorption equal to 10% for the concrete to be used in the production of building blocks. Thus, the concrete produced in this study exhibited satisfactory absorption.

## Conclusions

The study has shown that the recovery of slate waste is viable, from both mines and slate-benefitting industries. Taking into account the state of Minas Gerais' potential for the slates sector, many would be benefits from the use of rejects.

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## About the author(s)

Luciana Boaventura Palhares – Professor Dr. Materials Engineering
Paulo Renato Perdigão de Paiva - Professor Dr. Materials Engineering
Sthéfany Batista Pires da Silva – Materials Engineering
Mateus Araujo Dutra Rodrigues – Graduated Student of Materials Engineering
Victor Canesso Gonçalves – Graduated Student of Materials Engineering

Centro Federal de Educação Tecnológica de Minas Gerais (CEFET). Departamento de Engenharia de Materiais. Avenida Amazonas, 5352, Nova Suíça, Belo Horizonte, MG. CEP: 30.421-169. lbpalhares@hotmail.com

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# Stone waste as Eco-filler for self-compacting concrete

**Nuria Fernández Castro; Leonardo Cattabriga; Fábio Conrado de Queiróz; Rubens Curti; Rubens Monge; Paolo Marone; Caroline Umbinger de Oliveira**

**Synopsis**

This works describes the initial results of an ongoing research being developed by the International Marble Institute (Istituto Italiano del Marmo – IS.I.M), the Centre for Mineral Technology – CETEM and the Brazilian Association of Portland Cement – ABCP. It aims the use of stones processing waste as Eco-filler in Self-compacting Concrete – SCC. For that, 20 samples were collected at stones wastes landfills of the south region of the estate of Espírito Santo. Some characteristics of the wastes were first determined: grain-size distribution, real density, and chemical and mineralogical composition. Two of them, one representative of siliceous mixed materials (granite) and the other of the carbonate materials (marble) are being tested in ABCP laboratories regarding their possible use as Eco-filler. The initial results showed that there was no alkali-aggregate reaction for neither of the samples (short term test) and that initial characteristics of the concretes tested (with 50 kg/m$^3$ of marble waste) were acceptable. Further experiments are being made with mix composition variations.

**Keywords**

Natural Stones Wastes, Recycling, Self-Compacting Concrete.

## Introduction

Brazil is one of the main producers of natural stones of the world and despite its internal economical and political problems in recent years, according to Montani (2017) still holds the fourth position amongst the world's producing countries of those materials (preceded by China, India and Turkey). More than 9 Mt of natural stones, mainly commercial granites (which include granitoids, and sometimes quartzites and soapstone), are quarried in Brazil yearly and around 8 Mt of those are processed in the country. According to measurements of the Centre for Mineral Technology - CETEM, 26 to 30% in weight of the raw material becomes fine wastes during the sawing, polishing and finishing steps of the natural stones processing in Brazil, which give us more than 1.5 Mt of that stones waste per year (CAMPOS *et al.*, 2014). By the actual Brazilian legislation, those wastes are to be properly landfilled, as they are usually environmentally classified as 'Not Inert' though 'Not dangerous' (BRAZIL, 2010), which obliges the existence of many industrial landfills, occupying large areas. The estate of Espirito Santo, located north-east of the estate of Rio de Janeiro and south of the estate of Bahia, is the main stones producer, processer and exporter of Brazil, accounting for more than half of Brazilian production, and around 80% of processing and Brazilian stones exports (ABIROCHAS, 2017). Being so, there are more than 60 licensed stones landfills, most of them in the south region, that is Cachoeiro the Itaperim and surrounding municipalities. Considering the huge amounts of stone wastes available, uses need to be found and of the many possible industrial uses of the stones fine wastes, the building industry looks like a quite good alternative, because of the huge amounts of raw materials it needs. In that sense, CETEM approached the Italy Marble Institute - IS.I.M, as that institute has been researching for more than a decade, with a group of Italian companies, and found several ways to recycle the fine stone waste within the building industry. As the Brazilian stone wastes are mostly of siliceous composition and not

carbonate as the wastes studied by IS.I.M., both institutions signed in 2014 a cooperation agreement to develop useful solutions. The main goal of this joint project is to have a map of stones wastes of Brazil with locations, existent quantities and yearly production of wastes and, of course, their compositional and environmental characteristics. With this map and having developed technical solutions for the wastes use, it would be possible to define economic feasibility for interested parties, such as building, ceramic, glass companies which could use them. Focusing on the Brazilian building industry, another specific agreement was signed, in 2016, with the Brazilian Portland Cement Association - ABCP. By it, under coordination of IS.I.M., CETEM would map and characterize the wastes and ABCP would test their use. It was decided to start with the possibility of using stones wastes as Eco-filler in Self Compacting Concrete - SCC.

## Materials and Methods

Information of the existent landfills was obtained through the Estate's Environmental Agency - IEMA-ES and the municipalities of Cachoeiro de Itapemirim and Castelo. Relevant data such as location, wastes volumes licensed, and the manager's contact for each landfill were gathered. Then, the managers of more than 20 landfills were contacted to get more data about their landfills and agreement of participation within this project. CETEM sampled 19 materials from 13 landfills. In addition, it was also sampled waste from the sawing of white quartzite (diamond wire saw). Table 1 summarizes the types of wastes collected.

Table 1 – Collected wastes types

| Quantity | Code | Type |
|---|---|---|
| 13 | MIX | All mixed, all kind of sawing and polishing stones wastes |
| 1 | SIL | Only granite-like (not carbonate) stones wastes from sawing and polishing. |
| 1 | CAL | Only carbonate stones waste from sawing and polishing. |
| 1 | TRA | Only travertine waste from sawing and polishing. |
| 1 | M+F | Marble plus potassic feldspathic stones waste, from sawing and polishing. |
| 1 | MLA | Mixed stones waste from multiblade sawing. |
| 1 | MFI | Mixed stones waste from diamond wire sawing (mostly siliceous). |
| 1 | QTZ | White quartzite sawing waste (sampled at the diamond wire saw outlet). |

The samples were prepared in the Laboratory of Natural Stones - LABRO of the NRES, by drying, disaggregation, screening to 2.0 mm (10 mesh), homogenization, quartering and were determined: chemical composition by X-ray fluorescence - XRF in spectrometer (WDS-2), model AXIOS (Panalytical); mineralogical analysis by X-ray diffraction (XRD) by the powder method in a Bruker-D4 Endeavor equipment, with Bruker AXS Diffrac.Plus software; real density by pycnometry; and grain-size analysis, in a laser granulometer, model Mastersizer 2000, from Malvern. From all the samples, two were selected to be tested in the ABCP laboratory as Eco-filler for SCC: one of mixed wastes (representative of the main Brazilian stones wastes) and one of carbonate stones wastes (in order to replicate the good results already obtained by IS.I.M in Italy and other countries). Concrete mix ratio and admixtures

were defined and adjusted by the ABCP team after the original formulae from IS.I.M. Alkali-aggregate reaction was tested for both the samples selected, as that is a decisive parameter for SCC, and first tests were made with 50 kg/m$^3$ of marble waste as Eco-filler for SCC: drying shrinkage, normalized fresh concrete tests and compressive strength.

## Results and discussion

The granulometric distributions of the 20 samples were very similar, showing very fine uniform particles, with $d_{10}$ close to 2, 5 µm, $d_{50}$ ≈ 22 µm and $d_{90}$ from 50 to 120 µm. The diamond wire sawing wastes were finer (both MFI and QTZ) with $d_{90}$ close to 50 µm and most of the others close to 80 µm (86% < 0.075 mm), grain-size apropriate for SCC filler. Densities varied from 2.622 g/cm$^3$ e 2.861g/cm$^3$ and the chemical compositions are shown in Table 2.

Table 2 – Chemical analyses of the stone wastes sampled (oxydes %)

| SAMPLE | $Na_2O$ | MgO | $Al_2O_3$ | $SiO_2$ | $P_2O_5$ | $SO_3$ | $K_2O$ | CaO | $TiO_2$ | $Fe_2O_3$ | PPC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MIX 422 | 3,20 | 1,50 | 15,80 | 60,80 | 0,44 | < 0,1 | 3,70 | 4,60 | 0,72 | 7,40 | 1,40 |
| MIX 423 | 4,70 | 1,60 | 19,70 | 56,40 | 0,32 | 4,50 | 3,90 | 0,76 | 6,20 | 0,23 | 1,20 |
| MIX 424 | 3,90 | 1,50 | 17,70 | 61,00 | 0,35 | 4,00 | 3,70 | 0,69 | 5,20 | 0,12 | 1,30 |
| MIX 425 | 4,10 | 1,90 | 18,10 | 57,30 | 0,42 | 3,90 | 4,20 | 0,83 | 7,70 | 0,16 | 0,85 |
| MIX 427/3 | 3,30 | 2,00 | 14,60 | 67,80 | 0,21 | 3,20 | 2,70 | 0,41 | 3,50 | < 0,1 | 2,00 |
| MIX 428/1 | 3,50 | 1,50 | 14,70 | 66,50 | 0,29 | < 0,1 | 3,20 | 3,80 | 0,62 | 5,80 | 1,50 |
| MIX 430 | 3,50 | 1,60 | 16,50 | 61,50 | 0,38 | 0,11 | 3,60 | 3,40 | 0,70 | 7,10 | 1,20 |
| MIX 431 | 3,30 | 3,50 | 15,50 | 58,70 | 0,42 | 0,13 | 3,20 | 5,30 | 0,77 | 4,50 | 4,30 |
| MIX 434 | 3,60 | 1,60 | 16,60 | 61,60 | 0,41 | 0,13 | 3,60 | 4,20 | 0,71 | 6,40 | 0,69 |
| MIX 435 | 3,30 | 1,70 | 16,20 | 62,70 | 0,35 | < 0,1 | 3,60 | 3,80 | 0,62 | 5,80 | 1,50 |
| MIX 440 | 2,80 | 4,70 | 13,20 | 46,50 | 0,33 | < 0,1 | 2,80 | 12,40 | 0,57 | 4,70 | 11,60 |
| MIX 441 | 4,40 | 1,60 | 19,40 | 59,30 | 0,37 | < 0,1 | 4,60 | 3,60 | 0,77 | 4,00 | 1,10 |
| MIX 442 | 3,80 | 1,60 | 17,00 | 59,70 | 0,39 | < 0,1 | 3,90 | 4,30 | 0,73 | 6,50 | 1,40 |
| SIL 420/4 | 3,20 | 2,00 | 15,80 | 58,50 | 0,43 | 0,23 | 3,50 | 4,60 | 0,67 | 8,00 | 2,60 |
| CAL 420/1 | 0,16 | 21,10 | 0,60 | 5,80 | < 0,1 | < 0,1 | < 0,1 | 29,10 | < 0,1 | 0,12 | 42,70 |
| TRA 420/3 | < 0,1 | 21,60 | 0,31 | 4,80 | < 0,1 | < 0,1 | < 0,1 | 29,80 | ND | < 0,1 | 43,20 |
| M+F 420/2 | 1,40 | 12,50 | 5,80 | 27,20 | < 0,1 | < 0,1 | 1,10 | 21,60 | < 0,1 | 0,65 | 29,30 |
| MLA 427/1 | 3,40 | 1,40 | 16,40 | 64,20 | 0,23 | 3,70 | 3,20 | 0,50 | 5,70 | < 0,1 | 0,82 |
| MFI 427/2 | 3,5 | 0,79 | 14,4 | 72,8 | 0,16 | 3,3 | 1,5 | 0,34 | 2,1 | < 0,1 | 0,76 |
| QZT 439 | <0,1 | <0,1 | <0,1 | 99,4 | ND | ND | <0,1 | 0,14 | <0,1 | <0,1 | 0,22 |

Multiwire mixed waste (MFI 427/2) shows a high silica content which was expected, as that sawing technology is mostly used for harder stones, as quartzites and high silica commercial granites. Only considering the MIX samples, as it is the most usual kind of wastes found within the landfills, their chemical composition show variations in silica, lime and iron

contents that clearly depend on the quantities of wastes of the different types of stones and from different processing technologies mixed, e.g. landfills with more addition of marble and limestone wastes have higher contents of lime, and wastes becoming from the multiblade sawing will have higher iron and lime contents (though the iron content also depends on the type of stone processed).

The two selected samples to be tested at the ABCP were MIX 430 (called 'granite' with specific gravity 2.773 g/cm$^3$, 85.72% < 0.075 mm) and CAL 420/1 (called 'marble' specific gravity 2.766 g/cm$^3$, 89.67% < 0.075 mm) and their chemical compositions are shown in Table 2. It wasn't noticed alkali-aggregates reaction by the mortar bars accelerated test (ABNT NBR 15577-4:2009) for neither of waste samples (granite and marble) when compared to the ABCP's reference sand, with mortar mix ratio defined by the ABCP team (Table 3).

Table 3 – Mortar mix ratios (accelerated alkali-aggregates test - ABNT NBR 15577-4:2009)

| Components | Reference sand | Marble waste | Granite waste |
|---|---|---|---|
| Sand | 990 g | 495 g | 495 g |
| Marble waste | - | 495 g | - |
| Granite waste | - | - | 495 g |
| CPV Cement | 440 g | 440 g | 440 g |
| Superplasticizer | 5 g | 5 g | 5 g |
| Water | 206,8 g | 206,8 g | 206,8 g |

The results can be seen on Table 4. Though the long-term test must be still performed, it is interesting to point out the good results for the granite wastes, which could have been considered to present alkali-aggregates reaction, because of their silica content.

Table 4 – Results of accelerated alkali-aggregates test - ABNT NBR 15577-4:2009

| Age | Average length change (%) | | |
|---|---|---|---|
| | Reference sand | Marble waste | Granite waste |
| 2 days | 0,010 | 0,010 | 0,010 |
| 5 days | 0,020 | 0,020 | 0,020 |
| 7 days | 0,020 | 0,020 | 0,020 |
| 9 days | 0,030 | 0,030 | 0,020 |
| 12 days | 0,040 | 0,040 | 0,020 |
| 14 days | 0,050 | 0,050 | 0,030 |
| 16 days | 0,050 | 0,050 | 0,030 |
| 19 days | 0,060 | 0,060 | 0,030 |
| 21 days | 0,060 | 0,060 | 0,030 |
| 23 days | 0,080 | 0,070 | 0,040 |
| 28 days | 0,090 | 0,080 | 0,040 |

Two concretes were prepared with addition of 50 kg/m$^3$ of the marble waste as Eco-filler and two different cement types. Their properties in fresh state and compressive strength were

compared to a reference ABCP sample. Composition and results obtained with those concretes are shown in tables 5, 6, 7 and 8.

Table 5 – Reference and tested concrete mixtures

| CONCRETE MIXES | NO FILLER | ECOFILLER 1 | ECOFILLER 2 |
|---|---|---|---|
| CPII E 40 cement (CEM II) | 8.393 g | 10.071 g | |
| CPV cement (CEM I R) | | | 10.071 g |
| Natural sand (< 0,6 mm) | 14.872 g | 17.847 g | 17.847 g |
| Artificial sand (< 6,3 mm) | 9.005 g | 10.806 g | 10.806 g |
| Gravel (< 12,5 mm) | 24.082 g | 28.898 g | 28.898 g |
| Eco Filler (marble waste) | | 1.531 g | 1.531 g |
| Admixture 1 | 50 ml | 60 ml | 60 ml |
| Admixture 2 | 109 ml | 131 ml | 131 ml |

Table 6 – Shrinkage test results (ASTM C 157:2014)

| Age | Drying shrinkage – lenght change (%) | | |
|---|---|---|---|
| | NO FILLER | ECOFILLER 1 | ECOFILLER 2 |
| 7 days | + 0,009 | + 0,009 | + 0,005 |
| 14 days | - 0,017 | - 0,019 | - 0,019* |
| 28 days | - 0,036 | - 0,041 | - 0,033 |

* Measured on the 15th day due to operational reasons

Table 7 - Fresh concrete properties

| PROPERTIES | NO FILLER | ECOFILLER 1 | ECOFILLER 2 |
|---|---|---|---|
| Specific gravity (g/cm³) | 2,454 | 2,475 | 2,460 |
| Air content (%) | 1,4 | 1,4 | 1,3 |
| *Slump Flow* (mm) | 750 | 700 | 750 |
| $T_{500}$ (s) | 2,8 | 5 | 3 |

Table 8 – Compressive strength results

| Age | Concrete compressive strength (MPa) | | |
|---|---|---|---|
| | NO FILLER | ECOFILLER 1 | ECOFILLER 2 |
| 24 hours | 0,9 | - | 4,3 |
| 3 days | 34,3 | 35,8 | 39,8 |
| 7 days | 42,2 | 43,9 | 40,4 |
| 28 days | 53,6 | 55,0 | 49,2 |

These results indicate, preliminary, the feasibility of using stones wastes as Eco-filler, even though it hasn't been proved that this Eco-filler improves the SCC characteristics, as expected by the Italian results. It is important to point out the good results regarding the alkali-aggregates reaction tests and that all other tests, by now at least, have given results similar to the reference material. This is an on-going research and other tests have to be carried out and other mixtures will be also tested.

## Conclusions

Natural stones sawing and polishing waste seems adequate to be used as filler in concrete, especially by its grain size characteristics. Carbonate waste (from marble, limestone and travertine) use as filler seems to be obvious as carbonate materials powder is already widely used as a mineral addition, enhancing SCC behavior, though this is not usual within Brazilian building industry. On the other hand, the majority of natural stones waste in Brazil is of silicate composition, not yet used as an addition. This research aims to adjust several cement-based mixes from the Italian experience, testing different mix ratios and admixtures available in Brazil and using natural stones waste in their composition. By now, the research is on its first stage (50 kg/m$^3$ marble waste addition as Eco-filler) with satisfactory preliminary results. Different quantities (up to 150 kg/m$^3$) and different admixtures must be tested. In parallel, silicate materials waste will be tested too.

## Acknowledgments

The authors thanks the invaluable support and continuous availability and assistance of Riccardo Vannetti, from Chimica Edile do Brasil and all his company's team. The authors are also grateful for the support of ABCP and CETEM technicians, and the associations: AAMOL, ADAMAG, ASSES, and SINDIROCHAS.

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## About the authors

Nuria Fernandez Castro, Mining Engineer, MSc.

Technologist at the Centre for Mineral Technology (CETEM)
Av. Pedro Calmon, 900 – Cidade Universitária – 21941-908 Rio de Janeiro – RJ (Brazil)
Currículo Lattes | ncastro@cetem.gov.br | +55 21 38657336

Leonardo Cattabriga, Oil and Gas Engineer.

Technician at the Regional Unit of Espirito Santo - NRES
Centre for Mineral Technology (CETEM)
Rod. Cachoeiro Alegre, km 5 – Morro Grande – Cachoeiro de Itapemirim – ES (Brazil) Currículo Lattes | Currículo Lattes | lfreire@cetem.gov.br | +55 28 35118937

Fábio Conrado de Queiróz, Building Technologist, MSc.

Research Assistant at the Regional Unit of Espirito Santo - NRES
Centre for Mineral Technology (CETEM)
Rod. Cachoeiro Alegre, km 5 – Morro Grande – Cachoeiro de Itapemirim – ES (Brazil)
CV: http://lattes.cnpq.br/6045737281444449 / fqueiroz@cetem.gov.br / +55 28 35118937

Rubens Curti, Civil Engineer.

Concrete and mortar specialist at the Brazilian Association of Portland Cement – ABCP
Av. Torres de Oliveira, 76 - Jaguaré
CEP 05347-902 - São Paulo -SP (Brazil)
rubens.curti@abcp.org.br / +55 11 37605317

Rubens Monge, Civil Engineer.

Coordinator of the Concrete Wall Group at the Brazilian Association of Portland Cement – ABCP
Av. Torres de Oliveira, 76 - Jaguaré
CEP 05347-902 - São Paulo -SP (Brazil)
rubens.monge@abcp.org.br / +55 11 37605317

Paolo Marone, Civil Engineer

President of the International Italy Marble Institute. Civil Engineer from the Polytechnic University of Naples specialized in Stone Structural Design, Paolo Marone is an international stones expert, with more than 30 years of experience in stones quarrying, processing, installation and conservation and stones wastes recycling. President of the International Marble Institute of Italy – IS. I.M (Istituto Internazionale del Marmo founded by CONFINDUSTRIA MARMOMACCHINE, Italy). He has assessed and developed consultancy of training, quarries opening, factories realizations and natural stone architectural projects in more than 50 countries. IS.I.M.
Istituto Internazionale del Marmo - International Marble Institute
Corso Sempione n. 30 – MILANO
Via Manzoni n. 298 – NAPOLI
paolo.marone@stonetechtraining.it / +39 02315354

Caroline Umbinger de Oliveira, undergraduate Civil Engineer

Intern at Chimica Edile do Brasil
caroldryd1@gmail.com

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# Life Cycle Inventory of dimension stone supply chain technologies

**Isabella Bianco, Gian Andrea Blengini**

**Synopsis**

The dimension stone sector is more and more active in developing new solutions to improve the sustainability of its supply chain, partly as a consequence of the current EU policies on Circular Economy and Raw Materials. The Life Cycle Assessment (LCA) is a recognized scientific tool for evaluating environmental impacts of the processes. Nevertheless, in the stone sector, LCA is hindered by the scarce availability of Life Cycle Inventory (LCI) datasets for the specific technologies of the stone supply chain. This abstract shows the main achievements of a research project which developed LCI datasets of the most common and widespread technologies for stone quarrying, cutting and finishing. To this aim primary data were collected in Italian quarries and processing plants of both soft and hard stones and in enterprises that produce cutting tools which are commonly used in the stone sector. When necessary, industry data were complemented with secondary data from literature. The uncertainty of the resulting LCI datasets has been evaluated through the calculation of standard deviation on collected primary data and on impact results. The availability of these datasets is expected to boost the use of LCA and the enhancement of the stone sector sustainability.

**Keywords**

Life Cycle Inventory, LCI dataset, Stone supply chain, Stone production technologies, LCA.

## Introduction

The sustainability of the dimension stone sector is an issue of growing interest, for both stone enterprises and researchers in the Raw Material field. A sustainable stone supply chain is more and more required for enterprises who want to export their stone products or make them eligible to public procurements. These requirements are in line with the current European Circular Economy and Raw Material policies, which are encouraging the passage from a linear economy (made of the phases of extraction-production-use-disposal) to a circular economy, "*where the value of products, materials and resources is maintained in the economy for as long as possible*" (European Commission, 2015). To put in practice these concepts, the Life Cycle Assessment (LCA) has been identified as the "best framework for assessing the potential environmental impacts of products" by the European Commission's Integrated Product Policy Communication (COM (2003) 302). LCA is indeed a scientific and standardized tool, which considers the entire life cycle of a product/process in order to quantify materials, energy and emissions and to evaluate the environmental consequences. Nevertheless, in the stone sector, LCA is hindered by the current scarce availability of Life Cycle Inventory (LCI) datasets on the specific technologies of the stone sector.

In this framework, the present abstract aims at showing the main achievements of a PhD research project (2014-2017), whose goal is to model and make available environmental LCI datasets of the most common technologies of the dimension stone supply chain, with particular reference to the Italian stone sector. In literature, some Life Cycle Assessments (LCA) on stone supply chain have already been carried out, which were particularly focused on input flows of energy and water resources, while environmental impacts connected to the production and consumption of cutting tools were just marginally taken into account. In

Italy, Nicoletti et al. (2002) compared the environmental impact of ceramic and marble tiles; while other LCA studies were carried out to improve the stone supply chain of Perlato marble from Sicily (Traverso et al., 2010) and of Firenzuola stone from Tuscany (Torricelli and Palumbo, 2016). In other countries, LCA on stone products were developed by Taxiarchou (2007), Crishna (2011), Gazi et al. (2012), Ioannidou (2014) and Catarino et al. (2016). While the cited researches mainly aimed at evaluating the sustainability of specific stone production chains, another, more global, approach has been followed by the Brazilian research group of CETEM (Centro de Tecnologia Mineral) (Castoldi Borlini Gadioli et al., 2012), which developed (and is currently updating) a Life Cycle Inventory of the average production of stone slabs in Brazilian enterprises. Similarly to this latter, the study presented in this abstract refers to average data representative of the dimension stone sector, but with focus on the single technologies commonly employed in Italy (but highly exported also in the major stone production countries). The public availability of these LC datasets is expected to boost to use of the LCA tool among stone enterprises and to provide data able to support researchers and decision makers.

## Materials and methods

To develop significant LCI datasets it has firstly been necessary to identify the most common and widespread technologies currently employed for quarrying, cutting and finishing stone materials. Since the techniques generally vary according to the hardness of the stone, primary data were collected in Italian quarries and processing plants of both soft stones (mainly marbles from Carrara district) and hard stones (mainly gneisses from Verbano-Cusio-Ossola province and Luserna-Rorà district). Secondary data from literature (Primavori (1999), Cardu (2012, 2013), Careddu (2013), Giuffrida (2010), Traverso (2010), Capitano (2011), Masciullo (2016)) were also collected to evaluate the representativeness of the identified techniques also in other extractive areas. Secondly, the identified techniques were analyzed in detail to build the correspondent LCI dataset. Following the guidelines of the ILCD Handbook (European commission - Joint Research Centre, 2010), the quantitative data of the relevant input and output flows of the process were collected. Primary data were collected from: 4 marble quarries (2 located in the Carrara district and 2 in Piedmont); 10 gneiss quarries (located Turin and Verbano-Cusio-Ossola provinces); 7 processing plants (2 located in Carrara basin, 3 in Verbano-Cusio-Ossola province, 2 in Turin province); 3 enterprises connected to the ornamental stone supply chain (1 located in Carrara district, producing diamond wires; 1 located in Verbano-Cusio-Ossola province, producing cutting tools, 1 located in Liguria, producing sintered elements). When necessary, secondary data (from papers, patents and technical sheets) were also collected to complete the inventory or to cross-check the measured data. On the basis of these data, the average datasets of the stone supply chain techniques were modeled using Gabi software. Finally, data uncertainty on the collected data was handed through the calculation of the standard deviation, to assess the value ranges around the mean values and to evaluate the consequent precision of the LCI datasets. The modelled LCI datasets have been also submitted to an internal quality control based on impact assessment results. Uncertainty analyses have been developed through the calculation of standard deviation on the impact results and through Monte Carlo stochastic simulations, which evaluate the stability of the results toward random parameters constellations.

## Results

LC datasets were modeled for the processes listed in Tab. 1, identified as the most widespread in the Italian stone supply chain. Since the main LC databases do not have availability of some datasets related to specific tools consumed in quarries and processing plants, these latter have also been modeled.

Table 1 List of the developed LCI datasets, divided according to the stone production phases. Letter S identifies processes employed with soft stones, letter H identifies processes for hard stones.

| PHASE | DATASETS OF STONE PROCESS | DATASETS OF SPECIFIC TOOLS |
|---|---|---|
| QUARRYING | Discontinuous drilling (S, H)<br>Dynamic splitting (H)<br>Diamond wire technique (S, H)<br>Chain cutting technique (S) | Diamond wire/beads<br>Black powder<br>Slow-burning fuse<br>Detonation cord<br>Drilling rod |
| CUTTING | Squaring with mono diamond wire (S, H)<br>Squaring with mono diamond blade (S, H)<br>Squaring with giant disk (H)<br>Cutting with multi-blade gang saws (H)<br>Cutting with diamond multi blades (S)<br>Cutting with diamond disks (S, H) | Diamond wire/beads<br>Diamond blade<br>Diamond disks/sectors |
| FINISHING | Polishing with abrasives (S, H) | Metal abrasive<br>Resin diamond abrasive |

The standard deviation calculated on the collected data was, in some cases, quite high (up to 77%). This is reasonably due to the intrinsic variability of natural stone materials and to differences in enterprises practices. Nevertheless, the distribution on impact assessment results (for the impact categories of Climate change, Ozone, Metal, Fossil and Abiotic Depletions) calculated through the Monte Carlo analysis was generally lower (around 10%). To overcome the variability of the input flows, parameters were inserted into datasets in order to allow an easy adaptation to specific productions.

## Conclusions

The development of LCI datasets on stone cutting and finishing technologies is expected to provide a support to enterprises and LCA practitioners working in the field of dimension stone sector sustainability. Further details on the research project presented in this abstract and on the developed datasets will be available in the doctoral thesis of I. Bianco.

## Acknowledgments

Authors are pleased to thank all the owners, managers and workers of enterprises which collaborated to the project and provided primary data for the development of the LCI datasets.

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## About the authors

Isabella Bianco, PhD student

Politecnico di Torino, Department of Environment, Land and Infrastructure Engineering (DIATI), Corso Duca degli Abruzzi 24, 10129 Turin, Italy. isabella.bianco@polito.it.

Gian Andrea Blengini, Professor

Politecnico di Torino, Department of Environment, Land and Infrastructure Engineering (DIATI), Corso Duca degli Abruzzi 24, 10129 Turin, Italy. blengini@polito.it.

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