INSTITUTE OF ARCHAEOLOGY

BELGRADE, SERBIA

1ST INTERNATIONAL CONFERENCE WITH WORKSHOP

SCIENCE FOR CONSERVATION OF THE DANUBE LIMES

Mortar Design for Conservation – Danube Roman Frontier

2000 Years After

PROGRAMME AND ABSTRACTS

VIMINACIUM, SERBIA

JUNE 27TH - JULY 1ST, 2022

INSTITUTE OF ARCHAEOLOGY

BELGRADE, SERBIA

1ST INTERNATIONAL CONFERENCE WITH WORKSHOP

SCIENCE FOR CONSERVATION OF THE DANUBE LIMES

Mortar Design for Conservation – Danube Roman Frontier

2000 Years After

PROGRAMME AND ABSTRACTS

VIMINACIUM, SERBIA

JUNE 27TH - JULY 1ST, 2022

Publisher:
Institute of Archaeology, Kneza Mihaila 35/IV, 11000 Belgrade, Serbia
institut@ai.ac.rs; https://ai.ac.rs; tel. +381 11 2637-191
Editor in Chief:
Miomir Korać, Institute of Archaeology, Belgrade, Serbia
Editors:
Emilija Nikolić, Institute of Archaeology, Belgrade, Serbia
Mladen Jovičić, Institute of Archaeology, Belgrade, Serbia
Graphic Design:
Emiija Nikolić, Institute of Archaeology, Belgrade, Serbia
Mladen Jovičić, Institute of Archaeology, Belgrade, Serbia
Proofreading:
Dave Calcutt
Book Illustration: Nikola Korać
Cover Photo: Photo-documentation of the MoDeCo2000 Project

ISBN 978-86-6439-072-9
This publication was created by the funding support of the Science Fund. The Institute of Archaeology is solely responsible for the content of this publication and it does not express the views of the Science Fund of the Republic of Serbia.

Scientific Programme Committee

Prof. Dr Emeritus Ioanna Papayianni, Aristotle University of Thessaloniki, Thessaloniki, Greece
Prof. Dr Vladica Cvetković, University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia
Dr Miomir Korać, Institute of Archaeology, Belgrade, Serbia
Prof. Dr Jonjaua Ranogajec, University of Novi Sad, Faculty of Technology Novi Sad, Novi Sad
Dr Zagorka Radojević, Institute of Testing of Materials, Belgrade, Serbia
Prof. Dr Maria Stefanidou, Aristotle University of Thessaloniki, Laboratory of Building Materials, School of Civil Engineering, Thessaloniki, Greece
Prof. Dr Ana Radivojević, University of Belgrade, Faculty of Architecture, Department of Architectural Technologies, Belgrade, Serbia
Prof. Dr Anna Arizzi, University of Granada, Department of Mineralogy and Petrology, Faculty of Science, Granada, Spain
Dr Andreja Sironić, Ruđer Bošković Institute, Zagreb, Croatia
Prof. Dr Michele Secco, University of Padua, Department of Cultural Heritage; Inter-Departmental Research Centre for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy
Dr Yotam Asscher, Israel Antiquities Authority, Jerusalem, Israel
Dr Florian Matei Popescu, Vasile Pârvan Institute of Archaeology, Bucharest, Romania
Dr Emilija Nikolić, Institute of Archaeology, Belgrade, Serbia
Dr Mladen Jovičić, Institute of Archaeology, Belgrade, Serbia
Dr Snežana Vučetić, University of Novi Sad, Faculty of Technology Novi Sad, Novi Sad

Organisational Committee

Dr Emilija Nikolić, Institute of Archaeology, Belgrade, Serbia
Dr Mladen Jovičić, Institute of Archaeology, Belgrade, Serbia
Ivana Kosanović, Institute of Archaeology, Belgrade, Serbia
Dr Nemanja Mrđić, Institute of Archaeology, Belgrade, Serbia
Dr Ivan Bogdanović, Institute of Archaeology, Belgrade, Serbia
Dr Bojan Popović, Institute of Archaeology, Belgrade, Serbia
Dr Igor Bjelić, Institute of Archaeology, Belgrade, Serbia
Kristina Ponjavić, Institute of Archaeology, Belgrade, Serbia
Ljubomir Jevtović, Institute of Archaeology, Belgrade, Serbia
Dr Dragana Gavrilović, Institute of Archaeology, Belgrade, Serbia

CONTENTS

PREFACE

The dust that a building is transformed into when it becomes a ruin holds precious traces of the past. The hands of an archaeologist will search through it patiently, and find a necklace bead of a woman that lived in it. The hands of an architect will virtually transform the dust into a mortar, brick, or stone. The first profession sees through the unbuilt. The second one builds from it. However, both perform their work by communicating with the sciences.

Throughout history, various components were chosen, measured, and mixed into one of the most complex building composites ever - mortar, whose re-creation is of invaluable importance for architectural conservation. Geologists and chemists will best tell us about its composition. However, sometimes, while excavating a ruined wall, an archaeologist finds a mortar trowel, accidentally left by the past builder. Is this a more valuable trace for revealing the creation of a wall than the binder/aggregate ratio of the mortar used? Can we pick it up and imagine the hands that combined colourful aggregate grains with the earth, gypsum, lime, or cement?

From the exploitation, transport, and use of raw materials, to the product called mortar, we pass by the people from the past, the quarries, roads, and rivers, we look at the craftsmen working with tools, and observe the investors negotiating with engineers, and the rulers supervising the construction. The four hands from the beginning of the story can combine the chemistry of the red, blue, green, yellow, black, and white mineral grains with the found trowel, and help us revive many

unknown hands from the past. Thus, the research of historic mortars for conservation purposes must not be a purely technical process. Only by understanding the multiple values of a historic building, we can adequately protect it.

The project Mortar Design for Conservation – Danube Roman Frontier 2,000 Years After (MoDeCo2000), funded by the Science Fund of the Republic of Serbia, was created with the sincere intent and great hope that it could help in the future discoveries and preservation of the rich heritage in Serbia from the period of the magnificent Roman Empire, whose Danubian monuments are part of the preliminary list for UNESCO World Heritage. Different researchers and professionals - architects, archaeologists, geologists, chemists, materials scientists, physicists, biologists, restorers, craftsmen, and managers have all made an effort to get closer to the fulfilment of the wish of the project creators.

After sampling and investigating numerous mortars originating from the structures dating to the period from the 1st to the 6th century, many conclusions were made, but challenges for future researchers and conservators also arose, telling us we need to continue our work in the future, in an attempt to gain more knowledge and, thus, preserve our heritage more adequately.

We welcome you to the Viminacium Archaeological Park and the 1st International Conference with Workshop, Science for Conservation of the Danube Limes. With the hope that many new fruitful collaborations between our guest researchers will be developed on this occasion, taking us one step further towards long-term technical

solutions for architectural conservation and civil engineering based on nature, but also to new cognitions about the life of the past people, always for the cause of the preservation of rich world material and immaterial cultural heritage and our planet, we invite you to peruse this publication. All the authors have shown their enormous affection and passionate devotion towards the discoveries of ancient knowledge, advocating its use in the further preservation of the most monumental physical witnesses of the past – buildings, for future generations.

EDITORS

Members of the MoDeCo2000 Project team:

Dr Emilija Nikolić, PI, Institute of Archaeology, Belgrade
Dr Mladen Jovičić, Institute of Archaeology, Belgrade
Dr Snežana Vučetić, University of Novi Sad, Faculty of Technology Novi Sad, Novi Sad
Dr Jonjaua Ranogajec, University of Novi Sad, Faculty of Technology Novi Sad, Novi Sad
Ljiljana Miličić, Institute for Testing of Materials (IMS Institute), Belgrade
Ivana Delić-Nikolić, Institute for Testing of Materials (IMS Institute), Belgrade
Dr Nevenka Mijatović, Institute for Testing of Materials (IMS Institute), Belgrade
Dr Biljana Ilić, Institute for Testing of Materials (IMS Institute), Belgrade

PROGRAMME

MONDAY, JUNE 27TH

08.30 – 10.00 *Breakfast / Coffee and registration*

WELCOME AND INTRODUCTORY SPEECHES

10.00 – 10.40
MIOMIR KORAĆ, Institute of Archaeology, Director
EMILIJA NIKOLIĆ, Institute of Archaeology, PI MoDeCo2000
DUBRAVKA ĐUKANOVIĆ, Institute for the Protection of Cultural Monuments of Serbia Belgrade, Director
JAROSLAV KATONA, Faculty of Technology Novi Sad, University of Novi Sad, Vice Dean for Finances

10.40 – 11.00 NEMANJA MRĐIĆ, IVANA KOSANOVIĆ, MILICA MARJANOVIĆ
Danube Limes in Serbia: On the Way to a UNESCO World Heritage Site – Problems, Challenges and Solutions

11.00 – 11.20 EMILIJA NIKOLIĆ, MLADEN JOVIČIĆ, IVANA DELIĆ-NIKOLIĆ, LJILJANA MILIČIĆ, SNEŽANA VUČETIĆ, JONJAUA RANOGAJEC
Our MoDeCo2000: Results Overview of the Scientific and Research Project

11.20– 11.40 *Coffee break with snack*

LECTURES

11.45 – 12.05 MLADEN JOVIČIĆ

Researching Roman Mortars from the Danube Region - Archaeological Perspective of the MoDeCo2000 Project

12.05 – 12.25 SNEŽANA VUČETIĆ, JONJAUA RANOGAJEC, IVANA DELIĆ-NIKOLIĆ, LJILJANA MILIČIĆ, EMILIJA NIKOLIĆ, MLADEN JOVIČIĆ

Design of Compatible Mortars for Conservation Interventions

12.25 – 12.45 EUGEN VAIDA, VERONICA VAIDA, ALEXANDRA TEODOR

The Ambulance for Monuments - Safeguarding Heritage through Community Engagement

12.45 – 13.30 NIGEL COPSEY

Rediscovering Traditional Mortars, part 1

13.30 – 14.30 *Lunch break*

LECTURES

14.35 – 15.20 NIGEL COPSEY

Rediscovering Traditional Mortars, part 2

15.20– 15.35 *Coffee break*

LECTURES

15.40 – 16.25 NIGEL COPSEY

Rediscovering Traditional Mortars, part 3

17.00 – 18.30 *Viminacium sightseeing*

18.30 – 19.30 *Dinner*

21.00 *Viminacium Fest / Theatre festival*

(Closing night in the Viminacium amphitheatre with a jazz concert)

TUESDAY, JUNE 28TH

07.30 – 09.00 *Breakfast / Coffee*

PRACTICAL WORKSHOP ON LIME MORTARS

09.00 – 13.00 NIGEL COPSEY DEMONSTRATION
Building Experimental Structures of Brick and Stone with Lime Mortar

13.30 – 14.30 *Lunch break*

LECTURES

14.35 – 15.05 VLADICA CVETKOVIĆ, KRISTINA ŠARIĆ
Tuffs of Serbia – What We Need to Know when Characterising Them as Archaeological Raw Material

15.05 – 15.35 KRISTINA ŠARIĆ, SUZANA ERIĆ, VLADICA CVETKOVIĆ, JOSIP ŠARIĆ, DRAGANA ANTONOVIĆ, VESNA BIKIĆ
Geological Knowledge in Service to Archaeological Investigations: Rock and Ceramic Findings as Examples

15.35 – 15.55 YOTAM ASSCHER, MICHELE SECCO, GIULIA RICCI, SERGIO TAMBURINI, GILBERTO ARTIOLI *(virtual)*
Evaluation of Ancient Mortars Hydraulicity through the Characterisation of Long and Short-range Crystallinity

15.55 – 16.15 LJILJANA DAMJANOVIĆ VASILIĆ, VESNA BIKIĆ, SRNA STOJANOVIĆ, IVANA RADOSAVLJEVIĆ EVANS, DANICA BAJUK – BOGDANOVIĆ, IVANKA HOLCLAJTNER – ANTUNOVIĆ
Physicochemical Characterisation of the Medieval Pottery Excavated in Serbia

16.15 – 16.35 *Coffee break with snack*

LECTURES

16.40 – 17.00 MARIA STEFANIDOU
Technological Characteristics of Fired Bricks from Roman and Byzantine Period in Greece

17.00 – 17.20 SIMONE DILARIA, CATERINA PREVIATO, JACOPO BONETTO, MICHELE SECCO, ARTURO ZARA, DOMENICO MIRIELLO, RAFFAELLA DE LUCCA, GILBERTO ARTIOLI
Pyroclastic Rocks in the Structural Mortars of Roman Nora (Sardinia). A Green Material for the Production of Sustainable Concretes in Antiquity

17.20 – 17.40 ANNA ARIZZI
Learning from Historic Mortars: Studies on Lime Manufacturing and Fresco Conservation

17.40 – 18.00 MICHELE SECCO SIMONE DILARIA, GIULIA RICCI, ENRICO GARBIN, SERGIO TAMBURINI, YOTAM ASSCHER, GILBERTO ARTIOLI, CATERINA PREVIATO, JACOPO BONETTO
Novel Scientific Perspectives on Ancient Pozzolanicity

18.00 – 18.20 ANDREJA SIRONIĆ *(virtual)*

Radiocarbon Dating of Historical Mortars

18.30 – 19.30 *Dinner*

WEDNESDAY, JUNE 29TH

International Danube Day

07.30 – 09.00 *Breakfast / Coffee*

LECTURES

09.00 – 09.20 IVAN BOGDANOVIĆ

Roman Construction Techniques Used on the Viminacium Amphitheatre

09.20 - 09.40 FLORIAN MATEI-POPESCU

New Archaeological Excavations at the Drobeta Military Amphitheatre

09.40 – 10.00 JASMINA POPOVIĆ RUSIMOVIĆ

Restoration of Ram Fortress

EXCURSION

10.15 – 11.20 Viminacium – Golubac Fortress

11.30 – 12.30 Golubac Fortress Tour

12.40 – 13.45 Golubac Fortress - Golubinje

14.00 – 17.00 Hiking to viewpoint Ploče and back (lunch package at the top)

17.15 – 19.05 Golubinje – Ram Fortress

19.15 – 20.30 Ram Fortress tour

20.30 – 21.10 Ram Fortress – Viminacium

21.10 – 22.10 *Dinner*

THURSDAY, JUNE 30TH

07.30 – 09.00 *Breakfast / Coffee*

PRACTICAL WORKSHOP ON LIME MORTARS

09.00 – 13.00 NIGEL COPSEY DEMONSTRATION

Testing Conservation Mortar Mixtures on a Part of an Authentic Structure

13.30 – 14.30 Lunch break

LECTURES

14.35 – 15.05 IOANNA PAPAYIANNI

Analysis of Ancient Mortars from Roman Monuments in Northern Greece. Design and Application of Compatible Repair Mortars

15.05 – 15.25 SLAVICA VUJOVIĆ, RASTKO VLAJKOVIĆ

Holism as a Framework for Understanding and Preserving Heritage – the Example of the Cultural Landscape of Bač

15.25 – 15.45 BURCU TAŞCI ÖZDEMIR, HASAN BÖKE *(virtual)*

Raw Material Characterisation of Roman Mortars in Western Anatolia (Turkey)

15.45 – 16.05 ALEKSA JELIKIĆ

Lime Kiln. The Divine Crucible

16.05 – 16.25 LJUBOMIR JEVTOVIĆ

Ceramic Building Materials of Viminacium

16.25 – 16.45 *Coffee break with snack*

LECTURES

16.50 – 17.10 ANA RADIVOJEVIĆ

The Role of Brick in the Late Antique Architecture of the Central Balkan Roman Provinces

17.10 – 17.30 IGOR BJELIĆ

Construction Methods Applied to the Structures of the Trajan's Bridge over the Danube

17.30 – 17.50 BOJAN POPOVIĆ

Reconsidering the Archaeological Site of Glamija – Rtkovo, Serbia

17.50 – 18.10 TINO LELEKOVIĆ

How to Present the Ancient City of Aelia Mursa

18.10 – 18.30 HELENA HIRŠENBERGER, SNEŽANA VUČETIĆ, JONJAUA RANOGAJEC

Cross-disciplinary Collaboration in Conservation Projects – Managing Key Challenges

18.30 – 19.30 *Dinner*

FRIDAY, JULY 01ST

07.30 – 09.00 *Breakfast / Coffee*

LECTURES

09.00 – 10.30 BRANKO ORBANIĆ

Traditional Lime Production and its Application on the Monuments of Culture – Experience from the Work on Ancient Monuments

10.30 – 10.50 *Coffee break with snack*

LECTURES

10.55 – 11.15 MAJA FRANKOVIĆ, VESNA MATOVIĆ, NEVENKA NOVAKOVIĆ

Intrinsic Properties of the Limestone Used in the Belgrade Fortress and their Influence on Degradation Processes

11.15 – 11.35 DRAGANA GAVRILOVIĆ

Analyses of the Pigments and Plasters on the Examples of Roman Wall Paintings from Sirmium and Viminacium

11.35 – 11.55 MARIA ARGIROVA, GERGANA KABAKCHIEVA, DENITSA YANCHEVA, BISTRA STAMBOLIYSKA, NIKIFOR HARALAMPIEV, DIETER FISCHER, ALBENA LEDERER

Pigment Identification in the Mural Decoration from the Roman City of Ulpia Oescus by Vibrational Spectroscopy and SEM-EDS Analysis

11.55 -12.15 NIKOLA UNKOVIĆ, ŽELJKO SAVKOVIĆ, MILOŠ STUPAR, ALEKSANDAR KNEŽEVIĆ, IVICA DIMKIĆ, MILICA LJALJEVIĆ GRBIĆ
Fungal Proliferation on Fresco Painting: Deterioration of Mortar and Painted Layer

12.15 – 12.35 IVAN VANJA MARTINOVIĆ
Benefits and Limits of DRMS Technology in the Purpose of Designing Repair Mortars by Drilling Resistance Criterion

12.35 – 12.50 *Coffee break with snack*

LECTURES

12.55 – 13.15 MARKO NIKOLIĆ, ENA TAKAČ, JELENA ŠĆEKIĆ
Contemporary Approaches to the Revitalisation, Presentation and Promotion of Cultural and Natural Heritage of the Part of the Roman Limes - Case Study of the Late Antique Tomb in Brestovik

13.15 – 13.35 SILVANA BLAŽEVSKA, ANGELA PENCHEVA *(virtual)*
Master Conservation Plan for the Archaeological Site of Stobi: Goals and Outcomes

13.35 – 13.55 BOJAN MILJEVIĆ, ALENKA MAUKO PRANJIĆ, SERGEY E. KICHANOV, SNEŽANA VUČETIĆ
Computed Tomography as a Tool for Non-destructive Investigation of Cultural Heritage Materials' Inner Structure

13.55 – 14.15 ROMAN BALVANOVIĆ, PERICA ŠPEHAR, DRAGANA SPASIĆ-ĐURIĆ, OLIVERA MILOVIĆ, MIHAILO MILINKOVIĆ

Roman, Late Antique and Byzantine Window Glass from 3rd – 6th Century in Serbia: Chemical Characteristics, Compositional Groups and Provenance

14.15 – 14.30 *Closing of the event*

14.30 – 15.30 *Lunch*

SPECIAL GUEST OF THE WORKSHOP

NIGEL COPSEY, Stonemason and Building Conservator

Starting out as a dry-stone waller in Cornwall, Nigel trained after 1989 as a stonemason and carver at Weymouth College, working largely thereafter in the conservation industry across the south and south-west of England, as well as travelling widely in the USA, working and advising upon building conservation projects in Vermont, New York City and Nebraska as well as in Granada, Andalusia, and, more recently, in British Columbia and Alberta, Canada.

Nigel was consultant stonemason for the Irish Hunger Memorial project in Battery Park City, New York, 2001. Since 2001, Nigel has worked extensively as a consultant and practitioner in the field of building conservation and repair in North Yorkshire on a wide range of vernacular and high status buildings, as a building conservation consultant for the Fitzwilliam Estate in Malton, 2003-2010, designing, specifying and executing major repair projects on a wide range of historic buildings within the town, as well as researching, designing and specifying a number of building repair and conservation projects on behalf of Natural England, most recently at Scampston Hall.

A committed SPAB-member, Nigel is also a professionally accredited conservator-restorer and determined advocate for the thoroughgoing use of traditional materials in the care and repair of old buildings, and a leading advocate for the routine use of traditional

earth-lime and hot mixed lime mortars for most applications, working with Historic England, Historic Environment Scotland and CADW and international partners in the delivery of practical training and education regarding the informed use of traditional quicklime mortars for the like for like and compatible repair of historic buildings. In recent years, Nigel has worked closely with the North York Moors National Park, educating and upskilling builders and professionals regionally in the use of like-for-like traditional mortars.

A Research Associate of the Department of Archaeology, University of York, Nigel regularly delivers hot mixed earth and lime mortars and traditional skills training and led the Practical Skills module for the MA Conservation Studies 2012-2018. Nigel has a BA (Hons) in Political Science from the University of York, a PGDip in Building Conservation from Bournemouth University, and an MA (by research) awarded by the University of York in 2019, for his critical review of historic texts, thinking and craft practice in the preparation and use of lime (and earth-lime) mortars.

Nigel has contributed to several volumes of the recently published Historic England Practical Conservation series. He has published a book on the subject of Traditional Mortars (2019) as well as a review of Historic Literature on Lime and Lime Mortars (HES Technical Paper 30 (2019).

www.nigelcopsey.com

www.maltonbuildingsgroup.com

www.hotmixedmortars.com

ABSTRACTS

DANUBE LIMES IN SERBIA: ON THE WAY TO A UNESCO WORLD HERITAGE SITE – PROBLEMS, CHALLENGES AND SOLUTIONS

NEMANJA MRĐIĆ
Institute of Archaeology, Belgrade, Serbia

IVANA KOSANOVIĆ
Institute of Archaeology, Belgrade, Serbia

MILICA MARJANOVIĆ
Institute of Archaeology, Belgrade, Serbia

ivana.kosanovic@yahoo.com

Since 1987, when the first part of the Roman Limes was inscribed to the UNESCO List of World Heritage, there has been an idea to unite this system, stretching over 5,000 km across the Roman provinces in Europe, the Near East and North Africa, into one big site – Frontiers of the Roman Empire (Ployer, Polak and Schmidt 2017). Apart from Hadrian's and Antonine's wall, the Lower Germanic, the Upper German-Raetian Limes and the western part of the Danube Limes have also been inscribed to this list so far.

The Danube Limes was divided into two segments – western

and eastern, with the parts in Germany, Slovakia and Austria already inscribed. The nomination of the eastern part of the Danube Limes is a joint project of four countries – Croatia, Serbia, Romania and Bulgaria.

The Limes section in Serbia is 450 km long. Archaeological prospection and excavations have confirmed the existence of approximately 80 sites, 10 in the province of Pannonia Inferior and 70 in Moesia Superior (Korać et al. 2014). For the revised Tentative List, 35 sites were selected (Tentative List). The Serbian part of the Danube Limes is comprised of a large number of fortifications. It features a variety of sites – two legionary fortresses, several larger and smaller auxiliary forts, a few watchtowers, ports and civil settlements, as well as some unique features (Korać et al. 2014; Petrović 1996).

During the preparation of the nomination dossier, the Serbian team (Institute of Archaeology Belgrade, The Institute for the Protection of Cultural Monuments of the Republic of Serbia, and the Commission of the Republic of Serbia for UNESCO) encountered many problems and challenges. Despite the diverse and unique features on the Serbian part of the Limes, many sites have not been visited for decades since the excavations and conservation, so they are inaccessible, overgrown with weeds, some of them not even marked. Not a small number of them still have no legal status as a cultural property, and they are at risk from modern construction or looters.

Submission of the Tentative List in 2015, followed by the formation of the working group for the preparation of the nomination

in 2019, initiated and intensified the work on all these problems. The process of acquiring the legal protection for the sites has begun, and geophysical surveys and drone imagery have been conducted on many sites. The production of an archaeological map of Serbia with sites on the Limes as a test sample has started and some of the sites have been excavated systematically for the first time. Those sites that were submerged have been proven to still exist using underwater sonar surveys.

The Danube Limes has been a point of interest of national and international projects in the last decade, ever since its promotion started with the projects Danube Limes Brand and Itinerarium Romanum Serbiae, more recently Living Danube Limes and MoDeCo2000, to name but a few of them.

Keywords – UNESCO, nomination, Danube, Limes, Roman frontier

References:

Korać, M. Golubović, S., Mrđić, N. Jeremić, G. and Pop-Lazić, S. 2014
Danube Limes in Serbia (Rimski limes u Srbiji), Belgrade: Institute of Archaeology.

Petrović, P. (ed.) 1996
Roman Limes on the Middle and Lower Danube, Belgrade: Institute of Archaeology.

Ployer, R., Polak, M. and Schidt, R. 2017
The Frontiers of the Roman Empire: A Tematic Study and Proposed World Heritage Nomination Strategy, Vienna, Nijmegen and Munich: Bundesdenkmalamt Österreich, Radboud Universiteit Nijmegen, Bayerisches
Landesamt für Denkmalpflege.

Tentative List
Frontiers of the Roman Empire – The Danube Limes (Serbia)
https://whc.unesco.org/en/tentativelists/6475/ Accessed: 01. 06. 2022.

OUR MODECO2000: RESULTS OVERVIEW OF THE SCIENTIFIC AND RESEARCH PROJECT

EMILIJA NIKOLIĆ

Institute of Archaeology, Belgrade, Serbia

MLADEN JOVIČIĆ

Institute of Archaeology, Belgrade, Serbia

IVANA DELIĆ-NIKOLIĆ

Institute for Testing of Materials, Belgrade, Serbia

LJILJANA MILIČIĆ

Institute for Testing of Materials, Belgrade, Serbia

SNEŽANA VUČETIĆ

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

JONJAUA RANOGAJEC

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

e.nikolic@ai.ac.rs

Project *Mortar Design for Conservation - Danube Roman Frontier 2000 Years after (MoDeCo2000)* deals with mortars used from the 1st to the 6th century AD along the part of the Danube frontier that is situated in the territory of today's Serbia and whose monuments form the UNESCO tentative list "Frontier of the Roman Empire - Danube Limes in Serbia". The mentioned territory was a provincial area in the Roman period, and the construction activities that happened in this part of the empire were not particularly interesting to the international scientific community dealing with Roman architecture. The aim of this project is to gain knowledge of ancient mortar technology in this area, to allow conclusions to be made about building activities, the exploitation and use of raw materials, as well as the everyday life of the people on the frontier. After interpreting the results obtained in laboratories of testing historical materials, the project is making compatible mixtures of mortars for the future conservation of the Limes monuments, using local raw materials, but also improving the properties of these mortars with different additions.

Mortar is a composite that can carry a large amount of information about the moment in which it was created, the skill of those who created it, and the conditions of the time during which it lasted. Different combinations of the same local raw materials have led to different mortar mixtures. The results of research during the project were often a surprise, and interesting findings were obtained not only where we expected them, as is the case with the famous

Trajan's Bridge, but also in many other buildings. However, the landscape of Viminacium, as a unique cultural-historical and natural entity along the Danube River, which we can roughly observe from the mouth of the Morava River to the village Ram, is a space about which we have the most knowledge and from which we have gained the most research experience. Its value for this type of research is its wide time period of interactions humans developed with their surroundings, which left the remains of buildings in it. From the ancient and early Byzantine Viminacium, through the medieval fortresses, to monasteries and traditional village houses built using Roman building materials and later industrial facilities, this area provides us with material remains for a wide variety of research. The samples of mortar are some of the most interesting remnants of this kind, which can be connected with the life of this region through the centuries, through the exploitation and availability of raw materials and traces of their wider distribution. Targeted sampling of mortars from the 12th and 15th centuries and their comparison with samples from the period from the 1st to the 6th century during the project proved to be extremely important in this sense.

Will we be able to characterise all the components of the sampled mortars in the future? The answer is certainly no, but it is important to note that this project is a big step in the research of historical building materials in Serbia. Lime, river sand, crushed stone and brick have always been visually recognisable in mortars of this territory and, in most cases, they were probably the only mortar

components. However, the possibility of using natural materials with pozzolanic properties on the territory of Serbia in the Roman period has not been fully investigated, and deposits of natural pozzolanic materials in Serbia have not been recognised as places of historic exploitation. Following this project, it would be justified to make an attempt to research this topic further but, first, it is necessary to investigate the role of these materials in mortars we have already sampled through the project, and whose analysis led us to this idea, as well as to explore their reactions with other components of mortars, and the possibilities of the formation of different minerals in the mortars themselves due to different reactions and external conditions.

Today, one step away from the end of the project, the work on the research of Roman mortars of the Danube Limes has shown the exceptional scope and importance of the topic of ancient building materials for a large number of fields of science. Accordingly, to our satisfaction, the project covered a much larger number of research aspects than was originally conceived. The previous experience of the associates of the Institute of Archaeology in the research of Roman monuments of the Danube Limes was crucial in the selection of monuments for sampling, with great professional help from the associates of scientific and cultural institutions. However, although mostly humanities questions have guided and directed this multidisciplinary project, their answers depend entirely on properly selected and combined analyses of engineers and researchers in the natural sciences, in the "ocean" of possibilities offered by modern

equipment and laboratory techniques.

After researching historical mortars and interpreting the results in order to make numerous trial conservation mixtures, the time will come when the selected, tested and proven ones will actually be applied during the conservation works on the monuments themselves. It is certain that then, through the contact of this material with the hands of modern masters, who will revive our research in that way, a new world of issues related to the technology of production and the methods of using mortars for the creation of Roman buildings on the territory of today's Serbia will be entered.

Keywords – Roman mortar, Danube Limes, raw materials, characterisation of materials, historical building

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

Artioli, A. 2010
Scientific Methods and Cultural Heritage. An Introduction to the Application of Materials Science in Archaeometry and Conservation Science, Oxford: Oxford University Press.

Henry, A. and Stewart, J. 2011
English Heritage Practical Building Conservation. Mortars, Renders & Plasters, Farnham: Ashgate Publishing Limited.

Korać, M., Golubović, S., Mrđić, N., Jeremić, G. and Pop-Lazić, S. 2014
Roman Limes in Serbia/ Rimski limes u Srbiji, Belgrade: Institute of Archaeology.

Nikolić, E., Tapavički-Ilić, M. and Delić-Nikolić, I. 2022
Viminacium Landscape (Trans)formation. in: *Handbook of Cultural Heritage Analysis*, eds. S. D'Amico and V. Venuti, Cham: Springer Nature Switzerland AG, 2109-2131.

UNESCO 2015
Frontiers of the Roman Empire – The Danube Limes in Serbia. https://whc.unesco.org/en/tentativelists/6475/. Accessed 28 February 2022

RESEARCHING ROMAN MORTARS FROM THE DANUBE REGION - ARCHAEOLOGICAL PERSPECTIVE OF THE MODECO2000 PROJECT

MLADEN JOVIČIĆ
Institute of Archaeology, Belgrade, Serbia

mladen_jovicic@yahoo.com

Lime mortar is a building material that has been used since the 8th millennium BC. For thousands of years, people used it to make floors or plaster walls, while it was used as structural mortar from the period of the Roman Republic, after the beginning of the 2nd century BC (Artioli, Secco and Addis 2019: 172-173). The addition of pozzolanic materials enabled the development of Roman cement (*opus cementicium*) and the erection of monumental and durable buildings (Adam 2005: 116-156). The first constructions built with lime mortar on the territory of modern-day Serbia appear in the 1st century AD, after the Roman conquest of these areas and their inclusion into the Roman Empire. Historical sources and fresco depictions testify to the manner of preparation and use of lime mortar during Antiquity. However, these sources mainly refer to the territories of modern-day Italy. The only sources for studying the technology of making lime mortar and the use of raw materials in the

territory of *Moesia Superior* and *Pannonia Inferior* are the physical remains of the buildings built using this material, as well as the remains of the mortar-making process (e.g., lime slacking pits).

The area of the Danube region, where the Roman fortified border, or Limes, was located, was the area of the most intensive Romanisation and urbanisation in the territory of modern-day Serbia. On the right bank of the Danube, military camps, towns, villages, and villas were erected, which were connected by roads (Korać et al. 2014). Therefore, this area was the best source for the study of mortar with the application of modern archaeometric analyses.

During the previous decade, research on Roman lime mortar became relevant, so samples from Viminacium, for example, were the subject of several scientific papers (Nikolić, Rogić, and Milovanović 2015; Nikolić et al. 2016). However, the MoDeCo2000 project is, to date, the most comprehensive research of this construction material to have been conducted in the wider territory of our country. The research included 23 Roman sites and a large number of buildings, where over 100 samples of mortar from the period from the 1st to the 6th century were taken, which were then examined using modern laboratory analyses and a multidisciplinary approach. The character of the sampled buildings is diverse. Primarily, samples came from military buildings, both legionary camps in *Moesia Superior* - *Viminacium* and *Singidunum*, as well as medium-sized fortifications and smaller forts, such as *Lederata, Novae, Cuppa, Diana, Pontes*, etc. Finally, fortlets, such as Rtkovo, Mora Vagei, and Ćetaće, were also

sampled. In general, the samples were mostly structural mortars from the ramparts, towers, or gates of military fortifications, but also military facilities within the camp. The second category of sample sites includes civilian objects. Remains of the city walls in *Sirmium* and Prahovo, the walls of the imperial palace, the horeum and the Early Christian basilica in *Sirmium,* thermal baths and a villa in *Viminacium*, thermal baths in *Margum*, monumental tombs in Brestovik and *Viminacium*, etc. The most monumental building is certainly Trajan's Bridge, where samples were taken from the core of the supporting pillars.

The sampled material covers a large variety of buildings and all the centuries of Roman presence in the territory of modern-day Serbia. This created an excellent base for the reconstruction of the ancient technology of building and usage of raw materials.

Keywords – Roman mortars, Danube Limes, Roman construction, conservation science, raw materials

Keywords – Roman mortars, Danube Limes, Roman construction, conservation science, raw materials

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

Adam, J.-P. 2005
Roman Building: Materials and Techniques, London and New York: Routledge.

Artioli, G., Secco, M and Addis, A. 2019
The Vitruvian legacy: mortars and binders before and after the Roman world, *EMU Notes in Mineralogy, Vol.* 20 (2019), *Chapter* 4: 151–202.

Korać, M. Golubović, S., Mrđić, N. Jeremić, G. and Pop-Lazić, S. 2014
Danube Limes in Serbia. Frontiers of the Roman Empire, Belgrade: Institute of Archaeology.

Nikolić, E., Radivojević, A., Delić-Nikolić and Rogić, D. 2016
Roman Mortars from the Amphitheatre of *Viminacium,* in: *Proceedings of the 4th Historic Mortars Conference (HMC 2016), Santorini, Greece*, eds. I. Papayianni, M. Stefanidou and V. Pachta, Thessaloniki: Laboratory of Building Materials, Department of Civil Engineering, Aristotle University of Thessaloniki, 137-144.

Nikolić, E., Rogić, D. and Milovanović, B. 2015
The Role of Brick in Hydraulicity of Viminacium Mortars: Decorative Mortars from the Thermae, *Archaeology and Science* 10 (2014): 71-92.

GEOLOGY OF RAW MATERIALS IN ROMAN MORTARS OF THE DANUBE LIMES IN SERBIA

IVANA DELIĆ-NIKOLIĆ
Institute for Testing of Materials, Belgrade, Serbia

EMILIJA NIKOLIĆ
Institute of Archaeology, Belgrade, Serbia

LJILJANA MILIČIĆ
Institute for Testing of Materials, Belgrade, Serbia

MLADEN JOVIČIĆ
Institute of Archaeology, Belgrade, Serbia

ivana.delic@institutims.rs

Geological building materials have always played a very important role in the construction of all types of buildings. They were among the first mineral raw materials exploited, processed, and used by man (Prikril et al., 2016). In most cases, these are raw materials of a local character, cheap, and easily available. Accordingly, geological building materials used to make Roman mortars, known for their enviable mechanical properties and durability, played a very

important role in the area of the Danube Limes in Serbia. Geologically, this area is built of petrologically different rocks of different geological ages. The rocks formed from the Palaeozoic to the Quaternary contain all the basic geological building materials: sand and gravel, stone, clay, etc.

Probably the most important and most exploited and used mineral raw material in the Roman mortars of this area is sand and, less frequently, gravel, from the alluvial deposits of the Danube and other local watercourses, created by the mechanical accumulation of clastic material made in the process of decay of parent rocks. These alluvial sediments of the Quaternary age have a heterogeneous mineralogical-petrographic composition, conditioned by the hydrogeological regime and geological structure, i.e., the character of the rocks exposed to decay within the catchment zones and geomorphological conditions. They consist of unevenly rounded grains of quartz, chert, quartzite, metamorphic rocks, sandstones, volcanic rocks, etc. As the grain size of these unbound rocks decreases, the percentage of minerals increases.

In addition to sand and gravel, in the area of the Danube Limes, local stone fragments were occasionally used as an aggregate for making mortar. Thus, in the area around the village of Ram, schist grains were used as an aggregate, the origin of which is most likely the surroundings of the village itself, i.e., the Ram-Zatonje area. These schists represent the oldest geological formations in the wider area. They have a low degree of metamorphism, caused by the intensive

transformation of volcanogenic-sedimentary rocks, i.e., gabbroid rocks and fine-grained sandstones, siltstones and clays. According to the mineral composition, these schists are determined as: epidote-chlorite-actinolytic, chlorite-epidote-mica-actinolytic, epidote-amphibolytic, sericite-muscovite, muscovite, chlorite and chlorite-sericite-quartz.

Limestones are of special importance among geological building materials, as raw materials for lime production. Limestones are not very common in the area of the Danube Limes, they can be found in the area of Belgrade, in the vicinity of Golubac, and Veliko Gradište, along the Danube gorge. They are mostly Mesozoic, Cretaceous and Jurassic, but in the area of Belgrade, the Danube Key and in the vicinity of Donji Milanovac there are lithotamnian limestones with numerous remains of marine fauna. They are Tortonian, i.e., middle Miocene age.

In the area of Viminacium, crushed or ground bricks were often used as an aggregate, but also as an additive to mortars. In this area, brick raw materials had a significant distribution, so in accordance with that, Viminacium was a provincial centre for brick production. These raw materials are genetically related to Quaternary sediments, more precisely the occurrence of loess and clay, in the area of Požarevac ridge and villages around Kostolac: Kličevac, Majilovac, Kurjače, etc. In addition to brick and stone, “naturally baked bricks” were used to build ancient Viminacium. These were known locally as "crvenka", and were formed as a product of combustion of clay

sediments after self-ignition of coal deposits, which was found to have certain pozzolanic properties and is, therefore, assumed to have been added to lime mortars after crushing or grinding to improve their properties.

Natural materials with pozzolanic properties certainly played an important role in the production of historical mortars of the Danube Limes, and research into their use is still in its early stages. Since they did not necessarily have to be local raw materials, the process of their identification, role, importance, origin, etc. is a challenging task for researchers of various disciplines, and it can bring extremely important knowledge to the field of exploitation and use of raw materials and their transport, such as the economic flows between different territories in a given historical period.

Keywords - Roman mortars, raw materials, local resources, geological landscape, Danube Limes

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

Fragata, A., Candeias, C., Ribeiro, J., Braga, C., Fontes, L., Velosa, A. and Rocha, F. 2021 Archaeological and Chemical Investigation on Mortars and Bricks from a Necropolis in Braga, Northwest of Portugal, *Materials* 14, 6290: 1-17.

Korać, M., Golubović, S., Mrđić, N., Jeremić, G. and Pop-Lazić, S. 2014 *Roman Limes in Serbia/ Rimski limes u Srbiji*, Belgrade: Institute of Archaeology.

Pachta, V., Stefanidou, M., Konopisi, S., Papayianni, I. 2014
Technological Evolution of Historic Structural Mortars, *Journal of Civil Engineering and Architecture* 8/7(80): 846-854.

Rakić, M. 1979
Osnovna geološka karta SFRJ 1:100.000. Tumač za list Bela Crkva (L34-115), Beograd: Savezni geološki zavod.

Стојановић, Д. 1968
Вулкански туфови и седиментне стене у Србији са садржајем зеолита, Краљево, Београд: Институт за ватростална материјале, Српско геолошко друштво.

ENERGY DISPERSIVE X-RAY FLUORESCENCE IN THE INVESTIGATION OF THE COMPOSITION OF HISTORICAL MORTARS

NEVENKA MIJATOVIĆ
Institute for Testing of Materials, Belgrade, Serbia

LJILJANA MILIČIĆ
Institute for Testing of Materials, Belgrade, Serbia

IVANA NIKOLIĆ-DELIĆ
Institute for Testing of Materials, Belgrade, Serbia

BILJANA ILIĆ
Institute for Testing of Materials, Belgrade, Serbia

nevenka.mijatovic@institutims.rs

The use of X-ray fluorescence (XRF) spectrometers has increased in recent years due to its easy, rapid, non-destructive analysis and multiple element quantification. In this paper, XRF is proposed as a high-speed technique for classifying mortars from constructions of high historical value. Traditional wet chemistry methods for mineral dissolution in mortar are expensive and time-

consuming. The current energy dispersive X-ray fluorescence (EDXRF) devices are able to provide a lot of data (Gianoncelli et al. 2008). There are a few different options for quantifying elements, such as developing an empirical calibration and using a method based on fundamental parameters.

For this purpose, in the scope of the project MoDeCo2000 research, the performance of an energy dispersive X-ray fluorescence spectrometer (Spectro Xepos (Germany)) was evaluated using data analysis of Roman mortars sampled from the buildings situated along the Danube River in Serbia.

The aim of this work is to compare results gained during the research of the samples of historical mortars using two different methodologies (empirical calibration and fundamental parameters). Fundamental parameters are based on the physical theory of X-ray production rather than on empirical relationships between observed X-ray count rates and concentrations of standards (Janssens 2003). This quantification methodology is not particularly reliable, especially when analysing samples with very complex matrices, such as building materials. The methodology of empirical calibration based on used reference materials and eliminating matrix effects produces reliable results (Gullayanon 2011). The accuracy of the semi-quantitative results provided by the EDXRF spectrometer was compared with a previously validated and optimized EDXRF quantification method. Complete comparative research data treatment is followed by an ANOVA and t test as statistical methods for comparison of results (Baxter 2006).

However, a method based on fundamental parameters is utilised for qualitative assessments in an unknown matrix of samples. The analytical method based on an empirical calibration gives better results for quantitative results.

Keywords – chemical analysis; X-ray fluorescence, characterisation of historical mortars; Roman mortars; statistical verification of methodology

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

Baxter, 2006
A review of supervised and unsupervised pattern recognition in archaeometry, *Archaeometry* 48 (4) (2006): 671–694.

Gianoncelli, A., Castaing, J., Ortega, L., Dooryhée, E., Salomon, J., Walter, P., Hodeau J.L. and Bordet P. 2008
A portable instrument for in situ determination of the chemical and phasecompositions of cultural heritage objects, *X-Ray Spectrom* 37 (2008): 418–423.

Gullayanon, R. 2011
A Calibration Methodology for Energy Dispersive X-ray Fluorescence Measurements Based Upon Synthetically Generated Reference Spectra, PhD thesis, Georgia Institute of Technology.

Janssens, K. 2003
X-ray fluorescence analysis, in: *Handbook of Spectroscopy, Volume 1*, eds. G. Gaulitz and T. Vo-Dinh, Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA, 363–420.

DESIGN OF COMPATIBLE MORTARS FOR CONSERVATION INTERVENTIONS

SNEŽANA VUČETIĆ

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

JONJAUA RANOGAJEC

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

IVANA DELIĆ-NIKOLIĆ

Institute for Testing of Materials, Belgrade, Serbia

LJILJANA MILIČIĆ

Institute for Testing of Materials, Belgrade, Serbia

EMILIJA NIKOLIĆ

Institute of Archaeology, Belgrade, Serbia

MLADEN JOVIČIĆ

Institute of Archaeology, Belgrade, Serbia

snezanap@uns.ac.rs

Architectural heritage suffers from many deterioration patterns among which mortar aging and degradation present a

significant task for conservation practitioners and scientists. The functional requirements of compatible repair mortars strongly depend on the properties of historical mortars. In this sense, in-depth characterisation of historical mortars and technologies is crucial for the development and design of the repair mortars.

The main aim of our research, carried out in the PROMIS project MoDeCo2000, was design and laboratory and in-situ testing as well as monitoring of compatible mortars for conservation of the Roman military and residential objects along the Danube Limes in Serbia. This research covered: field architectural, archaeological, geological and technological investigation of historical technologies of mortar sample preparation and their comprehensive characterisation, as well as the characterisation of the available local raw materials. Moreover, laboratory design of conservation mortars, characterisation, testing and artificial ageing of the mortar models was also performed and promising recipes were applied and tested on the experimental walls and on the original structures. Laboratory characterisation of historical mortar samples and potential conservation mortars was performed using visual observations, stereo-optical and digital microscopy, spectrophotometry and colorimetry, mineralogical and petrological analyses, physical-mechanical tests, thermal characterisation, mechanical and chemical separation of aggregates and binders, and characterisation of samples, binders and aggregates using FTIR, RAMAN, XRF and XRD. The obtained results were used for the development of conservation

mortars mixtures. The promising mortar mixtures were selected based on the compatibility of chemical, mineralogical, textural, visual and mechanical characteristics of the newly designed mortars with those of the old mortars and bricks/stones of the investigated building walls.

The characteristics of the tested materials and the recipes for conservation mortar design, along with an understanding of everyday life along the Danube Limes, represent the main results of the study. They prove the possibility of learning about the past of this region and preserving procedure of the tangible cultural heritage objects.

Keywords – mortars, compatibility, laboratory and in-situ characterisation

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

Binda, L., Baronio, G. and Tedeschi, C. 2000
Experimental study on the mechanical role of thick mortar joints in reproduced Byzantine masonry, in: *International RILEM Workshop on Historic Mortars: Characteristics and Tests*, eds. P. Bartos, C. Groot and J.J. Hughes, Cachan: RILEM Publications, 227 – 247

TC 203-RHM 2012a
Repair mortars for historic masonry. The role of mortar in masonry: an introduction to requirements for the design of repair mortars. Mater Struct. doi: 10.1617/s11527-012-9847-9

TC 203-RHM 2012b
Repair mortars for historic masonry. From problem to intervention: a decision process. Mater Struct. doi:10.1617/s11527-012-9848-8

.

COMPATIBLE MORTARS FOR THE ARCHITECTURAL CONSERVATION OF THE DANUBE LIMES IN SERBIA – IMPORTANCE OF THE RAW COMPONENT CHARACTERISATION

LJILJANA MILIČIĆ
Institute for Testing of Materials, Belgrade, Serbia

EMILIJA NIKOLIĆ
Institute of Archaeology, Belgrade, Serbia

IVANA DELIĆ-NIKOLIĆ
Institute for Testing of Materials, Belgrade, Serbia

SNEŽANA VUČETIĆ
University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

ljiljana.milicic@institutims.rs

Recipes for compatible mortars for conservation must be based on raw materials whose presence was determined during the characterisation of historical mortars used on buildings on which we perform renewal or repairs. Additional materials are often used that improve the resistance of conservation mortars to various influences,

while all the time ensuring that they do not have any negative effects on any part of the structure.

Within the MoDeCo2000 project, lime mortars for the conservation of monuments that belonged to the former Roman frontier in today's Serbia were prepared. The process was preceded by research into the materials used to make Roman mortars in the area. The selection of component materials, primarily binders, for the creation of conservation mortars included tests, in accordance with the methods prescribed by the relevant standards, of parameters that could adversely affect the properties of fresh or hardened mortar. In slaked lime, the content of free water required for the calculation of the optimal amount of water that will be used for the preparation of the mixture, in order to obtain a mortar of good consistency and workability, was tested. Examination of unextinguished lime particles and the stability of the volume was carried out in order to avoid the use of lime, which can lead to the appearance of microcracks in the mortar after hardening. When it came to choosing the quality of quicklime, it needed to have high reactivity, low content of inextinguishable particles, and high yield.

In accordance with the results of laboratory tests of historical mortars, many mixtures for conservation were prepared with the exclusive use of lime and river aggregate, in different interrelationships and different granulations of aggregates. In addition to river aggregate, crushed stone aggregate was added to some mixtures. In the historical mortars used for plastering and

flooring, a larger amount of brick was mostly used as an artificial material with pozzolanic properties and, thus, used for the compatible mixtures as well. Mineralogical testing of certain samples allowed consideration of the possible use of natural materials with pozzolanic properties for their preparation, so the use of zeolitised tuffs and kaolin clays in new mixtures was also tested, but carefully, in parallel with additional testing of historical samples.

The characteristics of mortars made exclusively of lime and river aggregate are lower mechanical properties, low resistance to atmospheric influences, primarily freezing and defrosting, as well as high water absorption. Although their good degree of compatibility with old mortars recommends their use in conservation, their application, depending on the climatic conditions of the environment, is generally suitable in structures protected from external influences. In accordance with the climate that is present in our territory, it was necessary to formulate preparations for conservation mortar with improved mechanical properties and greater resistance to external influences, which entailed the use of various additives. Natural and artificial materials with pozzolanic properties were added to a number of mortar mixtures prepared as compatible with pure lime mortars, including local clays, bricks, zeolitized tuffs, and kaolin clays, which were mechanically activated in the laboratory and whose use was expanded by using an industrial product created by their thermal activation, i.e., metakaolin. By applying these additives, in addition to a significant improvement in mechanical properties and durability, an

attempt was made to achieve the desired appearance of the mortar, which included the colour of the mixture. In the phase of testing the suitability of applied recipes, in laboratory conditions, the appearance of cracks, fissures, flaking, discoloration due to drying or wetting, water absorption, volumetric mass, and mechanical properties, as well as their contact with samples of historical mortars were monitored.

Tests of the use of various components for the preservation of conservation mortars through the preparation of mixtures within the MoDeCo2000 project showed the possibility of using pure lime mortars for the conservation of Danube Limes monuments, but also the need to use different additives with pozzolanic properties in many cases. A large number of possibilities of combining these additives, in order to obtain more durable mortars for building conservation, while constantly adhering to the need to ensure the compatibility of old and new mortars and of existing built structures and new materials, raises the need for new research, which needs to be directed to acquiring additional knowledge related to the composition of historical mortars, especially when it comes to the use of natural additives with pozzolanic properties.

Keywords – historical mortars, mortars for conservation, compatibility, Roman mortars, Danube Limes

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6067004, MoDeCo2000*

References:

BS EN 459-1:2015 2015
Building Lime - Part 1: Definitions, Specifications and Conformity Criteria.

Henry, A. and Stewart, J. 2011
English Heritage Practical Building Conservation. Mortars, Renders & Plasters, Farnham: Ashgate Publishing
Limited.

Ilić, B., Mitrović, A. and Miličić, Lj. 2019
Mechanically Activated Kaolin as Supplementary Cementitious Material, in: *Proceedings of the 15th International Congress on the Chemistry of Cement (ICCC 2019) Prague, Czech Republic*, ed. J. Gemrich, Prague: Research Institute of Binding Materials Prague.

Ilić, B., Mitrović, A., Miličić, Lj. and Zdujić, M. 2018
Compressive Strength and Microstructure of Ordinary Cured and Autoclaved Cement-based Composites with Mechanically Activated Kaolins, *Constr Build Mater.* 178: 92-101.

Schueremans, L., Cizer, Ö., Janssens, E., Serre, G. and Van Balen, K. 2011
Characterization of Repair Mortars for the Assessment of their Compatibility in Restoration Projects: Research and Practice, *Constr. Build Mater.* 25/12: 4338-4350.

THE AMBULANCE FOR MONUMENTS - SAFEGUARDING HERITAGE THROUGH COMMUNITY ENGAGEMENT

EUGEN VAIDA

Monumentum Association, Alţâna, Sibiu, Romania; The Prince's Foundation, Dumfries House, Cumnock, UK

VERONICA VAIDA

Monumentum Association, Alţâna, Sibiu, Romania

ALEXANDRA TEODOR

Atelierul de Patrimoniu Association| UAUIM, Bucharest, Romania

alexandra_teodor@yahoo.com

The Ambulance for Monuments is a project initiated in 2016 by the Monumentum Association, based in Sibiu County, Romania. It started with a pilot project in Transylvania, where the team already had relevant experience with interventions on historical buildings. Since then, the project has expanded, covering approximately half of Romania's territory, coordinated by eight local NGOs. The interventions are usually focused on repairing damaged roofs, securing walls from collapse, implementing proper water drainage and stabilising wall paintings, in historical buildings such as churches,

mills, manor houses, train stations and ruins of historic fortifications, among others. [1]

The project was internationally acknowledged by Europa Nostra in 2020 with the Education Training and Awareness-Raising Award and the Public Choice Award. [2]

The variated span of the project will be highlighted with a brief typology of the past interventions. However, as a response to the topic of the workshop, the presentation will focus on the main principles of the project – of which the community engagement is seen as essential –, illustrated through a case study selection for masonry structures (predominantly of the medieval and modern period).

In a secondary plan, a complementary project will be briefly mentioned, as it refers to a tile workshop that was built, starting in 2013, at Apoș, Sibiu County - also by the Monumentum Association. It became functional in 2015 and since then it has produced around 240,000 tiles and 35,000 bricks. [3]

Keywords - built heritage; traditional techniques; tile workshop; emergency interventions; community engagement.

References:

[1] http://ambulanta-pentru-monumente.ro/?lang=en (visited June 14th, 2022)

[2] https://www.europeanheritageawards.eu/winners/the-ambulance-for-monuments/ (visited June 14th, 2022)

[3] https://transilvania-train.com/en/tiglaria-de-la-apos/ and http://asociatiamonumentum.ro/cms/construirea-tiglariei-traditionale-din-apos2/ (Romanian only) (both visited June 14th, 2022)

REDISCOVERING TRADITIONAL MORTARS

NIGEL COPSEY

Earth, Stone & Lime Company and Associates, Thornton Dale, Pickering, England

nigelcopsey@hotmail.com

The presentation will draw upon extensive research into old texts on lime; upon archived building accounts and specifications, as well as upon 18 years of experience using hot mixed lime mortars. Many of the assumptions of the 'Lime Revival' were well intentioned, but mistaken.

This presentation - and these demonstrations - will set out a revised narrative of mortar use over the last 2,000 years and demonstrate that traditional mortars meet all of the technical criteria for what a mortar needs to be and to do, and that traditional mortars are economic, efficiently prepared, workable and water retentive, are easy to use and are truly sustainable.

Keywords – lime, hot mixed lime mortar, earth-lime mortars, hot mixing, natural hydraulic lime, pozzolans.

References:

Copsey, N. and Gourley, B. 2013
Hot-Mixed Lime Mortars, in: *Proceedings of the 3rd Historic Mortars Conference HMC13, Glasgow, 11.09.2013-13.09.2013.,* ed. J. Hughes, Glasgow: University of the West of Scotland, 1-9.

Copsey, N. 2015
Hot-mixed lime mortars, *The Journal of Building Limes Forum* 22: 70-76

Copsey, N. 2017
Hot Limewashes and Sheltercoats, *The Building Conservation Directory* 2017: 136-139.

Copsey, N. 2019
A Critical Review of Historic Literature Concerning Traditional Lime and Earth-lime Mortars. MA Thesis, University of York, Department of Archaeology, Conservation Studies.

Copsey, N. 2020
Like-for-like and Compatible Mortars for the Repair of Traditional Buildings, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIV-M-1-2020, 2020 HERITAGE2020 (3DPast | RISK-Terra) International Conference, 9–12 September 2020, Valencia, Spain, 1017-1024.

TUFFS OF SERBIA – WHAT WE NEED TO KNOW WHEN CHARACTERISING THEM AS ARCHAEOLOGICAL RAW MATERIAL

VLADICA CVETKOVIĆ

University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

KRISTINA ŠARIĆ

University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

vladica.cvetkovic@rgf.bg.ac.rs

The geological history of Serbia involves volcanic processes different in age (>300 - 5 Ma) and in eruption style (subaquatic and subaerial, effusive and explosive), which resulted in a wide petrological variability. In this paper we focus on tuffs known as suitable building material throughout the entire history of human civilisation. By highlighting their origin during the most productive volcanic episodes in the geological past of this territory, we emphasise the significance of specific geological information for establishing archaeological constraints.

The tuffs are pyroclastic rocks that form exclusively during highly

explosive volcanic eruptions, typical for intermediate to acid magmatism (Fisher and Schmincke 1984). Explosive fragmentation is controlled by the expansion of volcanic gasses and it produces a wide range of particles (pyroclast) that are collectively named tephra. The tuffs consist of volcanic dust and ash (particles <2 mm in diameter) and the finest fraction of the tephra is deposited from eruption columns that rise high, directly above and laterally from the volcanic centre. The tuffs are predominantly (>90 wt.%) composed of fragments of highly expanded volcanic glass called pumice but also contain variable proportions of dense clasts (phenocrysts and groundmass); the presence of secondary phases, such as zeolites, chlorites and clays, which are formed by the devitrification of volcanic glass and/or by the alteration of primary minerals, is responsible for the pozzolanic features that make tuffs suitable for using as a building material.

The oldest explosive volcanism occurred in the Permian but it is represented by small and rare occurrences of volcanic and volcaniclastic rocks near Đerdap, Bor and Zaječar; Layers of the Permian tephra are found in Romania (the Sirinia complex) but these tuffs are mostly welded (i.e., emplaced at high temperature) (Šarić et al. 2021). Triassic and Jurassic volcanic formations are widespread in Serbia, but they were mostly formed by subaqueous emplacements of basaltic magma, and this eruption style is not favourable for tuff formation. In the Upper Cretaceous, huge andesite±dacite volcanic complexes associated with large Cu-Ag deposits formed in present-

day Eastern Serbia (Bor, Majdanpek). This volcanism was characterised by the emplacement of intermediate lava flows and autoclastic deposits, whereas tuffs were subordinate; tuffs that resulted from explosive events occur as thin layers of volcanic ash covered by younger lavas (rarely) and as fine-grained Si-Al volcanogenic detritus mixed with marls in adjacent (coeval) deep water marine basins. The acid to intermediate Cenozoic volcanism was surely most productive in terms of tuff formation (Cvetković 2014). This is particularly valid for the period between 30 Ma and 20 Ma, when large volcanic (±plutonic) complexes, such as Srebrenica, northern Šumadija, Rudnik-Borač-Kotlenik, southern Kopaonik, as well as part of the Golija and Radan Mts, were formed. The Cenozoic volcanism was highly explosive and, therefore, gave rise to large volumes of fine-grained tephra. The primary deposition and reworking and re-deposition of the finest pyroclasts resulted in the formation of pyroclastic/volcaniclastic deposits that are usually collectively named 'tuffs' (sometimes also tuffites, tuffaceous marls, etc.). The majority of this volcanic ash was preserved in adjacent lacustrine basins where they either formed individual tuffaceous layers or mixed with authigenic marls and clays. The last significant explosive volcanic events occurred around 14 Ma, but their pyroclastic products are found only in drill holes in northern Vojvodina (Cvetković et al. 1998).

It is clear that a solid petrogenetic understanding is needed when characterising the raw material of tuff origin used for

building/constructing archaeological objects. The Cenozoic volcanic complexes are certainly the best candidates for provenance sites; however, it must be taken into account that some primary volcanic ash could have been deposited in Neogene lacustrine basins far from the eruptive centre.

Ackowledgements: *The research has been financed by the "Contract on realization and financing of scientific research of SRI in 2022", Nr. 451-03-68/2022-14/ 200126.*

Keywords – explosive volcanism, volcanic formations of Serbia, Cenozoic volcanism of Serbia

References:

Cvetković, V. 2014
About Cenozoic magmatism in Serbia – by words understandable to every geologist, *XVI Serbian Geological Congress, 22-25.05.2014, Donji Milanovac*, 29-40.

Cvetković, V., Žumberković, V., Resimić, K. and Popov, O. 1998
Miocene pyroclastics of northern Bačka. *13th Congress of Yugoslavian Geologists, 6-9 October 1998, Herceg Novi, IV,* 187-194. (In Serbian with English summary).

Fisher, R.V. and Schmincke, J.-U. 1984
Pyroclastic Rocks, Berlin: Springer-Verlag.

Šarić, K., Šarić, J.A. and Cvetković V. 2021
Advanced petrographic study of chipped stone artefacts from Lepenski Vir (Serbia): Evidence for accross-Danube communication in the Mesolithic? *Quaternary Science Reviews* 252: 106741. https://doi.org/10.1016/j.quascirev.2020.106741

GEOLOGICAL KNOWLEDGE IN SERVICE TO ARCHAEOLOGICAL INVESTIGATIONS: ROCK AND CERAMIC FINDINGS AS EXAMPLES

KRISTINA ŠARIĆ

University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

SUZANA ERIĆ

University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

VLADICA CVETKOVIĆ

University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia

JOSIP ŠARIĆ

Institute of Archaeology, Belgrade, Serbia

DRAGANA ANTONOVIĆ

Institute of Archaeology, Belgrade, Serbia

VESNA BIKIĆ

Institute of Archaeology, Belgrade, Serbia

kristina.saric@rgf.bg.ac.rs

Many archaeological findings are made of geological materials: minerals (non-metals and metals), mineraloids and rocks, or are products of technological treatments of geo-materials (ceramic, glass, metal and alloy items). Mobilisation of overall geological knowledge, from the selection and systematic application of appropriate analytical methods to the interpretation of data, is crucial for deriving high quality conclusions regarding the provenance of raw material, technological processes applied, selection of appropriate raw material for experimental archaeology, etc. In this paper we justify this statement through three study examples: 1) stone artefacts from Lepenski Vir (Iron Gate, Serbia), 2) stone artefacts from Masinske njive (Šumadija, Central Serbia) and 3) ceramics from the Monastery of Studenica (Ušće, Western Serbia).

Šarić et al. (2021) re-examined a collection of 909 chipped stone artefacts from Mesolithic layers of Lepenski Vir, applying polarised transmitted-light microscopy. A set of volcanic rocks (≈6 % of the used raw material), was volcanologically devided into two subgroups: pyroclastic rocks (devitrified welded tuffs, and pyroclastic-fall and phreatomagmatic deposits), and coherent volcanic rocks (hypocrystalline to vitrophyric rhyolite and dacite-rhyodacite). This volcanological analysis, together with field evidence and data about the regional geology, implies that this raw material originated from a complete volcanic succession. The only possible

candidate is the Permian volcanic complex of Sirinia in Romania, on the opposite side of Lepenski Vir (across the Danube), which represents a conclusion with significant archaeological implications.

Šarić et al. (2017) reported results of mineralogical-petrological analyses of 12 abrasive and polished tools from the Eneolithic site of Masinske njive. In the studied collection, there are small samples not representative enough for a basic (macroscopic) petrographical classification. Previously, this has caused mistakes in nomenclature which have led to inaccurate conclusions about the provenance of the raw material. However, the application of optical and SEM-EDS investigations provided the recognition of: hydrothermally altered volcaniclastics (HAV), coherent mica-bearing quartzlatites (M-QL), and pyroxene-bearing quartzlatite (P-QL), among others. HAV is characterised by the presence of pumice. M-QLs exhibit specific petrogenetic features: sieved plagioclases, and phlogipitized biotites (38.54-41.85 wt% SiO_2, 16.80-20.35 wt% MgO and 9.41-12.36 wt% FeO(t), with a decrease of Al_2O_3 and increase of MgO content). Both HAV and M-QL are typical products of the Cenozoic volcanic complexes of Serbia (e.g, Rudnik, Kopaonik, Golija, Rogozna and Lece). Although all these complexes could be regarded as potential sources of the raw material, the authors considered Rudnik, the closest site to Masinske njive, a major provenance area. The P-QL does not show products of phlogopitization and most probably has different provenance from the mentioned M-QL. This is a solid example of how detailed petrogenetic insight into magmatic rocks

occurring as chipped artefacts can be a source of information that has archaeological bearings.

Šarić et al. (2018) demonstrated that the combination of compatible methods (optical microscopy, SEM-EDS and XRPD), applied in a petrological study of 63 ceramic samples from the Medieval Monastery of Studenica and three samples of clays as potentially raw material, provided conclusions regarding: a) local production (according to type of clasts and the similarity in composition of ceramic matrix and clay samples), except for three samples which were regarded as imports (specific paste texture, chemical composition of the matrix and the style of decoration), b) firing temperatures for two ceramic groups at 600-700 ^{o}C and 800-900 ^{o}C (according to matrix crystallinity, mineral reactions and the shape of fracture surfaces), and c) the recognition of technological and morphological standardisation in the ceramic production.

Keywords – geological expertise, mineralogical-petrological analysis, raw material, provenance.

Acknowledgements: *The research has been financed by the "Contract on realization and financing of scientific research of SRI in 2022", Nr. 451-03-68/2022-14/ 200126.*

References:

Šarić, K., Bikić, V. and Erić, S. 2018
Microstructural, mineralogical and petrographical characteristics of the Medieval ceramics from the Studenica Monastery (UNESCO world heritage site): Implications on the pottery

technology and provenance of the raw material, *Microscopy and Microanalysis* 24: 744-761. doi: 10.1017/S1431927618015349

Šarić, K., Erić, S., Cvetković, V., Šarić, J. and Antonović, D. 2017
Mineralogical-petrographical characterization and possible origin of raw material used for making abrasive and polished stone tools at the Eneolithic site of Masinske njive, *The journal of the Serbian Archaeological Society* 33: 283-307. (In Serbian with English summary).

Šarić, K., Šarić, J.A. and Cvetković V. 2021.
Advanced petrographic study of chipped stone artefacts from Lepenski Vir (Serbia): Evidence for accross-Danube communication in the Mesolithic?, *Quaternary Science Reviews* 252: 106741. https://doi.org/10.1016/j.quascirev.2020.106741

EVALUATION OF ANCIENT MORTARS' HYDRAULICITY THROUGH THE CHARACTERISATION OF LONG AND SHORT-RANGE CRYSTALLINITY

YOTAM ASSCHER

Israel Antiquities Authority, Jerusalem, Israel

MICHELE SECCO

University of Padua, CIRCe – Center for the Investigation of Cement Materials, Padua, Italy

GIULIA RICCI

University of Padua, CIRCe – Center for the Investigation of Cement Materials, Padua, Italy

SERGIO TAMBURINI

Institute of Condensed Matter Chemistry and Technologies for Energy, Padua, Italy

GILBERTO ARTIOLI

University of Padua, CIRCe – Center for the Investigation of Cement Materials, Padua, Italy

yotama@israntique.org.il

Ancient hydraulic mortars are complex systems with chemical and mineralogical features that evolve over time, depending on the original formulation, the extent of the hydraulic reaction, and the chemical stability of the environment in which the material evolved. Most hydraulic products in the binder are amorphous or poorly crystalline, and their identification is often problematic when using long range crystallinity as assessed by diffraction (XRD). Here, we show an approach of combining the long- and short-range crystallinity, from different pre-Roman and post-Roman mortars and plasters, obtained on wet- and dry-separated fractions by XRD, MAS-NMR and FTIR measurements. The information on the binder fraction from two independent spectroscopic methods can be correlated showing the short-range atomic structure of the hydraulic products from various reactive materials (encompassing charred plant remains, crushed pottery and amorphous volcanic glass). The evaluation of ancient mortars' hydraulicity is demonstrated by long-range information (XRD mineral phases), short-range information (NMR and FTIR) and local microstructure, with chemical information on the reaction interfaces by SEM/EDS measurements used to constrain the system

Keywords - hydraulicity, FTIR, NMR, XRD, long and short-range crystallinity

References:

Asscher, Y., Van Zuiden, A., Elimelech, C., Gendelman, P., Sharvit, J., Secco, M., Ricci, G. and Artioli, G. 2020
Prescreening Hydraulic Lime-Binders for Disordered Calcite in Caesarea Maritima: Characterizing the Chemical Environment Using FTIR, *Radiocarbon* 62(3): 527-543.

Secco, M., Dilaria, S., Bonetto, J., Addis, A., Tamburini, S., Preto, N., Ricci, G. and Artioli, G. 2020
Technological transfers in the Mediterranean on the verge of Romanization: Insights from the waterproofing renders of Nora (Sardinia, Italy), *Journal of Cultural Heritage* 44: 63-82.

PHYSICOCHEMICAL CHARACTERISATION OF THE MEDIEVAL POTTERY EXCAVATED IN SERBIA

LJILJANA DAMJANOVIĆ-VASILIĆ

University of Belgrade, Faculty of Physical Chemistry, Belgrade, Serbia

VESNA BIKIĆ

Institute of Archaeology, Belgrade, Serbia

SRNA STOJANOVIĆ

University of Belgrade, Faculty of Physical Chemistry, Belgrade, Serbia

IVANA RADOSAVLJEVIĆ EVANS

Department of Chemistry, Durham University, Durham, UK

DANICA BAJUK-BOGANOVIĆ

University of Belgrade, Faculty of Physical Chemistry, Belgrade, Serbia

IVANKA HOLCLAJTNER-ANTUNOVIĆ

University of Belgrade, Faculty of Physical Chemistry, Belgrade, Serbia

ljiljana@ffh.bg.ac.rs

Archaeologists most often classify pottery fragments according to their style, colour, shape and texture. However, in the field of material science it is widely accepted that the properties of a particular product are determined by its composition and structure, which is a result of the used raw materials and applied production processes. The detailed micro-chemical and micro-structural characterisation of an archaeological artefact can significantly contribute to solving problems of restoration, conservation, dating and authentication in the art world. Also, knowledge of manufacturing techniques allows archaeologists to reconstruct how people lived in the past and how they interacted with their natural and social environments.

In order to investigate medieval pottery excavated on the territory of Serbia, a multi-analytical approach has been employed. The following characterisation methods have been used: optical microscopy, X-Ray powder diffraction, X-Ray fluorescence spectroscopy, and vibrational spectroscopies, Fourier transform infrared and micro-Raman spectroscopy, inductively coupled plasma-mass spectrometry, scanning electron microscopy with energy dispersive spectrometry and multivariate statistical analysis. In total, 134 samples of glazed and unglazed ceramic shards, dated from the 12th to the 15th century, were studied. The aim of these systematic archaeometric studies was to determine the medieval ceramic's provenance, technology of preparation as well as influence from neighbouring countries and specific characteristics of different

workshops. The main results obtained during the characterisation of pottery shards from four archaeological sites: the Ras fortress (Damjanovic et al, 2011), the Novo Brdo fortress (Damjanovic et al, 2016), the Studenica monastery (Stojanovic et al, 2019), which is UNESCO world heritage site, and the Belgrade fortress (Damjanovic-Vasilic et al, 2019) will be presented. The obtained results reveal that local pottery production in the medieval Serbian state was under the strong influence of Byzantine pottery production.

Keywords – medieval pottery, production technology, vibrational spectroscopy, synchrotron XRPD, multivariate statistical analysis.

References:

Damjanović-Vasilić, Lj., Bikić, V., Stojanović. S., Bajuk-Bogdanović, D., Džodan, Đ., Mentus, S. 2020
Application of analytical techniques for unveiling the glazing technology of medieval pottery from the Belgrade Fortress, *Journal of the Serbian Chemical Society* 85 (2020): 1329-1343.

Damjanović, Lj., Holclajtner-Antunović, I., Mioč, U.B., Bikić, V., Milovanović, D., Radosavljević Evans, I. 2011
Archaeometric study of medeival pottery at Stari (Old) Ras, Serbia, *Journal of Archaeological Science* 38 (2011): 818-828.

Damjanović, Lj., Mioč, U., Bajuk-Bogdanović, D., Cerović, N., Marić-Stojanović, M., Andrić, V., Holclajtner-Antunović, I. 2016
Archaeometric investigation of medieval pottery from excavations at Novo Brdo, Serbia, *Archaeometry*, 58 (2016): 380-400.

Stojanović, S., Bikić, V., Miličić, Lj., Radosavljević Evans, I., Scarlett, N.V.Y., Brand, H.E.A., Damjanović-Vasilić, Lj. 2019
Evidence of continuous pottery production during the late Byzantine period in the Studenica Monastery, a UNESCO World Heritage Site, *Microchemical Journal* 146 (2019): 557-567.

TECHNOLOGICAL CHARACTERISTICS OF FIRED BRICKS FROM THE ROMAN AND BYZANTINE PERIOD IN GREECE

MARIA STEFANIDOU

Aristotle University of Thessaloniki, School of Civil Engineering, Laboratory of Building Materials, Thessaloniki, Greece

stefan@civil.auth.gr

Fired bricks were, for millennia, one of the main building materials of masonry structures of old civilizations developed around the Mediterranean Basin. In ancient Greece, fired bricks systematically appeared in buildings from the 4th century BC, although ceramic manufacturing was well known since the pre-historic period. During the Roman and Byzantine period, brickwork was one of the main building materials for the load-bearing structural members of a construction. In Greece, there were many important monuments of the Roman and Byzantine period, such as palaces, forums, theatres, baths, churches and castles. They were built with stones and bricks of good quality, usually joined with thick mortars. During the Roman period, large quantities of bricks were produced, the use of which was widespread, and bricks constituted a basic structural material. In this research study, the morphological, mechanical and physical

characteristics, as well as the microstructure of old bricks from Greek monuments dated from the Roman and Byzantine period, are presented. Based on the results, bricks were usually produced manually by using empirical criteria. The bricks of that period were mainly plates of 30x30 or 30x40 cm. Their thicknesses ranged from 2.5 to 6 cm. Different additives were used to improve their properties, such as fine and coarse aggregates or fibrous materials (wood chips). Generally, these bricks were traditionally produced and were fired at low temperature (not higher than 900–950 ^{o}C). Consequently, this technological characteristic affects important properties of the final products. As a result, their porosity was high and they were prone to water absorption both naturally and by capillarity. They were materials of low apparent specific density (1.5–1.8), high absorption (13–30 %) and relatively low compressive strength (5–20 MPa) in comparison to modern bricks. However, these characteristics helped bricks to present a relatively high resistance to weathering. Additionally, due to their surface roughness, the adhesion with the lime-based mortars was also relatively high. The chemical reaction of lime mortar with the amorphous siliceous materials present in old bricks has often contributed to an improvement in the mortar–brick bond. Since the characteristics and behaviour of old bricks of the aforementioned historic periods do not differ much, it implies that both raw materials and the manufacturing techniques used for brick production did not changed over a long historic period.

The importance of preserving historic structures is as important as the preservation of human history. The evolution of technology in construction is traced through historic structures and, nowadays, researchers study materials and techniques in order to understand the past. The aim is to go a step further and design compatible and durable repair materials using the principles of sustainability and keeping in mind environmental protection ethics. As long as scholars and restorers can apply compatible materials, tailor made for each case, following the analysis results derived from authentic materials and critically adapt new technologies, the aim to deliver the monuments to the new generation can be achieved.

Keywords – fired bricks, morphology, mechanical properties, physical properties, microstructure

References:

Papayianni, I. and Stefanidou, M. 1995
Characteristics of bricks of old masonries, in: *NATO SfS Workshop On Materials for Consolidation and Restoration of Monuments and Historical Buildings: reading, interpreting and recovering knowledge from traditional materials*, eds. I. Papayianni, and P. Astreinidou, Thessaloniki, 35-48.

Papayianni, I. and Stefanidou, M. 2000
Characteristics of bricks of Byzantine period, in: *12th International Brick/ Block masonry Conference, Madrid, Spain, 25-26 June 2000*, ed. J. M. Adell, Madrid: Construction and Architectonic Technology Department of the Polytechnic University of Madrid, 185-192.

Radivojević, A. 2006
Evolution of Bricks and Brick Masonry in the Early History of Its Use in the Region of Today's Serbia", *ASCE Journal of Materials in Civil Engineering, Vol.* 18, *No.*5: 692-699.

Stefanidou, M. and Papayianni I. 2006
Technological characteristics of bricks from roman monuments, in: *2nd International Congress on Ancient Greek Technology*, eds. P. Tasios and C. Palyvou, Athens: Technical Chamber of Greece, 502-507.

Van Balen, K. 2009
A Damage Atlas and Questionnaire for Evaluation of Deterioration of Ancient Brick Masonry Structures, in: *Conservation of Historic Brick Structures*, ed. N.S. Baer, S. Fitz and R.A Livingston, Shaftesbury: Donhead Publishing Ltd, 117-134.

PYROCLASTIC ROCKS IN THE STRUCTURAL MORTARS OF ROMAN NORA (SARDINIA). A GREEN MATERIAL FOR THE PRODUCTION OF SUSTAINABLE CONCRETES IN ANTIQUITY

SIMONE DILARIA

University of Padua, Department of Cultural Heritage (DBC), Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

CATERINA PREVIATO

University of Padua, Department of Cultural Heritage, Padua, Italy

JACOPO BONETTO

University of Padua, Department of Cultural Heritage, Padua, Italy

MICHELE SECCO

University of Padua, Department of Cultural Heritage (DBC); Inter-Departmental Research Centre for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

ARTURO ZARA

University of Padua, Department of Cultural Heritage, Padua, Italy

DOMENICO MIRIELLO

University of Calabria, Department of Biology, Ecology and Heart Science (DIBEST), Rende, Italy

RAFFAELLA DE LUCA

University of Calabria, Department of Biology, Ecology and Heart Science (DIBEST), Rende, Italy

GILBERTO ARTIOLI

University of Padua, Department of Geosciences; Inter-Departmental Research Centre for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

simone.dilaria@unipd.it

It has been estimated that about 8 % of the total CO_2 emissions into the atmosphere of our planet is as a result of the production of cement. A large part of these emissions derives from the clinker manufacturing method, whose production, even nowadays, mainly requires coal, necessary to reach the very high temperatures (~1500 °C) at which the formation of clinker occurs. In order to reduce the global CO_2 emissions, many companies are studying traditional building techniques to re-discover alternative materials suitable for the production of cementitious compounds for modern construction without lowering the physical-mechanical capabilities offered by

traditional cements. The Romans did not know cement but were able to produce highly cohesive concretes based on "aerial" lime, produced by calcination at relatively low temperatures (~850 °C) of carbonate rocks in wood-fired lime kilns. This happened because the ancient builders empirically knew the properties of certain elements (pozzolanic materials, i.e., volcanic tephra and terracotta), which, by chemically reacting with lime, could improve the properties of the final concrete once it had set, thus obtaining structural properties sometimes comparable to modern cements. The most famous pozzolanic materials, cited even by Vitruvius and Pliny, are the pyroclastic rocks outcropping in loose deposits in the Phlegrean Fields around Pozzuoli. This pulvis gave excellent structural characteristics and waterproofing properties to ancient concretes, and it was recommended by authors for the construction of opus caementicium maritime piers. In fact, Brandon et al. 2014 and Marra et al. 2016 demonstrated the use of Phlegrean tephra in the construction of the maritime pilae of Roman Mediterranean ports, preserved in excellent condition even today.

In this paper, we discuss the presence of pyroclastic rocks in the concretes and renders of some Roman buildings in Nora, Sardinia. Preliminary archaeometric investigations (OM, XRPD, SEM-EDS, EMPA, XRF), carried out in collaboration with the Department of Biology, Ecology and Earth Sciences of the University of Calabria, highlight the provenance of most of these materials from the Phlegrean area. These are mainly pumices and tuffs, which were used

in large quantities in the opus caementicium structures of the large public buildings of Nora dated to the Imperial Age. In some circumstances, the materials were also used to improve the waterproofing of the mortar linings of some cisterns, where they represent a component subordinate to the prevalent terracotta fragments (Secco et al. 2020). The import into Nora of such volcanic materials seems primarily targeted at strengthening masonries. This evidence aligns perfectly with the functional destination of the pulvis as intended by Vitruvius. Moreover, whereas the presence of locally sourced Phlegrean pyroclastic rocks in mortars appears common at sites near the Gulf of Naples (i.e., Rispoli et al. 2019), their use for the construction of above-ground masonries appears less frequent elsewhere. This raises new questions about the constructive reasons the demand for these products was intended for.

Keywords – Campanian pumices and tuffs, provenance analysis (XRF and XRPD), pozzolanic reaction, *pulvis puteolana*, Nora

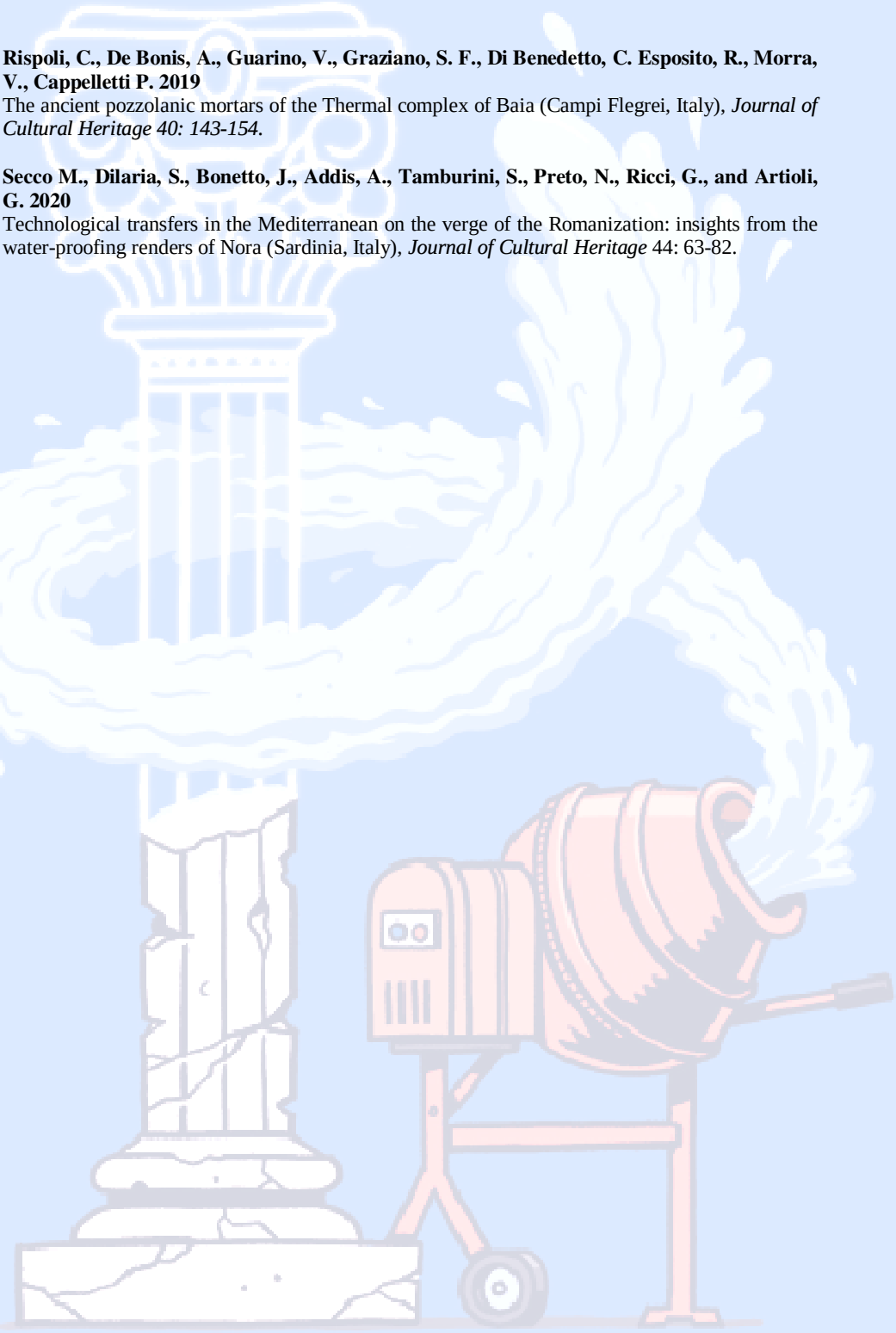
References:

Brandon, C.J., Hohlfelder, R. I., Jackson, M. D., and Oleson, J. P. 2014
Building for Eternity. The History and Technology of Roman Concrete Engineering in the Sea, Oxford: Oxbow books.

Marra, F., Anzidei, M., Benini, A., D'Ambrosio, E., Gaeta, N., Ventura, G., and Cavallo, A. 2016
Petro-chemical features and source areas of volcanic aggregates used in ancient Roman maritime concretes, *Journal of Volcanology and Geothermal Research* 328: 59-69.

Rispoli, C., De Bonis, A., Guarino, V., Graziano, S. F., Di Benedetto, C. Esposito, R., Morra, V., Cappelletti P. 2019
The ancient pozzolanic mortars of the Thermal complex of Baia (Campi Flegrei, Italy), *Journal of Cultural Heritage 40: 143-154.*

Secco M., Dilaria, S., Bonetto, J., Addis, A., Tamburini, S., Preto, N., Ricci, G., and Artioli, G. 2020
Technological transfers in the Mediterranean on the verge of the Romanization: insights from the water-proofing renders of Nora (Sardinia, Italy), *Journal of Cultural Heritage* 44: 63-82.



LEARNING FROM HISTORIC MORTARS: STUDIES ON LIME MANUFACTURING AND FRESCO CONSERVATION

ANNA ARIZZI

University of Granada, Department of Mineralogy and Petrology, Faculty of Science, Granada, Spain

arizzina@ugr.es

As widely recommended in literature and as specifically indicated in the European regulations (EN 17187:2020), the characterisation of historic mortars is an essential step to ensure proper conservation and restoration measures. Knowing the mortar typology is crucial when choosing compatible and suitable restoration mortars and, therefore, it must be established prior to any intervention on the original materials. Beyond that, the study of historic mortars also contributes to the broadening of knowledge about ancient building techniques, laying a foundation for the design of new mortars with similar characteristics and durability to the ancient ones. In this sense, it is worth mentioning the technological progress achieved in the field of construction in Roman times, with the introduction of new building practices ranging from the use of raw materials of excellent quality (DeLaine 2021), to rigorous methods of manufacture and the application of mortars according to their final

function (Lancaster 2021).

Based on the knowledge gained through the study of Roman mortars, plasters and wall paintings, and with the aim of formulating mortars of a quality comparable to that achieved in Roman times, the present work aims to provide an overview of the ongoing research works carried out by our team. Three main topics will be tackled:

- Lime burning: A multidisciplinary study on lime manufacturing in artisanal and industrial kilns, focused on the burning step of the lime cycle. This research has a twofold objective: 1) to update and broaden the technical-scientific knowledge about the currently active lime kilns and their products, and 2) to disseminate and enhance the value of the "forgotten" heritage of the artisanal lime kilns that have fallen into disuse, proposing their correct cataloguing, as well as a plan for their conservation, recovery and dissemination.
- Lime slaking: An assessment of the mineralogical and textural changes of industrial and artisanal lime putties stored under water for more than 20 years. The aim of this research is to understand whether the portlandite crystal structure continues to suffer a modification over a very long period under water, with final improved workability and reactivity towards CO_2, as observed in literature on lime putties stored for shorter periods of time (up to 10 years) (Cazalla et al. 2000).
- Chromatic reintegration of frescos: a study of the compatibility between fresco paintings and chromatic reintegration. The

purpose of this research is to study the possible interactions between the original components of ancient frescos (lime and pigments) and the products used for the chromatic reintegration (pigments dispersed in nano-silica), also considering their long-term durability towards different climatic conditions.

Keywords – lime putty, fresco painting, compatibility, mineralogy, durability.

***Acknowledgements**: This research is funded by the Spanish Ministry of Innovation and Science, under the project "Manufacture and suitability of natural hydraulic limes as a binder in sustainable construction and restoration (Id-Cal)" (PID2020-119838RA-100).*

References:

Cazalla, O., Rodriguez-Navarro, C., Sebastian, E., Cultrone, G., & De la Torre, M. J. 2000
Aging of Lime Putty: Effects on Traditional Lime Mortar Carbonation, *J Amer Ceram Soc*, 83(5): 1070–1076. https://doi.org/10.1111/j.1151-2916.2000.tb01332.x.

DeLaine, J. 2021
Production, transport and on-site organisation of Roman mortars and plasters, *Archaeol Anthropol Sci* 13: 195 (2021). https://doi.org/10.1007/s12520-021-01401-5.

EN 17187: 2020
Conservation of Cultural Heritage. Characterization of mortars used in cultural heritage.

Maurenbrecher, A.H.P. 2004
Mortars for repair of traditional masonry, *Pract Period Struct Des Constr* 9 (2): 62–65.

Lancaster, L. C. 2021
Mortars and plasters-How mortars were made. The literary sources, *Archaeol Anthropol Sci* 13: 192 (2021). https://doi.org/10.1007/s12520-021-01395-0.

NOVEL SCIENTIFIC PERSPECTIVES ON ANCIENT POZZOLANICITY

MICHELE SECCO

University of Padua, Department of Cultural Heritage (DBC), Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

SIMONE DILARIA

University of Padua, Department of Cultural Heritage (DBC), Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

GIULIA RICCI

University of Padua, Department of Geosciences, Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

ENRICO GARBIN

University of Padua, Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

SERGIO TAMBURINI

National Research Council, Institute of Condensed Matter Chemistry and Technologies for Energy (CNR-ICMATE), Padua, Italy

YOTAM ASSCHER

Israel Antiquities Authority (IAA), Jerusalem, Israel

GILBERTO ARTIOLI

University of Padua, Department of Geosciences, Inter-Departmental Research Center for the Study of Cement Materials and Hydraulic Binders (CIRCe), Padua, Italy

CATERINA PREVIATO

University of Padua, Department of Cultural Heritage (DBC), Padua, Italy

JACOPO BONETTO

University of Padua, Department of Cultural Heritage (DBC), Padua, Italy

michele.secco@unipd.it

The use of pozzolanic materials to trigger low-temperature hydraulic reactions in calcium-based inorganic binders was the most relevant technological evolution in the field of construction materials

since the beginning of pyrotechnology. After the first applications by ancient Mediterranean societies of the Second and First Millennium B.C., the potential of pozzolanic binders was fully exploited by ancient Romans, who used them for large-scale structural purposes through the formulation and development of Roman concrete.

Driven by the necessity of parametrising its production techniques, the Roman technology of pozzolanic binders pushed from the beginning to the systematic quarrying of the most suitable geological sources of pyroclastic materials from the central Italian volcanic districts (Phlegraean Fields, Monti Sabatini/Alban Hills) (Brandon et al. 2014; Marra et al. 2016). Such marked standardisation led to remarkable trades of raw materials throughout the Roman Empire. Nevertheless, several pieces of evidence indicated that such established supply criteria were often overcome by the employment of non-standardised local pozzolanic materials, both natural and anthropogenic, with obvious geographic and social advantages.

In this study, a combined mineralogical-spectroscopic-microstructural analytical approach has been adopted for the characterisation of the mineralogical and crystal-chemical features of Roman pozzolanic binders, considering several materials collected from various archaeological sites in the Italian peninsula and around the Mediterranean region.

The study demonstrated that, besides the import of traditional pyroclastic compounds, several alternative materials were used by Roman craftsmen, including natural products such as volcanic

breccias, microcrystalline sedimentary silicates, and artificial compounds including ceramic by-products and combustion residues (Secco et al. 2020). The information obtained on the microstructural features, reaction interfaces, short range atomic structure of hydration products, and extent of hydraulic reactions allowed a better understanding of the advanced levels of technical knowledge and the exceptional physical and engineering performances of the Roman structural materials. A new model for the reaction products of Roman pozzolanic materials is presented.

Keywords – pozzolanic reaction, Calcium-Silicate-Hydrate (C-S-H), Magnesium-Silicate-Hydrate (M-S-H), Rietveld quantitative phase analysis, nuclear magnetic resonance (NMR).

References:

Brandon, C.J., Hohlfelder, R. I., Jackson, M. D., and Oleson, J. P. 2014
Building for Eternity. The History and Technology of Roman Concrete Engineering in the Sea, Oxford: Oxbow books.

Marra, F. D'Ambrosio, E., Gaeta, M. and Mattei, M. 2016
Petrochemical identification and insights on chronological employment of the volcanic aggregates used in ancient Roman mortars, *Archaeometry* 58: 177-200.

Secco M., Dilaria, S., Bonetto, J., Addis, A., Tamburini, S., Preto, N., Ricci, G., and Artioli, G. 2020
Technological transfers in the Mediterranean on the verge of the Romanization: insights from the water-proofing renders of Nora (Sardinia, Italy), *Journal of Cultural Heritage* 44: 63-82.

RADIOCARBON DATING OF HISTORICAL MORTARS

ANDREJA SIRONIĆ
Ruđer Bošković Institute, Zagreb, Croatia

asironic@irb.hr

The method of radiocarbon dating of mortar has been a Holy Grail since the revolution in archaeology when Libby introduced the radiocarbon dating method in 1946. However, there is still no established universal method for mortar sample preparation that would always provide a true date.

The method relies on the principle that during mortar hardening, atmospheric CO_2 is introduced in the mortar structure in the form of calcium carbonate, preserving the information related to the ^{14}C activity of the atmosphere at the time of its formation. This lime-carbonate is, however, difficult to extract since it is chemically and crystallographically identical to the geogenic limestone carbonate used in mortar production, which is of different origin and does not contain ^{14}C. Limestone remains can be present due to unburned particles or it could also have been used as aggregate. If the lime-carbonate is not completely separated from the geogenic limestone, the obtained dates will appear inaccurately old. Erroneous dates could also be obtained due to recrystallised carbonates that were

precipitated from environmental waters, if the construction survived fire and carries information of the fire event, or the hardening process stopped and restarted and, consequently, carries information of the later dates. Due to all the difficulties, archaeologists closely collaborate with analysts and special attention is paid to sampling principles (Daugbjerg et al. 2020).

In recent years, with the introduction of accelerator mass spectrometry, mortar dating has seen a significant improvement. International mortar intercomparison studies named MODIS have been conducted (Hajdas et al. 2017), further exchanging and promoting different approaches, gathering ideas and improving the method for the radiocarbon dating of mortars.

Here, the different approaches to lime-carbonate separation and the currently most promising results for mortar dating will be presented.

Keywords – ^{14}C mortar dating, lime carbonate, sampling, sample preparation, MODIS - mortar dating inter-comparison.

References:

Daugbjerg, T. S., Lindroos, A., Heinemeier, J., Ringbom, Å., Barrett, G., Michalska, D., Hajdas, I., Raja, R., and Olsen, J. 2021
A field guide to mortar sampling for radiocarbon dating, *Archaeometry* 63: 1121– 1140. https://doi.org/10.1111/arcm.12648.

Hajdas, I., Lindroos, A., Heinemeier, J., Ringbom, Å, Marzaioli, F., Terrasi, F. and Guibert, P. 2017
Preparation and Dating of Mortar Samples—Mortar Dating Inter-Comparison Study (MODIS), *Radiocarbon* 59(6): 1845-1858. doi:10.1017/RDC.2017.112

ROMAN CONSTRUCTION TECHNIQUES USED ON THE VIMINACIUM AMPHITHEATRE

IVAN BOGDANOVIĆ
Institute of Archaeology, Belgrade, Serbia

leshicka@gmail.com

Amphitheatres are one of the symbols of Roman civilization and architecture. These particular buildings originated from the Apennine Peninsula and they were used for spectacles, including gladiatorial combats, shows with animals and executions. Later, the mentioned edifices were erected throughout the Roman state, mainly within important and rich urban centres, but many amphitheatres were also found in provinces next to legionary fortresses as well as in the vicinity of some auxiliary forts (Golvin 1988; Le Roux 1990; Sommer 2009).

This paper deals with the amphitheatre at Viminacium and its construction. Viminacium was initially a legionary fortress located close to the confluence of the Mlava and Danube rivers. In the vicinity of the north-western corner tower, the amphitheatre was built at the beginning of the 2nd century. To the west of the fortress, a settlement developed and became the capital of the province of Moesia Superior, later the province of Moesia Prima. The construction of city ramparts

in the late 2nd century led to the integration of the amphitheatre into the area defended by the walls, situated in its north-eastern corner. The building remained in use until the first half of the 4th century, after which it was abandoned (Nikolić and Bogdanović 2015; Богдановић, Рогић и Вуковић-Богдановић 2018).

The Viminacium amphitheatre is currently the only example on the territory of Serbia. The edifice was built next to the legionary fortress as a typical military amphitheatre. Later it was incorporated into the area of the city and attained characteristics of a civilian building. Based on archaeological data, it was possible to define the existence of its primary wooden structure. After a short period of time, it was replaced by a stone-wooden amphitheatre, which underwent remodelling over time (Nikolić and Bogdanović 2015; Bogdanović and Nikolić 2017; Богдановић, Рогић и Вуковић-Богдановић 2018). Based on their architectural characteristics and analogies, the wooden and the masonry amphitheatre are classified into specific types of such buildings determined by J.-C. Golvin (1988).

This study implies the determination of the building techniques within different phases and stages of construction of the Viminacium amphitheatre. It is an important addition to the previous research of architecture at Viminacium (Nikolić 2013) and improves our knowledge about amphitheatres in the Danubian provinces. It was observed that construction techniques are related to certain building materials. The use of various materials, such as timber, raw clay, brick, tile, stone and mortar, also provide information about the Viminacium

environment and locally available building materials or the position of the exploited natural resources in the broader area. According to the latter, it is also possible to suggest the method of transportation of the building materials for the construction of the amphitheatre.

Keywords – Roman period, Viminacium, amphitheatre, construction techniques, building materials

References:

Bogdanović, I. and Nikolić, S. 2017
In the Beginning There Was a Timber Construction... The Wooden Amphitheatre of Viminacium, in: *Columna Traiani: Traianssäule – Siegesmonument und Kriegsbericht in Bildern: Beiträge der Tagung in Wien anlässlich des 1900. Jahrestages der Einweihung, 9.-12. Mai 2013*, eds. F. Mitthof und G. Schörner, TYCHE Sonderband 9, Wien: Holzhausen der Verlag, 87–94.

Богдановић, И., Рогић, Д. и Вуковић-Богдановић, С. 2018
Виминацијумски амфитеатар, у: *Римски лимес и градови на тлу Србије*, ур. М. Кораћ и С. Поп-Лазић, Београд: Српска академија наука и уметности и Археолошки институт Београд, 44–49.

Golvin, J.-C. 1988
L'amphithéâtre romain: Essai sur la théorisation de sa forme et de ses fonctions, Paris: Diffusion de Boccard.

Le Roux, P. 1990
L'amphithéâtre et le soldat sous l'empire romain, en: *Spectacula I. Gladiateurs et amphithéâtres: Actes du colloque tenu à Toulouse et à Lattes les 26, 27, 28 et 29 mai 1987*, éds. C. Domergue, C. Landes et J.-M. Pailler, Lattes: Imago, 203–215.

Nikolić, E. 2013
Contribution to the study of Roman architecture in Viminacium: construction materials and building techniques, *Archaeology and Science* 8 (2012): 21–48.

Nikolić, S. and Bogdanović, I. 2015
Recent Excavations on the Amphitheatre of Viminacium (Upper Moesia), in: *Proceedings of the 22nd International Congress of Roman Frontier Studies, Ruse, Bulgaria, September 2012*, eds. L. Vagalinski and N. Sharankov, Sofia: National Archaeological Institute with Museum of the Bulgarian Academy of Sciences, 547–555.

Sommer, S. 2009
Amphitheatres of Auxiliary Forts on the Frontiers, in: *Roman amphitheatres and Spectacula, a 21st-Century Perspective: Papers from an international conference held at Chester, 16th-18th February, 2007*, ed. T. Wilmott, Oxford: Archaeopress, 47–62.

NEW ARCHAEOLOGICAL EXCAVATIONS AT THE DROBETA MILITARY AMPHITHEATRE

FLORIAN MATEI-POPESCU

Vasile Pârvan Institute of Archaeology, Bucharest, Romania

florian.matei@gmail.com

The military amphitheatre in Drobeta was discovered by chance in 2010 in the courtyard of the Iron Gates Museum, Drobeta-Turnu Severin, within an open area located between the Medieval church, to the east, and the Roman military baths, to the west, at approximately 140 m west of the south-western corner of the Roman auxiliary fort. Unfortunately, on that occasion the south-eastern and south-western areas was damaged by the intervention, especially on the south-eastern part of the arena wall, where a part was totally removed. Thus, almost the entire eastern half has been partially uncovered, without relevant registration of the archaeological features and the constructive or architectural remains. On that occasion parts of the northern, eastern and southern entrances were also highlighted, but fortunately only partially uncovered.

As everyone already knows, a timber framed amphitheatre is depicted at Drobeta, near the bridge, on Scene C of Trajan's column, which depicts the bridge being inaugurated by the emperor in AD 105

(Cichorius 1900: 142-153).

The archaeological excavations began in 2012 and were carried out season by season until 2017 by a joint team of archaeologists from the Vasile Pârvan Institute of Archaeology, Bucharest, and the local Iron Gates Museum. Since the eastern half had been partially uncovered, we decided to excavate the western half in order to recover relevant archaeological information of the possible different constructive phases and their chronology (Matei-Popescu 2015). The archaeological excavations were resumed this year, in order to gain all the needed information for a conservation project and for the entire uncovering of the amphitheatre.

Thus, the preserved arena wall of the amphitheatre was uncovered and all four entrances, providing relevant arguments that the porta pompae was located on the western side and the amphitheatre was oriented east-west, like other Roman amphitheatres on the Danube bank. Following those excavations, we were able to determine the possible constructive phases of the amphitheatre: a first entire timber phase, both of the arena and the stands, and a second stone phase, when the arena wall was built in stone, but the stands retained the previous timber frame, being probably only repaired. The monumental entrances, especially on the western side, were erected by the end of the 2nd century AD, during the Severan period, as the discoveries of the stamped tiles of the V Macedonica legion, the Potaissa type (L(egionis) V M(acedonicae)) seem to prove. That monumental stone phase was destroyed

sometime after AD 251, as the recovered Provincia Dacia coins from the debris layers at the Western entrance attest (Găzdac et al. 2015: 176). After that time, by the end of the 3rd century AD or at the beginning of the 4th century AD, the entrances were repaired, and a new threshold was set at the southern entrance, where a Galerius coin, dated to AD 308/309, was recovered, and a simple way into the arena was also arranged at the eastern entrance. If the amphitheatre had the same function during the first half of the 4th century is difficult to say, but it can at least be assumed that the still standing arena was reused. The most interesting built feature was uncovered at the western entrances, where a new construction was erected and overlapped the southern side wall of the entrance and the entire destruction layer of the middle of the 3rd century AD. Taking that into account, one can conclude that the new building was erected at the beginning of the 4th century AD, since the construction technique is Roman and not medieval.

The amphitheatre probably went slowly into decay during the second half of the 4th century AD and the area was overlapped by a medieval settlement starting in the 14th century AD, at the same time as the church mentioned above and the Donjon type tower located at the former south-western corner of the Roman auxiliary fort. All around the outside of the arena wall sunken houses have been discovered, together with their supply pits, and the inside of the arena was used as a rubbish area. It seems this settlement ceased sometime after the middle of the 15th century AD, without having any traces of

destruction. It was probably simply deserted.

Keywords – Roman Dacia, Drobeta, amphitheatre, Trajan, Severan period

References:

Cichorius, C. 1900
Die Reliefs der Traianssäule, III, Berlin: Verlag von Georg Reimer.

Găzdac, C., Neagoe, M., Alföldy-Găzdac, A., and Neagoe, O. 2015
Drobeta. The Never Abandoned City of Roman Dacia, *Coins from Roman Sites and Collection of Roman Coins from Romania IX*, Cluj-Napoca: Mega Publishing House.

Matei-Popescu, F. 2015
L'amphithéâtre militaire romain de Drobeta, in: *Colonne Trajane et trophées romains. Actes du Colloque franco-roumain «Études sur la Colonne Trajane. 1900 ans depuis l'inauguration (113–2013)» Bucarest, 28–29 octobre 2013*, eds. C. C. Petolescu, M. Galinier and Matei-Popescu, F., Bucharest: Publishing House of the Romanian Academy, 100-113.

RESTORATION OF RAM FORTRESS

JASMINA POPOVIĆ RUSIMOVIĆ
Regional Institute for the Protection of Monuments Smederevo, Smederevo, Serbia

j.p.rusimovic@spomenicikulture.rs

Ram Fortress, as a specific achievement of military architecture from the end of the 15th century, was built with the aim of defending the border of Turkey and the border area with Austria, so its architectural concept is the result of such a purpose. Its importance declined after the Battle of Mohács (1526) and the shifting of the border to Buda and Vienna. At the end of the 17th and the beginning of the 18th century, it gained importance again, but then it slowly faded away, and in the first half of the 19th century, the Turks completely abandoned it. In the period that followed, it was overgrown with vegetation, wild, untidy, and almost completely inaccessible to visitors. Since 1948, when it was determined as an immovable cultural property - a cultural monument, a number of activities have been carried out regarding its protection and research. In 1979, it received the status of a cultural monument of exceptional importance, and the following year, the first archaeological probe excavations were conducted and extensive technical documentation

was prepared.

Extensive works on the renewal of Ram Fortress were carried out from the beginning of 2017 to the end of 2018. The realisation of the works was preceded by research works and the preparation of the necessary project documentation in the period from the beginning of 2013 to the end of 2014. In these six years, a lot of work was done, both in terms of the scope and quality of work. Excellent international professional cooperation has been achieved between the design house ANB Mimarlik Musavirlik Insaat ve Ticaret LTD. Sti., Bascavus Sokak 1112/15 K.Esat, Ankara; Turkish Agency for International Development and Cooperation as an investor; ABMA INSAAT RESTORASYON LTD. STI from Istanbul as a contractor; PIRAY MIMARLIK INS. MUH. MIM. DREAM. VE TIC.LTD. STI from Bursa, which performed expert supervision; and the Regional Institute for the Protection of Cultural Monuments Smederevo, which performed conservation supervision during the execution of the works. This cooperation was especially useful, because important professional conservation issues and dilemmas were resolved in a good spirit of exchange of knowledge, experience, joint thinking and searching for the best solutions. Along with the works on the renewal of Ram Fortress, archaeological excavations were carried out, which were specific in relation to the previous archaeological excavations, being a much larger volume of researched areas, and simultaneously implemented with the works on the renewal of the fortification.

By investing significant funds of the Republic of Serbia and the

Republic of Turkey in a relatively short period of time, visible results have been achieved in the restoration of Ram Fortress and its active involvement in modern life.

Keywords - Ram Fortress, fortification, Ram

References:

Цуњак, М. 2008
Рам и Рамска тврђава кроз векове, Пожаревац-Смедерево: Народни музеј Пожаревац, Регионални завод за заштиту споменика културе Смедерево.

Čelebi, E. 1979
Putopis-odlomci o jugoslovenskim zemljama, Sarajevo: Svjetlost.

Симић Г. и Симић, З. 1984
Град Рам, *Саопштења* XVI: 32-56.

ANALYSIS OF ANCIENT MORTARS FROM ROMAN MONUMENTS IN NORTHERN GREECE. DESIGN AND APPLICATION OF COMPATIBLE REPAIR MORTARS

IOANNA PAPAYIANNI

Professor Emeritus, Aristotle University of Thessaloniki, Thessaloniki, Greece

papayian@civil.auth.gr

The Roman period is characterised by outstanding monumental masonry structures found around the Mediterranean Basin and in Europe. It could be said that masonry as a structural element was systemised and dominant in that period. A great number of impressive masonry structures, such as Palaces, aqueducts and marine structures, have survived. The Galerian Complex, Rotunda and the Roman Agora are situated in the centre of Thessaloniki and connected closely with the history and physiognomy of the city.

After the earthquake of 1978, the challenge was to take emergency measures and restore the monuments with compatible mortars/grouts to enhance their monumental value.

Knowledge of original building materials and how to design and apply repair materials compatible with old ones was limited and extensive research work was required to bridge this lack of knowledge.

In the paper the holistic analysis of ancient mortars from Roman monuments is presented, as well as the method of design of compatible repair mortars and how they should be applied. Given that more than twenty years have passed since their restoration, some comments concerning the evaluation of their long-term performance are also included.

Keywords - mortars, Greek Roman monuments, holistic analysis, characteristics, compatible repair mortars.

References:

Athanasiou, Ph., Malama, V., Misa, M. and Sarandidou M. 2015
The restoration of the ruins of the Galerius complex (1994-2014). Documentation and Interventions, Thessaloniki. Ephorate of Thessaloniki Antiquities, Greece.

Papayianni I. and Tsolaki A. 1995
Microstructure and mechanical strength of ancient mortars, in: *Proceedings of Workshop on Materials for Consolidation and Restoration of Monument and Historical Buildings. Reading, Interpreting and Recovering the Knowledge of Traditional Materials*, eds. I. Papayianni and P. Astrinidou, Thessaloniki, 49-58.

Papayianni, I. 2004
Design of Compatible Repair Materials for the restoration of Monument, *International Journal for Restoration, Vol.* 10, *No* 6: 623-636.

Papayianni, I., Stefanidou, M., Pachta, V., Konopisi, S., Athanasiou, F. and Sarandidou M. 2019
Evaluation of lime-based mortars for repairing the Galerius Palace (4th century AD) during restoration project (1994-2014), in: *Proceedings of the International Conference on Sustainable Materials Systems and Structures (SMSS2019) Durability, Monitoring and Repair of Structures*, eds. A. Baričević, M. Jelčić, D. Damjanović and M. Guadagnini, Paris: RILEM Publications S.A.R.L., 660-667.

Penelis, G. 1995
Mortars and Grouts in restoration of roman and byzantine monuments, in: *European seminar on Ancient and traditional mortar technology and their importance in conservation projects*, Rethymnon, Crete.

HOLISM AS A FRAMEWORK FOR UNDERSTANDING AND PRESERVING HERITAGE – THE EXAMPLE OF THE CULTURAL LANDSCAPE OF BAČ

SLAVICA VUJOVIĆ
The Provincial Institute for the Protection of Cultural Monuments, Petrovaradin, Serbia

RASTKO VLAJKOVIĆ
The Provincial Institute for the Protection of Cultural Monuments, Petrovaradin, Serbia

slavaheritage@yahoo.com

The essence of heritage is the preservation of its values - as a special structure of communication, information, and importance functions. The division of heritage into cultural and natural heritage, and then cultural heritage into tangible (movable and immovable) and intangible heritage inevitably jeopardized the comprehensive understanding of the concept of heritage. At the same time, each type of heritage is inevitably regulated by special protection system, which is developed in accordance with national and international theory and practice. The introduction of the category of the cultural landscape provided an opportunity to replace the rigid divisions with synergies,

to which UNESCO made a special contribution in 1996, including the cultural landscape among the existing categories on the List of World Cultural and Natural Heritage.

The cultural landscape of Bač is located in the west of the northern Serbian province of Vojvodina with the border on the Danube, which has had a key influence on the formation of the territory and on cultural and historical processes lasting more than eight millennia. In this example, the path of uniting the elements as a whole was passed through multidisciplinary research, applying the concept of holism as a framework so that the parts are not a simple sum, but that they become something more, or something else - past time in the present time. It started with the networking of primarily unique cultural properties through work on the components that enable their preservation and protection (A-research; B-technical protection and C-use). In this way, the problems present in the entire territory were solved. The aspect of materials is an important part of the overall activities carried out in the period 2006-2021. In a certain way, the result of networking activities is the establishment of the Laboratory for Materials in Cultural Heritage at the Faculty of Technology in Novi Sad, but also significant international cooperation. The results of research, knowledge of the degradation process, and the use of traditional materials and techniques were further brought closer to the public through workshops and popularisation.

Key words - Bač cultural landscape, UNESCO, holism, lime mortars

References:

Пашић, И. 2021
Заштита археолошког наслеђа – методолошки приступ Покрајинског завода за заштиту споменика културе на почетку XXI века. *Грађа за проучавање споменика културе Војводине* XXXIV: 7-23.

Pihler, V., Vasiljević, N. and Vujović, S. 2016
Landscape as a Contemporary Medium for Spatial Development Planning, in: Proceedings of the Third International Conference Preservation and Improvement of Historic Towns, Sremski Karlovci 12th-13th May, 2016, ed. D. Đukanović, Petrovaradin: Provincial Institute for the Protection of Cultural Monuments, 329-350.

Vujović, S. 2019
Integrated Approach to Heritage Conservation, in: *The Best in Heritage, 19th Edition*, Zagreb: European Heritage Association / The Best in Heritage, 130-133.

Vujović, S. 2020
Cultural heritage - how to preserve and use: Centuries of Bac contribution, Petrovaradin: Provincial Institute for the Protection of Cultural Monuments.

Вујовић, С. 2021
Од споменика културе до културног предела – холистички приступ и искуства *Векова Бача", Грађа за проучавање споменика културе Војводине (Нови Сад), бр.* XXXIV (2021): 201-219.

Vujović, S., Vučetić, S., Ducman, V. and Ranogajec, J. 2013
Pozzolanic mortars for the conservation treatment of old masonry: Case study- Bac Fortress, *Građevinar* 65 (8): 721–729.

RAW MATERIAL CHARACTERISATION OF ROMAN MORTARS IN WESTERN ANATOLIA (TURKEY)

BURCU TAŞCI ÖZDEMİR

İzmir Katip Çelebi University, Department of Architecture, İzmir, Turkey

HASAN BÖKE

İzmir Institute of Technology, Department of Conservation and Restoration of Cultural Heritage, İzmir, Turkey

burcu.tasci@ikc.edu.tr

The Roman Empire had a large influence both in Europe and Anatolia regarding architecture, construction techniques and building materials. However, there are few studies on Western Anatolia, which had been settled densely in the Roman period, despite its cultural importance. In this study, the characteristics of Roman lime mortars taken from a wide area including twenty-four archaeological sites in Western Anatolia were determined to understand the mortar production technology in the Roman Empire. The basic physical properties, raw material compositions, mineralogical and chemical compositions, mechanical, microstructural, and hydraulic properties of mortars, pozzolanicity and geochemical characteristics of

aggregates were identified by SEM-EDS, XRD, TGA, FTIR analyses and point load tests. The results indicated that Roman mortars were compact, heterogeneous, low density and highly porous materials. The mortars were predominantly greyish and light brownish in colour. Romans produced lime mortars by following the ideal lime/aggregate ratios given in the Roman sources and using aggregates of different sizes, especially those coarser than 1 mm. Despite using high calcium lime in the production of mortars, the compressive strengths of mortars were found compatible with the NHL3.5 type of lime due to the use of pozzolanic aggregates that were produced from rhyolite and dacite (silicic rocks). The overall results can be proof of a common mortar technology, produced by using local raw material sources throughout the Roman Empire.

Keywords – conservation, Roman lime mortar, characterisation, Turkey

References:

Adam, J.P. 2005
Roman Building Materials and Techniques, London and New York: Routledge.

Lancaster, L. 2019
Pozzolans in Mortar in the Roman Empire: An Overview and Thoughts on Future Work, in: *Mortiers et Hydraulique En Méditerranée Antique*, ed. I. Fumadó Ortega and S. Bouffier, Aix-en-Provence: Presses Universitaires de Provence, 31–39.

Uğurlu Sağın, E. 2012
Characteristics of Roman Mortars Produced from Natural and Artificial Pozzolans in Aigai and Nysa, Ph.D. thesis, İzmir Institute of Technology.

Ward-Perkins, J. B. 1994
Roman Imperial Architecture, New Haven and London: Yale University Press.

LIME KILN - THE DIVINE CRUCIBLE

ALEKSA JELIKIĆ
Institute for the Protection of Cultural Monuments of Serbia - Belgrade, Belgrade, Serbia

aleksa.jelikic@heritage.gov.rs

Lime is the most important and widespread binding material in almost all civilisations of the world. Until the appearance of Portland cement, it was the basis for construction, and even today it is experiencing a renaissance primarily as an unavoidable conservation material in wide use in architectural conservation and painting and restoration work on immovable cultural properties. The use of lime on historic buildings is more convenient due to its mechanical, physical and chemical properties (compatibility), as well as the absence of alkaline carbonates and sulphates (Rodriguez Navarro 2012). Today, lime is mass-produced by high-tech industrial processes. The discovery of lime corresponds to the discovery of fire. The original method of production took place by burning and heating limestone in an open space (Balksten, Persson and Eriksson 2013). However, the calcination reaction that produces quicklime in the lime-making cycle requires a huge amount of energy to be invested, so that the process was gradually transferred to the kiln. The development of efficient

furnaces was gradual. Variations in construction and production technology were characteristic of the time of origin and geographical features of the region. The first primitive furnaces were holes dug in the ground on elevated ground in which stone was not separated from the fuel. Wood or coal was used as fuel, and it was mixed and stacked alternately with pieces of limestone (Mitchell 2012). The material thus obtained and the mortar derived from it had a high content of ash, i.e., alkaline carbonates, and other soluble salts. In the part of the world where lime was used for wall paintings and other construction works that required impeccable quality of materials, a furnace was constructed and technologically designed so that there was no ash in the final product. This was achieved by the constructive separation of fuel combustion (stokehole) from the raw materials (limestone).

Obtaining quicklime of the desired quality depends on the baking temperature and the duration of calcination. The properties of top-quality lime suitable for conservation purposes are determined by each step in the production cycle. Such conditions can be achieved by the correct construction of the furnace, the appropriate size of the opening of the stokehole and the upper opening of the kiln, as well as the adequate size and stacking of the stone and the correct execution of the firing cycle. The whole process has been perfected by the skill of craftsmen who have experienced improvements and come up with the best solutions over several generations. Since the furnace is a place where transmutation takes place, the transformation of matter from one form to another with the help of fire, the process of calcination,

and the traditional production of lime, are fascinating and have a magical dimension (Elijade 1982).

Keywords – lime, lime cycle, lime kiln, construction, conservation

References:

Balksten K., Persson C. and Eriksson J. 2013
Lime burning tradition in field kilns: a case study of the Jamtland tradition i Sweden, in: *Proceedings of the 3rd Historic Mortars Conference HMC13, Glasgow, 11.09.2013-13.09.2013.,* ed. J. Hughes, Glasgow: University of the West of Scotland, 1-9.

Elijade, M. 1982
Kovači i alkemičari, Zagreb: Grafički Zavod Hrvatske.

Mitchell, D. 2020
'That important branch of rural science': historical geographies of lime burning in Scotland, PhD Thesis, University of Glasgow. http://theses.gla.ac.uk/81481/

Rodrigez Navarro, C. 2012
Binders in historical buildings: Traditional lime in conservation, *Seminarios SEM Volume* 09: 91–112.

CERAMIC BUILDING MATERIALS OF VIMINACIUM

LJUBOMIR JEVTOVIĆ
Institute of Archaeology, Belgrade, Serbia

jevtoviclj@gmail.com

Ceramic building materials[1] were one of the key building materials of the Roman Empire. They were introduced to the area of the province of Moesia Superior and ancient Viminacium by the Romans. Prior to their arrival, the province was sparsely urbanised, and in the following centuries, Viminacium grew to be its largest agglomeration[2]. The site is located in Eastern Serbia, next to the modern town of Kostolac, on the right bank of the Mlava river, near its confluence with the Danube. It was first established as a legionary camp (castrum legionis), whose oldest phase dates to the Flavian period. In the late 1st - early 2nd century, a civilian settlement developed to the west of the camp. The city gained the status of municipium in AD 117, during the reign of Emperor Hadrian, and in AD 239, during the reign of Emperor Gordianus III it was granted the status of colonia. The city and its surroundings were destroyed by the

[1] Hereafter CBM.
[2] Regarding the history and development of Viminacium *cf.* Mirković 1986, 21–59.

Huns in AD 441 and never again regained its former glory.

In the earliest phases of its development, locally available construction materials were preferred,[3] but from the late 1st – early 2nd century onwards came the widespread usage of CBM. The intense CBM production in Viminacium is attested by the immense quantities of the material, used in all types of buildings and objects, as well as by numerous traces of the production process, including more than 15 quadrangular kilns and several production structures and features (cf. Jevtović and Danković, in print).

The purpose of this study is to analyse the CBM material from Viminacium. Our primary focus will be on the shapes and their morphometric characteristics, as well as the characteristic features of some shapes. During the Empire, the Romans used some eight standardised forms of CBM, all of which, as well as some unorthodox ones, are present in Viminacium, but in significantly varying quantities. As the quantities of the discovered materials are vast, we will primarily focus on the stamped material. This will provide a chronological aspect to our study. Additionally, the study will include a comparative analysis regarding the provincial and regional characteristics of the CBM. Unfortunately, the material was rarely the subject of dedicated studies, although there are some noteworthy examples (cf. Jeremić 1997; Radivojević 2018). As the brickyards of

[3] For the construction materials and techniques applied in the territory of Viminacium, *cf.* Nikolić 2013.

Viminacium were the largest producer of CBM in the Middle Danube region, these studies are key for understanding the regional brick and tile industries and, more importantly, the intricacies of architecture during the Roman period.

Keywords – Viminacium, *figlinae*, ceramic building materials, Roman bricks and tiles

References:

Jeremić, M. 1997
L'évolution du format des briques sur la territoire de la Serbie, de l'antiquité au moyen age, *MEFRA, moyen age, Tome 109* -1997-1: 7-20.

Jevtović, Lj. and Danković, I. (in print)
An overview of the CBM industries of ancient Viminacium, in: *Roman ceramic and glass manufactures, Production and Trade in the Adriatic region and beyond. Proceedings of the 4th International archaeological colloquy, Crikvenica (Croatia), 8th – 9th november 2017*, eds. G. Lipovac Vrkljan, A. Konestra and A. Eterović Borzić, in print.

Mirković, M. 1986
Inscriptions de la Mésie Supérieure, Volume II, Viminacium et Margum, Beograd: Centre d'études épigraphiques et numismatiques.

Nikolić, E. 2013
Contribution to the study of roman architecture in Viminacium: construction materials and building techniques, *Arheologija i prirodne nauke* 8 (2012): 21–48.

Radivojević, A. 2018
Opeke u kasnoj antici. Zapisi u materijalu / Bricks in Late Antiquity. Records in the Material, Beograd: Univerzitet u Beogradu, Arhitektonski fakultet.

THE ROLE OF BRICK IN THE LATE ANTIQUE ARCHITECTURE OF THE CENTRAL BALKAN ROMAN PROVINCES

ANA RADIVOJEVIĆ
University of Belgrade, Faculty of Architecture, Department of Architectural Technologies, Belgrade, Serbia

ana@arh.bg.ac.rs

Complex research of late antique bricks from the area of today's Serbia, conducted at the beginning of the 21st century, included the analysis of this material from several archaeological sites, including the ancient Viminacium. The idea was to determine the similarities and deviations of bricks and brick construction techniques in the observed areas concerning the overall late antique architecture of ancient Rome. Therefore, extensive analyses of the literature and the results of previous research were conducted, in conjunction with fieldwork and laboratory testing of appropriate samples from the field.

The research indicated that construction techniques that were used in the area of today's Serbia in the time of late Late Antiquity were completely in line with the method of building in the area of the Eastern Roman Empire. As a rule, they included the use of bricks, and

most often in the opus mixtum technique, performed in a manner characteristic of Late Antiquity, while in the case of smaller buildings, the opus testaceum technique could also have been be used.

The analysed area had a specific role in the turbulent period of the invasion of barbarian tribes in the Eastern Roman Empire, resulting in the fact that by the end of the 4th century the area was mostly devastated and depopulated. However, during the 6th century and the reign of Emperor Justinian, the area of northern Illyricum revived and gained strategic importance to preserve the northern borders of the Empire, so that some cities were revived, and completely new fortified settlements were also built.

The new circumstances contributed to the intensification of construction activities with a noticeably more extensive use of brick and more frequent application of the opus testaceum technique on significantly larger buildings than was the case in the previous period of construction activity during the 4th century. At the same time, there was a certain change in the formats of bricks, which, from the elongated rectangular formats that were typical of Late Antiquity in the observed areas, become closer in shape to a square. Visual observation of 6th-century bricks gives the impression of their poorer quality compared to 4th-century bricks.

Morphological, as well as physicochemical analyses conducted on bricks of the 4th and 6th centuries from selected sites, give an initial picture of the quality of used bricks. The gained knowledge of the quality of the analysed bricks in combination with their format and

applied building technique represents a good basis for a better understanding of the behaviour of late antique buildings, but the real picture of this can be obtained in combination with similar research focussed on the mortars that were applied.

Keywords – brick, brickwork, morphological properties, physicochemical properties.

References:

Adam, J. 1995
La construction romaine, Matériaux et techniques, Paris: Grands manuels Picard.

Boucheron, P., Broise H. et Thébert, Y. (eds.) 2000
La brique antique et médiévale. Production et commercialisation d'un matériau, Rome: École française de Rome.

Jeremić, M. 1997
L'évolution du format des briques sur la territoire de la Serbie, de l'antiquité au moyen age, *MEFRA, moyen age, Tome* 109 -1997-1: 7-20.

Papayianni, I. and Astrinidou P. (eds.) 1995
Materials for Consolidation and Restoration of Monuments and Historical Buildings: Reading, Interpreting and Recovering the Knowledge of Traditional Materials, Thessaloniki: Museum of Byzantine Culture.

Radivojević, A. 2018
Opeke u kasnoj antici. Zapisi u materijalu / Bricks in Late Antiquity. Records in the Material, Beograd: Univerzitet u Beogradu, Arhitektonski fakultet.

CONSTRUCTION METHODS APPLIED TO THE STRUCTURE OF TRAJAN'S BRIDGE OVER THE DANUBE

IGOR BJELIĆ
Institute of Archaeology, Belgrade, Serbia

igor_bjelic@yahoo.com

After the first Roman conquest of Dacia, Emperor Trajan decided to celebrate the territorial expansions and successes of his empire with unprecedented construction activities in this part of the world. He gave his architect Apollodorus the challenging task of designing and building the largest known bridge in the ancient world, over 1,000m long, which would bridge one of Europe's largest rivers - the Danube. The speed of the construction of the bridge that the emperor insisted on, imposed the use of several different methods that were related to specific parts of the construction of the bridge.

The construction of Trajan's Bridge consists of three basic parts: the construction of the part of the bridge on the river bank, the part of the supporting structure in the riverbed, and the part of the bridge over the surface of the Danube (Crăciun, Sion 2006). While the last part was made exclusively of wood, the first two parts were mostly made of masonry structures (Bjelić 2020). By following artistic and historical sources, *in-situ* remains, and analogies around the

world, one can roughly define the appearance of the masonry structures of the bridge (Garašanin, Vasić 1984; Vulpe 2006; Витрувије 2009). At the same time, the use of different materials for masonry structures was conditioned by the speed of bridge construction and the surrounding natural conditions.

There are clear prints of vertical planks on the faces of the foundations, which show the extent to which the *opus caementicum* was tamped and how the foundations were constructed. On the facades of the above-ground parts of the columns, brick facades were built with variable widths of horizontal beds of lime mortar between them on the longitudinal sides, while the sides were built of stone blocks firmly connected to the rest of the columns with a wooden grid. The use of all the listed different materials had its justification in Apollodorus' idea of building a bridge. On the collapsed faces of the columns, it is noticeable that the pouring and tamping of the *opus caementicum* were done in layers and were quite consistent with the installation of a wooden grid. The lower the compressive strength and uniformity of the mortar mixture, the greater would be the need for larger and more properly cut building units, and vice versa (Vitti 2021). In the cores of the columns of Trajan's bridge large pieces of irregularly shaped stone were used for the inside filling, firmly embedded in layers of lime mortar, and the combined settlement during the process of construction was controlled with a wooden grid. For the end parts of columns on the shore, larger and properly cut ashlars were used, while walls of columns between these ends were

faced with layers of densely staggered bricks.

All the interventions the Roman engineers used during the construction of the masonry columns of Trajan's bridge show that their approach was devoted to the security of the masonry construction (in the empirical sense of that time).

Keywords - construction methods, building materials, masonry structures, Trajan's bridge, Roman architecture, Serbia.

References:

Bjelić I. 2020
Trajan's Bridge – Analysis of Apolodorus' Design Concept, in: *Illyricum Romanum – Studiola in honorem Miloje Vasić*, eds. I. Popović and S. Petković, Belgrade: Institute of Archaeology, 22-39.

Crăciun, C., Sion, A. 2006
Preliminarii la proiectul de restaurare al piciorului podului lui Traian de la Drobeta-Turnu Severin, In : *Dacia Augusti Provincia. Crearea provinciei. Actele simpozionului desfăşurat, Editura Cetatea de Scaun. Octombrie 13-14 2006, Bucureşti*, eds. E. S. Teodor and O. Tentea, Bucureşti: la Muzeul Naţional de Istorie a României, 359-409.

Гарашанин, М., Васић, М. 1980
Трајанов Мост – Кастел Понтес, Претходни извештај 1979., у: *Ђердапске свеске I*, ур. В. Кондић, Београд: Археолошки институт, Народни музеј, Одељење за археологију Филозофског факултета у Београду, 7-25.

Витрувије, М. Р. 2009
О Архитектури. превод и предговор: З. Бојић, Београд: Завод за уџбенике.

Vitti, P. 2021
Mortars and Masonsry – structural lime and gypsum mortars in Antiquity and Middle Ages, *Archaeological and Antropological Sciences 13, issue 10, September 2021*: 164 (1-19).

Vulpe, R. 2002
Columna lui Traian = Trajan's Column, R. Vulpe. Trad.: A. Doina Cornaciu, Bucuresti: CIMEC.

RECONSIDERING THE ARCHAEOLOGICAL SITE OF GLAMIJA – RTKOVO, SERBIA

BOJAN POPOVIĆ
Institute of Archaeology, Belgrade, Serbia

pop984@hotmail.com

Previous research at the site of Glamija-Rtkovo was conducted from 1980 to 1982, and after a long break, continued in 2020 as revisional archaeological excavation in order to prepare project documentation for conservation and restoration work. The results of the new excavations shed a different light on this late antique site and provided an opportunity for a new interpretation of the discovered structures of the younger and older fortifications, their relationships, as well as structural characteristics, and materials used.

Keywords – Glamija, Limes, late antique, architecture, building materials

References:

Bajenaru, C. 2010
Minor fortifications in the Balkan – Danubian Area from Diocletian to Justinian, Cluj-Napoca: Editura Mega.

Gabričević, M. 1986
RTKOVO-GLAMIJA I - UNE FORTERESSE DE LA BASSE EPOQUE, Foullies de 1980-1982, in: *Ђердапске свеске* III, ур. В. Кондић, Београд: Археолошки институт, Народни музеј, Одељење за археологију Филозофског факултета у Београду, 71-91.

Gabričević, M. 1988
Natpis sa lokaliteta Glamija I, in: in: *Ђердапске свеске* IV, ур. В. Кондић, Београд: Археолошки институт, Народни музеј, Одељење за археологију Филозофског факултета у Београду, 143-146.

Jeczimenovski, E. 2017
Roman fortifications along the Former Upper Moesian Limes AD 270-378, in: *Roman in the Middle and Lower Danube Valley, 1st century BC – 5th century AD: Case studies in archaeology, epigraphy and history*, eds. E.C. De Sena and C. Timoc, Oxford: BAR Int. Series 2882, 97-106.

Pop-Lazić, S., Rumel, C. 2020
Characteristic of late Roman fortifications on the Middle Danube Limes, in: *ILLYTICVM ROMANVM: Studiola in honorem Miloje Vasić*, eds. I. Popović, S. Petković, Belgrade: Institute of Archaeology, 224-239

HOW TO PRESENT THE ANCIENT CITY OF AELIA MURSA

TINO LELEKOVIĆ
Croatian Academy of Sciences and Arts, Zagreb, Croatia

tilelek@hazu.hr

The paper focuses on problems encountered in searching for the best ways to excavate and present the remains of the ancient Roman colony of Aelia Mursa (Osijek, Croatia).

Aelia Mursa was the largest civil settlement and the only colony on the Limes in Lower Pannonia. Accordingly, its significant economic and administrative role is assumed. Recovered remains of Roman architecture derive from two lines of excavations. Large-scale rescue excavations on the University campus in the western part of the site unearthed large areas of the colony suburb, posing considerable challenges in combining the design of new buildings with the preservation and presentation of Roman remains. Another line of research follows a scientific approach.

For over a decade, a research project has been trying to excavate essential parts of the colony and discover the municipal and public buildings. Preservation and presentation of remains from both lines of research encountered several difficulties and challenges. The

paper will present some of the solutions. The paper will include a short overview of the current research on the Limes and the presentation of plans for sites on the Croatian part of the imperial border.

Keywords – Aelia Mursa, Roman Limes, Lower Pannonia

References:

Leleković, T. 2020
Elija Mursa: novo čitanje grada, Arheološki radovi i rasprave 19: 77-161.

Lolić, T. and Wiewegh, Z. 2021
Urbanism and Architecture, in: The Archaeology of Roman Southern Pannonia. The state of research and selected problems in the Croatian part of the Roman province of Pannonia, ed. B. Migotti, Oxford: BAR Intern.Ser. 2393, 191–224.

Marin, E. 2018
Mursa: Hadrijanova kolonija uz limes Rimskog carstva, edicija Mursa Aeterna IV, Zagreb - Osijek: Hrvatska akademija znanosti i umjetnosti, Znanstveno vijeće za antropologijska istraživanja, Zavod za znanstveni iumjetnički rad u Osijeku.

Pinterović, D. 1978
Mursa i njeno područje u antičko doba, Osijek: Centar za znanstveni rad Jugoslavenske akademije znanosti i umjetnosti.

CROSS-DISCIPLINARY COLLABORATION IN CONSERVATION PROJECTS – MANAGING KEY CHALLENGES

HELENA HIRŠENBERGER

Metropolitan University, Faculty of Economics, Finance and Administration, Belgrade, Serbia

SNEŽANA VUČETIĆ

University of Novi Sad, Faculty of Technology, Laboratory for Materials in Cultural Heritage, Novi Sad, Serbia

JONJAUA RANOGAJEC

University of Novi Sad, Faculty of Technology, Laboratory for Materials in Cultural Heritage, Novi Sad, Serbia

hhirschenberger@fefa.edu.rs

In the past decades, the concept of cultural heritage has been increasingly enlarged and the number of documents that consider different aspects of cultural and natural heritage preservation continues to grow. In the modern era, cultural heritage is considered a public asset, a source of value, identity and knowledge (Douglas-Jones et al. 2016). It is also recognised as an important contributor to

economic development, employability and social cohesion. Cultural heritage plays a role in education, tourism and emerging creative industries, while investments in the conservation, rehabilitation, and maintenance of architectural heritage and monuments accounts for almost a quarter of the annual value of the European construction industry.

In these contexts, heritage conservation has evolved into a holistic and inclusive science that coordinates various attempts and approaches to preserve historical objects and landscapes as material testimonies of the past for generations to come. Many professions of diverse backgrounds and expertise; restorers, scientists, private companies, public institutions, and construction workers, to name but a few, are required to work together (Fielden 2003), usually under an umbrella of projects, which has become a prevalent way for the organisation of contemporary, non-routine tasks, in all kinds of industries. The cross-disciplinary character of projects in cultural heritage conservation brings essential knowledge and value, much needed to tackle project objectives and deliver solutions, and particularly suited to the materials and degradations in question. However, dissimilarities in professional languages and approaches among disciplines and sectors that participate as partners, subcontractors, funding authorities and stakeholders, together with a lack of their previous close collaboration (Hirsenberger et al. 2019), substantially increases the complexity and raises new challenges for project managers and teams (Lehtiranta 2014). Coupled with

frequently limited funding possibilities, opposed interests of heritage owners and conservators/restorers, and risks associated with the fragile non-renewable character of historical materials, collaborative challenges require adequate responses, to allow project time and resources to be fully utilised in an optimal manner.

While each project represents a unique combination of objectives, resources, and schedules, the project management body of knowledge continually advances around best practice in the field and its systematic evaluation (Padalkar and Gopinath 2016). Although some of challenges, risks and opportunities might be highly contextual, this paper explores how the increased complexity of the internal environment in cultural heritage projects influences the organisation of project tasks, teamwork and cooperation. The findings reveal some common challenges directly associated with the cross-disciplinary setting of modern conservation projects and links them with useful references on how these can be managed and mitigated. The proposed measures start right from the early recognition of organisational and collaborative challenges, the well-informed selection of a project management methodology; waterfall, agile or most likely hybrid, which will effectively address the specific characteristics of the collaboration in question, and the inclusion of preventive measures already in the project design, a stakeholder engagement plan, network building actions and the needed exchange of practices. This paper intends to assist present and future researchers and practitioners to recognise and manage key challenges

of the knowledge intensive cross-disciplinary setting in collaborative conservation projects.

Keywords – cultural heritage, conservation projects, collaborative projects, project management methodology, collaboration challenges

References:

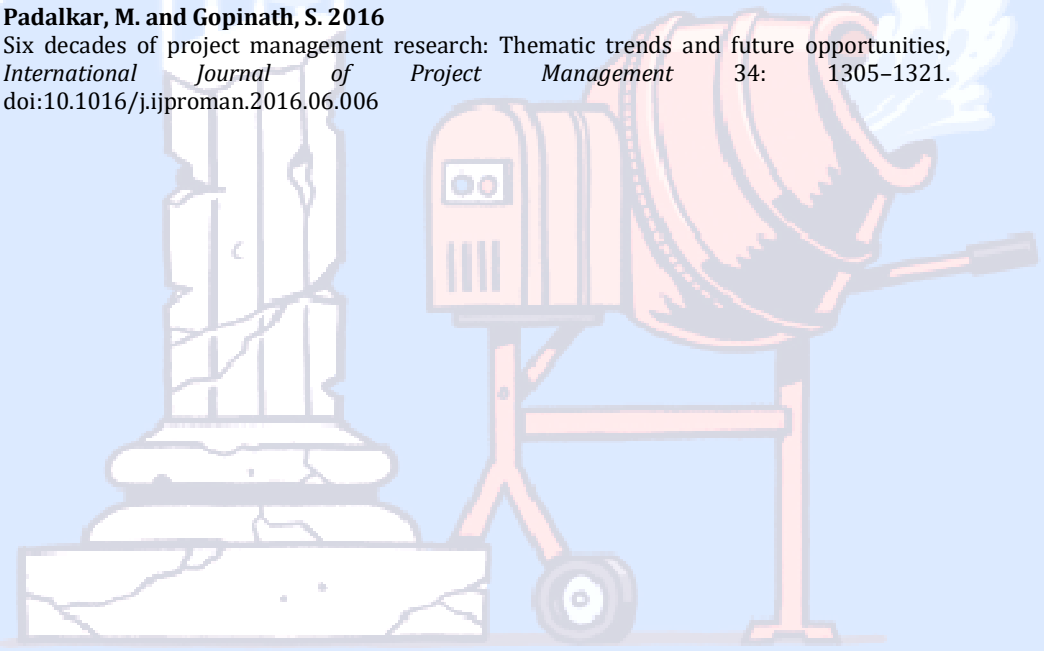
Douglas-Jones, R., Hughes, J.J., Jones, S., and Yarrow, T. 2016
Science, value and material decay in the conservation of historic environments, *Journal of Cultural Heritage* 21: 823–833. doi:10.1016/j.culher.2016.03.007

Feilden B.M. 2003
Conservation of Historic Buildings Third edition, Oxford: Architectural Press, Elsevier.

Hirsenberger, H., Ranogajec, J., Vucetic, S., Lalic, B. and Gracanin, D. 2019
Collaborative projects in cultural heritage conservation – management challenges and risks, *Journal of Cultural Heritage* 37: 2015-224. doi:10.1016/j.culher.2018.10.006

Lehtiranta, L. 2014
Risk perceptions and approaches in multi-organizations: A research review 2000-2012, *International Journal of Project Management* 32: 640–653. doi:10.1016/j.ijproman.2013.09.002

Padalkar, M. and Gopinath, S. 2016
Six decades of project management research: Thematic trends and future opportunities, *International Journal of Project Management* 34: 1305–1321. doi:10.1016/j.ijproman.2016.06.006



TRADITIONAL LIME PRODUCTION AND ITS APPLICATION ON MONUMENTS OF CULTURE – EXPERIENCE FROM THE WORK ON ANCIENT MONUMENTS

BRANKO ORBANIĆ
Kapitel d.o.o., Žminj, Croatia

branko.orbanic@kapitel.net

Lime is a traditional product with a variety of uses. Today, we know that in the past lime was mostly used in the construction of buildings and in final building work such as plastering, painting, and flooring. Lime is also widely used in agriculture to produce solutions for spraying or coating fruit trees and for crop protection. In everyday life, lime was used to disinfect drinking water in cisterns and wells, to disinfect outbuildings, and particularly to maintain the healthiness and appearance of houses. We also know that in the past every house used to have a pit with slaked lime that was regularly filled so that a household would never be left without this universal substance.

People have produced lime for construction purposes since ancient times. Lime was used several thousand years before Christ, and the period that provides us with the most written and oral testimony about lime and advice for using it is Antiquity.

Traditional limekilns are used to heat stone (calcium

carbonate) to temperatures up to 1200°C until all the water evaporates and calcium dioxide is released. The result of this process is quicklime (calcium oxide), which is then slaked in basins with water and stored in lime pits to sediment. This is slaked lime (calcium hydroxide).

We will present our research and practical work on the production of the hydraulic lime mortar and its use on ancient monuments in Croatia.

Keywords – lime, limekilns, traditional lime production, slaked lime

References:

Historical drawings:
I Cantieri nell'Arte (Edifir Firenze 2009.) – Gabriella Orefice

Karleuša, R. 2007
Iz povijesti graditeljstva: Proizvodnja i primena vapna (I), *Građevinar* 59/1: 55-60.

Karleuša, R. 2007
Iz povijesti graditeljstva: Proizvodnja i primena vapna (II), *Građevinar* 59/2: 149-156

Karleuša, R. 2007
Iz povijesti graditeljstva: Proizvodnja i primena vapna (III), *Građevinar* 59/3: 249-257.

Stark, J., Wicht, B. 1999
Zement Und Kalk: Der Baustoff Als Werkstoff, Basel: Birkhauser Verlag AG.

Vitruvius (Lopac, M., Bedenko, V. tr.) 1999
De architectura libri decem - Deset knjiga o arhitekturi, Zagreb: Golden Marketing, Institut građevinarstva Hrvatske

Weissenbach, H. 2001
Prezentacija tehnike vapna, Zagreb

INTRINSIC PROPERTIES OF THE LIMESTONE USED IN THE BELGRADE FORTRESS AND THEIR INFLUENCE ON DEGRADATION PROCESSES

MAJA FRANKOVIĆ
National Museum of Serbia, Belgrade, Serbia

VESNA MATOVIĆ
University of Belgrade, Faculty of Mining and Geology, Department of Mineralogy, Petrology, Crystallography and Geochemistry, Belgrade, Serbia

NEVENKA NOVAKOVIĆ
Cultural Heritage Preservation Institute of Belgrade, Belgrade, Serbia

m.frankovic@narodnimuzej.rs

Soft limestone varieties are often used in architecture due to their good workability and low weight, especially for carved decorative elements. Being usually highly porous, they are prone to weathering caused by water movement and the transport of soluble salts. The building stone dominantly used in the Belgrade fortress is autochthonous corallinacean limestone of the Badenian Age, called "Leitha limestone" or "Lithotamnium limestone". It contains red algae

(Lithotamnium ramisissimum) fossils, together with other tropical, shallow sea organisms – molluscs, snails, sea urchins, corals, bryozoa and foraminifera, as well as a variable percentage of clastic component. The result of the limestone heterogeneity is the uneven appearance, colour, mechanical properties and porosity. Lithological heterogeneity, in conjunction with environmental and anthropogenic influences, results in high degradation intensities.

Two dominant microfacies used in the Belgrade fortress, Grainstone and Algal rudstone, were determined by the lithological mapping of several gates. Their petrological, chemical, physical and mechanical properties were examined. Correlating intrinsic factors with the present weathering forms and extrinsic (environmental) factors of decay, enabled the definition of physicochemical degradation processes of built limestone microfacies. Understanding stone properties and degradation processes enables informed decision making in the conservation-restoration of monuments of culture, especially when considering preventive conservation measures and the compatibility of applied conservation materials.

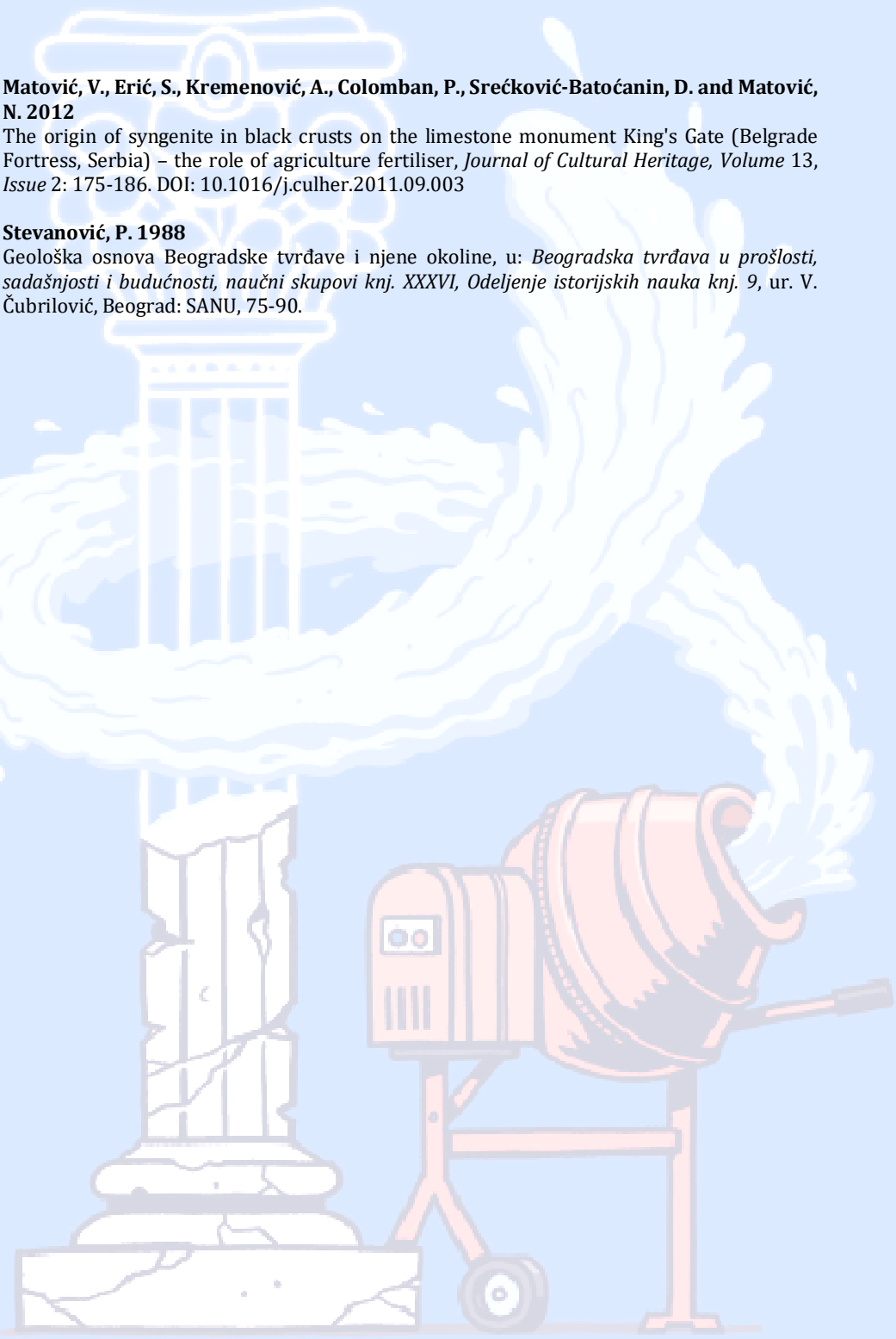
Keywords – Lithotamnium limestone, Belgrade fortress, physical and mechanical properties, degradation processes.

References:

Franković, M., Novaković, N., Matović, V. 2015
Damage quantification of built stone on Dark Gate (Belgrade, Serbia): sample of damage index application for decay rate evaluation, *Environmental Earth Sciences* 73(10): 6181-6193. doi10.1007/s12665-014-3843-z

Matović, V., Erić, S., Kremenović, A., Colomban, P., Srećković-Batoćanin, D. and Matović, N. 2012
The origin of syngenite in black crusts on the limestone monument King's Gate (Belgrade Fortress, Serbia) – the role of agriculture fertiliser, *Journal of Cultural Heritage, Volume* 13, *Issue* 2: 175-186. DOI: 10.1016/j.culher.2011.09.003

Stevanović, P. 1988
Geološka osnova Beogradske tvrđave i njene okoline, u: *Beogradska tvrđava u prošlosti, sadašnjosti i budućnosti, naučni skupovi knj. XXXVI, Odeljenje istorijskih nauka knj. 9*, ur. V. Čubrilović, Beograd: SANU, 75-90.



ANALYSES OF THE PIGMENTS AND PLASTERS OF THE EXAMPLES OF ROMAN WALL PAINTINGS FROM SIRMIUM AND VIMINACIUM

DRAGANA GAVRILOVIĆ
Institute of Archaeology, Belgrade, Serbia

gavrilovicdragana@yahoo.com

This paper highlights both the advantages and limitations of the analytical techniques performed on fragments of plasters of Roman wall paintings of Viminacium and Sirmium using different analytical techniques. The results of analytical methods can enable an understanding of the painting technology applied in ancient times, as well as help to identify the painting palette (Rogić, Gajić-Kvaščev and Andrić 2012: 267-290; Vujović, Gavrilović and Gajić-Kvaščev 2020: 121-129) used in a certain period. Physical-mechanical properties, mineralogical-petrographic and chemical composition can be determined during the analysis of mortar (Nikolić et al. 2016: 137-144). For experts who deal with the protection of cultural heritage, it is most important to understand what certain analytical techniques can contribute. Analytical techniques used to characterise the pigments and plasters of the Roman period wall paintings from Viminacium and Sirmium: pEDXRF (portable energy dispersive X-ray

fluorescence analysis), XRD (X-ray diffraction), SEM-EDS (scanning electron microscopy with energy-dispersive spectrometry), and optical microscopy.

Keywords – pigments, plasters, wall paintings, Sirmium, Viminacium

References:

Nikolić, E., Radivojević, A., Delić-Nikolić, I. and Rogić, D. 2016
Roman Mortars from the Amphitheatre of *Viminacium, in: Proceedings of the 4th Historic Mortars Conference (HMC 2016), Santorini, Greece*, eds. I. Papayianni, M. Stefanidou and V. Pachta, Thessaloniki: Laboratory of Building Materials, Department of Civil Engineering, Aristotle University of Thessaloniki, 137-144.

Vujović, M., Gavrilović, D. and Gajić-Kvaščev, M. 2020
Mermerna ikonica kulta Podunavskih konjanika iz Muzeja grada Beograda, u: *Ancient Cult in Balkans through Archaeological Findings and Iconography, Srpsko Arheološko društvo*, ed. S. Petković and N. Gavrilović-Vitas, Belgrade: Serbian Archaeological Society, 119-129.

Rogić, D., Gajić-Kvaščev, M. and Andrić, V., 2012
Analysis of blue and green pigments from the fresco painted tombs of Viminacium, *Archaeology and Sciences* 7: 268-290.

PIGMENT IDENTIFICATION IN THE MURAL DECORATION FROM THE ROMAN CITY OF ULPIA OESCUS USING VIBRATIONAL SPECTROSCOPY AND SEM-EDS ANALYSIS

MARIA ARGIROVA

Institute of Organic Chemistry with Centre of Phytochemistry, Bulgarian Academy of Sciences, Sofia, Bulgaria

GERGANA KABAKCHIEVA

National Archaeological Institute with Museum, Bulgarian Academy of Sciences, Sofia, Bulgaria

DENITSA YANCHEVA

Institute of Organic Chemistry with Centre of Phytochemistry, Bulgarian Academy of Sciences, Sofia, Bulgaria

BISTRA STAMBOLIYSKA

Institute of Organic Chemistry with Centre of Phytochemistry, Bulgarian Academy of Sciences, Sofia, Bulgaria

NIKIFOR HARALAMPIEV

National Academy of Art, Faculty of Applied Arts, Sofia, Bulgaria

DIETER FISCHER
Institute of Macromolecular Chemistry, Leibniz-Institut für Polymerforschung Dresden, Dresden, Germany

ALBENA LEDERER
Institute of Macromolecular Chemistry, Leibniz-Institut für Polymerforschung Dresden, Dresden, Germany

maria.argirova@orgchm.bas.bg

The antique Roman city of Ulpia Oescus, situated near the bank of the river Danube at Gigen village, Pleven province, Bulgaria, was one of the main cities of the Roman province of Lower Moesia (Кабакчиева 2000). Ulpia Oescus was established in the 1st century A.D as a Roman legionary camp. Later it was granted the status of a colony after the victory of Emperor Mark Ulpius Trajan against the Dacians. Due to its crossroad location, Ulpia Oescus became an important centre in the period from the 2nd to the 3rd century A.D. In the central city area were built a forum, Capitolium, basilica civilis and templum Fortunae. The city flourished again in the first half of the 4th century A.D. during the reign of Emperor Constantine the Great (306 – 337 AD) and it was personally visited by the emperor in 328 A.D. for the official opening of a large stone bridge constructed over the Danube River.

Here, we present an analytical study on the painting materials and technology used to create the mural decoration of a public

building in Ulpia Oescus. The study was conducted on a series of mural fragments comprising decoration of three or four colours in different combinations - grey, black and red; white, yellow and red; white, green, red and black; red, white, yellow and black etc., recovered during excavation work. A visual examination and an optical microscopy observation showed that the paint layers of different colour were applied on different ground layers – white or yellow. The microscopic observation of the fragments also demonstrated a highly heterogeneous character of the paint layers of the mural decoration. The mineral pigments, paint binder, fillers and other inorganic components in the ground layers of the mural decoration were studied by ATR and absorption measurements in the middle and far IR region, micro-Raman analysis and Scanning Electron Microscopy–Energy-Dispersive X-ray Spectroscopy (SEM-EDS). The SEM-EDS analysis provided detailed information on the elemental composition of the studied painting layers and the distribution of the elements within the heterogeneous paint matrix. The vibrational spectroscopy enabled a more precise characterisation of the mineral pigments and the other component in the non-invasive and micro-invasive approach. The combined analytical data showed that the colour palette is based mainly on natural pigments such as red and yellow ochre, green earths, calcite and kaolinite. Cinnabar, carbon black and a copper green pigment were also found in some of the colours. Additional colour shades were achieved by using pigment mixtures. Calcite was identified as the paint binder without the addition of any organic

substances (fresco technique). The ground layers were created using calcite or a calcite/yellow ochre mixture.

Keywords – Roman monuments, wall paintings, pigments, ATR-FTIR, micro-Raman analysis

Acknowledgments: *This work has been financially supported by the National Science Fund of Bulgaria, Contract КП-06-ОПР 05/5. Equipment of INFRAMAT (Research Infrastructure from National roadmap of Bulgaria), supported by a contract with the Bulgarian Ministry of Education and Science was used in a part of the present investigations.*

References:

Кабакчиева, Г. 2000
Ранноримския военен лагер при устието на р. Искър, Oescus 1. Castra Oescensia, София: Албатрос.

FUNGAL PROLIFERATION ON FRESCO PAINTING: DETERIORATION OF MORTAR AND PAINTED LAYER

NIKOLA UNKOVIĆ

University of Belgrade, Faculty of Biology, Belgrade, Serbia

ŽELJKO SAVKOVIĆ

University of Belgrade, Faculty of Biology, Belgrade, Serbia

MILOŠ STUPAR

University of Belgrade, Faculty of Biology, Belgrade, Serbia

ALEKSANDAR KNEŽEVIĆ

University of Belgrade, Faculty of Biology, Belgrade, Serbia

IVICA DIMKIĆ

University of Belgrade, Faculty of Biology, Belgrade, Serbia

MILICA LJALJEVIĆ GRBIĆ

University of Belgrade, Faculty of Biology, Belgrade, Serbia

unkovicn@bio.bg.ac.rs

Due to the mineral composition and porous nature of lime mortar and the organic components present within the painted layer, fresco paintings are extremely susceptible and receptive to fungal growth. The establishment of fungi on the painted layer surface, inside mortar or in the interspace between can lead to structural and aesthetic damage that manifests as a variety of symptoms: salt efflorescence, blistering, exfoliation, cracking, discoloration, patina formation, etc. (Milanesi et al. 2006; Pepe et al. 2011; Sterflinger and Piñar 2013; Unković et al. 2016; Unković et al. 2018). Fungal proliferation was studied on the frescoes decorating the walls of the nave and exonarthex of the old Church of the Holy Ascension (Veliki Krčimir), using several microscopic (in situ, optical and SEM) and classic microbiological methods for the isolation and cultivation of a viable part of the total mycobiota. A total of 46 fungal taxa was documented (43 from fresco surfaces and 8 from the mortar), with a dominance of Aspergillus, Penicillium and Cladosporium species, i.e., species that are frequently cited as the most common fresco painting contaminants, as well as the primary fresco deterioration agents in temperate climates. Furthermore, in addition to dominant members of the fungal community, documented fungi from less represented genera can significantly contribute to the damage of fresco paintings, e.g. Phoma species from the surface of the painted layer indicate that given frescos are in an active process of deterioration, while Aureobasidium and Epicoccum species, due to strong proteolytic activity, degrade the protein binders of the painted layer, which

results in the lifting and separation of the painted layer from the support. The greatest species diversity was recorded in the summer, while the highest abundance of fungal propagules per unit area ("fungal print") was observed in the winter. The performed cluster analysis showed that the position of the fresco paintings in relation to the openings determines the degree of similarity to the mycobiota of the external environment, with physically close frescoes more often having a similar mycobiota due the similarity of the microclimate and the easier dispersion of inoculum among spatially close paintings. Microscopic analyses revealed structures of Cladosporium and Chaetomium species as the main biodeteriogens, with observed deterioration symptoms likely formed due to hyphal penetration through the entire painted layer, all the way to the mortar support, and the formation of fruiting bodies and other fungal structures.

Keywords – biodeterioration, conservation, fresco paintings, fungi, mortar

Acknowledgments: *This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #GRANT No. 6066210, PROTECTA*

References:

Milanesi, C., Baldi, F., Borin, S., Vignani, R., Ciampolini, F., Faleri, C. and Cresti, M. 2006 Biodeterioration of a fresco by biofilm forming bacteria, *International Biodeterioration and Biodegradation* 57: 168-173.

Pepe, O., Palomba, S., Sannino, L., Blaiotta, G., Ventorino, V., Moschetti, G. and Villani, F. 2011
Characterization in the archaeological excavation site of heterotrophic bacteria and fungi of deteriorated wall painting of Herculaneum in Italy, *Journal of Environmental Biology* 32: 241-250.

Sterflinger, K. and Piñar, G. 2013
Microbial deterioration of cultural heritage and works of art - tilting at windmills? *Applied Microbiology and Biotechnology* 97: 9637-9646.

Unković, N., Dimkić, I., Stupar, M., Stanković, S., Vukojević, J. and Ljaljević Grbić, M. 2018
Biodegradative potential of fungal isolates from sacral ambient: *In vitro* study as risk assessment implication for the conservation of wall paintings, *PLoS ONE 13(1)*: e0190922.

Unković, N., Ljaljević Grbić, M., Stupar, M., Savković, Ž., Jelikić, A., Stanojević, D. and Vukojević, J. 2016
Fungal-induced deterioration of mural paintings: in situ and mock-model microscopy analyses, *Microscopy and Microanalysis* 22(2): 410-421.

BENEFITS AND LIMITS OF DRMS TECHNOLOGY IN THE PROCESS OF DESIGNING REPAIR MORTARS USING DRILLING RESISTANCE CRITERION

IVAN VANJA MARTINOVIĆ

University of Zagreb, Academy of Fine Arts, Department of Conservation and Restoration of Works of Art, Zagreb, Croatia

ivmartin@alu.hr

This lecture aims to present how DRMS (drilling resistance measurement system) technology can be used to design repair plaster recipes and to demonstrate certain practical difficulties encountered during the phase of the utilisation of the results of the research. The topic will be presented through the case study of the conservation-restoration of a baroque wall painting located in the Chapel of Passion of the Christ in St. Cosmas and Damian church in Kuzminec (Croatia). Since repair plasters should be "weaker" than the original structure, during the conservation-restoration campaign in the Chapel, one of the main tasks was to develop plaster recipes that satisfy the needs of physical compatibility. It was decided to evaluate potential plaster recipes in term of hardness and to choose the right ones by comparing them with the hardness of the original plasters. For that purpose, DRMS was used and drilling measurements were conducted on the

wall painting and on plaster samples of different repair recipes. Although plasters of the chosen recipes, physically compatible with the original (having lower values of drilling resistance), were behaving well in the process of the sample preparation, in some cases they showed unsatisfactory properties during the application on the original wall. Given the practical shortcomings of plasters can overrun their potential functional benefits, this lecture will elaborate some of the reasons why drilling resistance should not be the only criterion in the process of designing repair plasters recipes.

Keywords – DRMS, repair plasters, Kuzminec, wall paintings

References:

Costa, D., Magalhaes, A. and Do Rosario Veiga, M. 2010
Characterization of mortars using DRMS: test on field mortar samples Title, in: *Historic Mortars and RILEM TC 203-RHM Final workshop HMC2010. Proceedings of the 2nd Conference and of the Final Workshop of RILEM TC 203-RHM*, eds. J. Valek, C. Groot and J. J. Huges, Prague: RILEM Publications S.A.R.L., 447-455.

Henry, A. and Stewart, J. (eds.) 2012
Practical Building Conservation: Mortars, Renders & Plasters, Farnham: Ashgate Publishing Limited.

Martinović, I. V. 2017
Smjernice za konzervatorsko-restauratorske radove na zidnim slikama kapele Muke Kristove crkve sv. Kuzme i Damjana u Kuzmincu, Master thesis, Academy of Fine Arts, University of Zagreb

CONTEMPORARY APPROACHES TO THE REVITALISATION, PRESENTATION AND PROMOTION OF CULTURAL AND NATURAL HERITAGE OF THE PART OF THE ROMAN LIMES - CASE STUDY OF THE LATE ANTIQUE TOMB IN BRESTOVIK

MARKO S. NIKOLIĆ
University of Belgrade, Faculty of Architecture, Department of History and Theory of Architecture and Art, Belgrade, Serbia

ENA R. TAKAČ
University of Belgrade, Faculty of Architecture, Department of History and Theory of Architecture and Art, Belgrade, Serbia

JELENA V. ŠĆEKIĆ
University of Belgrade, Faculty of Architecture, Department of History and Theory of Architecture and Art, Belgrade, Serbia

2021_41001@edu.arh.bg.ac.rs

The Roman Limes is recognised as a cultural landscape of exceptional universal values of international importance by the relevant organisation for the protection of cultural and natural heritage - UNESCO. In the Republic of Serbia, the Roman Limes include

the Danube Valley, where there are sites of different historical periods (prehistoric, ancient, medieval), which represent evidence of the continuity of life on the border of the Roman Empire. Protection, revitalisation, presentation and promotion of sites along the Danube is a prerequisite for the entry of the Roman Limes in Serbia on the UNESCO World Cultural and Natural Heritage List. From 2020, this area is on the UNESCO Tentative List. Bearing in mind the current state of a large number of localities, the question of their protection, revitalisation, presentation and promotion in a contemporary context arises. Referring to the principles of international charters and conventions, including the Document of Authenticity, the Landscape Convention and the Charter on Cultural Routes, the main goal of this paper is to spread knowledge about the possibilities of protection, revitalisation, presentation and promotion of the cultural and natural heritage of the Roman Limes in Serbia through the application of the principles defined in international charters and conventions, all for the integration of cultural and natural heritage into the contemporary environment and the establishment of sustainable landscape development.

The results are presented through a case study of the archaeological site of the late antique tomb in Brestovik, through the conceptual solutions of architecture students, within which the possibilities of integrating contemporary architecture into spaces of natural and historical values were examined, while preserving the identity of natural and cultural heritage that requires specific

protection, presentation and promotion. Through the process of educating students of architecture, there is a possibility of the comprehensive consideration of the problem of preserving cultural and natural heritage, its historical and urban context, origin, development, cultural, urban and architectural values, and examining the possibility and comparison of different approaches to presentation and contemporary use. In designing the future approach to the presentation and inclusion in *the contemporary* life of the late antique tomb in Brestovik and its surroundings, the student analyses focused on comprehensive research of the life of the tomb, from its origins to modern times, as well as discovering specific cultural values that are the basis for future preservation. The goal was to design sustainable solutions that will preserve the development phases, and the authenticity and integrity of the late antique tomb in Brestovik, while ensuring its reactivation and quality integration into its environment, which, despite numerous inadequate modern interventions, has preserved elements of the recognisable historical *ambiance*. Through their proposals, students have filled the complex with a large amount of contemporary cultural, educational and artistic content that correlates with its character and significance, and provides it with an active life. The expected results of the research include raising awareness of the possibilities of integrating natural and cultural heritage into the contemporary context, as well as considering the natural and cultural heritage as a driver for establishing sustainable landscape development.

Keywords – Roman Limes, cultural and natural heritage, late antique tomb, contemporary revitalisation and presentation, sustainable development.

References:

Милошевић, Г. 1993
Касноантичка гробница из Брестовика, in: *Царски градови и палате у Србији*, ур. Д. Срејовић, Београд: САНУ, 181-183.

Nikolić, E., Rogić, D. and Anđelković Grašar, J. 2018
Architectural space in the wall painting of the roman tomb in Brestovik, in: *Vivere Militare Est. From Populus to Emperors - Living on the Frontier, Volume II*, eds. S. Golubović and N. Mrđić, Belgrade: Institute of Archaeology, 195-268.

Ротер-Благојевић, М., Милошевић, Г. и Николић, М. 2009
Истраживање могућности обнове и презентације археолошког локалитета TIMACUM MINUS у контексту специфичног културног пејзажа, *Гласник ДКС* 33: 101-108.

Симић, З. 2009
Касноримска гробница у Брестовику, Београд: Завод за заштиту споменика културе града Београда.

Валтровић, М. 1906
Римска гробница у селу Брестовику, *Старинар* 1: 128-138.

Вујичић - Вуловић, М. 1967
Римска гробница у Брестовику (конзерваторско-рестаураторски радови – прва фаза), *Зборник заштите споменика културе* XVIII: 86-92.

MASTER CONSERVATION PLAN FOR THE ARCHAEOLOGICAL SITE OF STOBI: GOALS AND OUTCOMES

SILVANA BLAŽEVSKA

National Institution Stobi, Stobi, North Macedonia

ANGELA PENCHEVA

Balkan Heritage Foundation, Sofia, Bulgaria

silvana.blazevska@gmail.com

The Master Conservation Plan for the archaeological site of Stobi was created in cooperation with NI Stobi (RN Macedonia) and the Balkan Heritage Foundation (Bulgaria), with the generous support of the J.M. Kaplan Fund (USA). The plan was produced in the period between 2019 and 2021, involving professionals from the partnering institutions as well as foreign and local experts.

The Master Conservation Plan for Stobi is a strategic document created with the main goal of offering directions and recommendations for the better preservation and presentation of the diverse cultural heritage of the site, to promote a modern methodological approach to the assessment of the potential risks, damages and problems, to offer the best possible solutions, to foster

usage of the appropriate conservation materials and methods, and to highlight the importance of building institutional capacity and skilled professionals in the field of cultural heritage preservation. The plan also offers directions for the improvement of the tourist presentation of the site, as well as guidelines for the development of a fundraising strategy with a list of potential donors, programmes, funds and grants.

The plan especially emphasises the recommendations concerning two segments of our work: authentic preservation and preventive conservation methods, that are practiced worldwide, during the ongoing excavations, something that is crucial for the preservation of the excavated structures; and to diminish the imbalance between excavations and conservation, for which serious changes in the legislation, especially concerning archaeological remains, are needed.

In fact, the Master Conservation Plan is a basic tool for present and future managers of the archaeological site of Stobi to better plan short- and long-term activities related to the preservation, presentation and maintenance of Stobi, thus providing opportunities for its sustainable development.

Keywords - Stobi, conservation, plan, management, strategy

References:

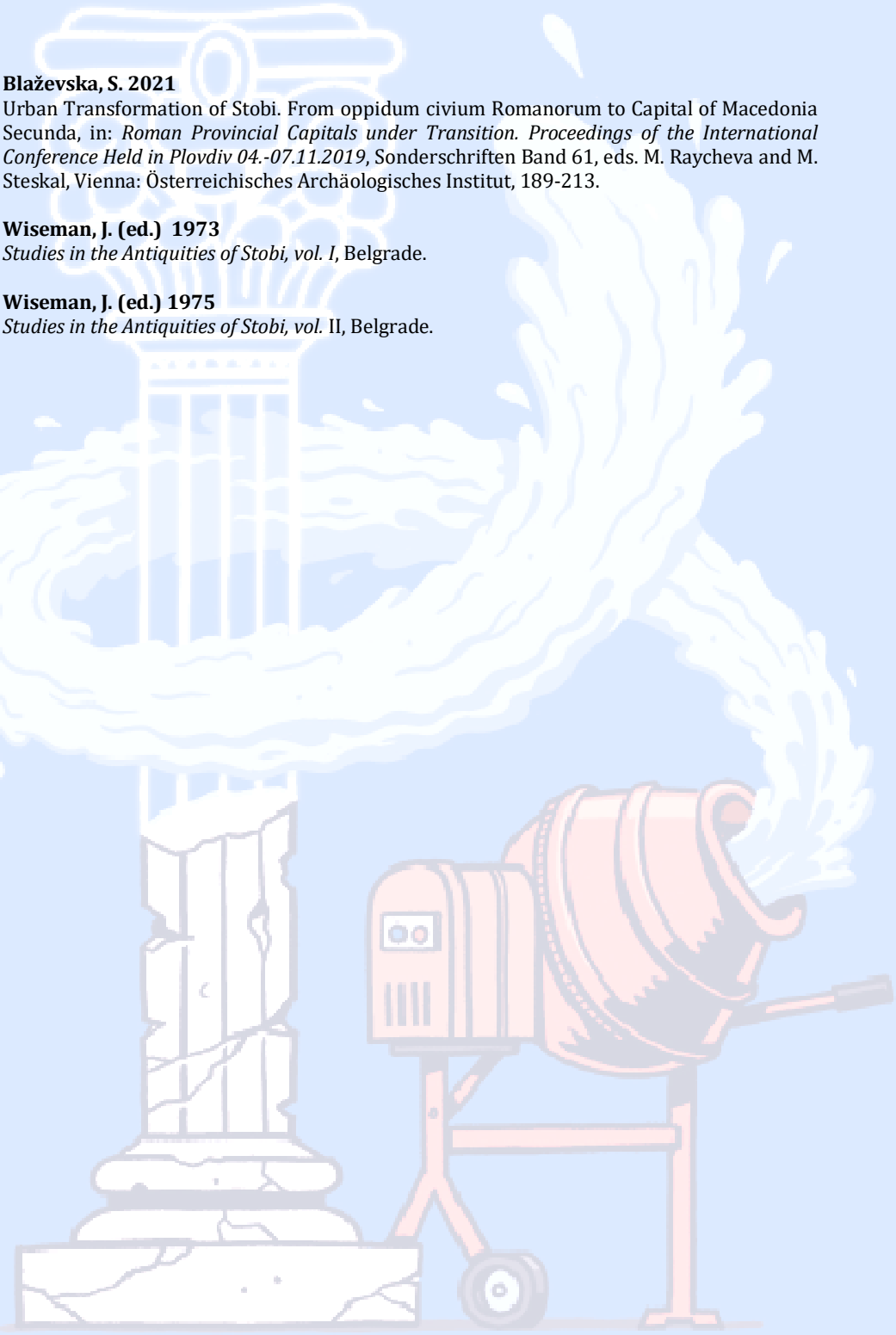
Aleksova, B. – Wiseman, J. (eds.) 1981
Studies in the Antiquities of Stobi, vol. III, T. Veles.

Blaževska, S. 2018
Studies in the Antiquities of Stobi, vol. IV, Stobi.

Blaževska, S. 2021
Urban Transformation of Stobi. From oppidum civium Romanorum to Capital of Macedonia Secunda, in: *Roman Provincial Capitals under Transition. Proceedings of the International Conference Held in Plovdiv 04.-07.11.2019*, Sonderschriften Band 61, eds. M. Raycheva and M. Steskal, Vienna: Österreichisches Archäologisches Institut, 189-213.

Wiseman, J. (ed.) 1973
Studies in the Antiquities of Stobi, vol. I, Belgrade.

Wiseman, J. (ed.) 1975
Studies in the Antiquities of Stobi, vol. II, Belgrade.



COMPUTED TOMOGRAPHY AS A TOOL FOR NON DESTRUCTIVE INVESTIGATION OF CULTURAL HERITAGE MATERIALS' INNER STRUCTURE

BOJAN MILJEVIĆ

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

ALENKA MAUKO PRANJIĆ

ZAG, Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

SERGEY E. KICHANOV

Joint Institute for Nuclear Research, Frank Laboratory of Neutron Physics, Dubna, Russian Federation

SNEŽANA VUČETIĆ

University of Novi Sad, Faculty of Technology, Novi Sad, Serbia

miljevic@uns.ac.rs

Computed tomography as a method for the volumetric examination of material interiors opens up a number of possibilities and its basic advantages are reflected in the non-destructiveness and non-invasiveness and particularly in the ability to observe the

microstructure within the examined body, which is not possible using traditional radiographic methods. The possibilities of using both X-ray and neutron computed tomography for testing materials in cultural heritage are extremely high, because these method can be applied to various materials, regardless of whether the material is better or worse at absorbing X-ray radiation. Thus, it is possible to examine historical construction materials, such as stone, brick and mortar, and objects of cultural heritage made of various metals, but also from glass, wood, plastic or any other material of inorganic and organic origin. In the literature, there are examples of the use of computed tomography on stone for the examination of its microstructure or porosity (Abel 2011: 878-884), or for determination of the depth of penetration of consolidators (Slavíková 2012: 357–364). The CT method was also used for the examination of cultural heritage objects made up of various types of metals, such as ancient Greek bronze coins (Griesser 2012: 1-5) or medieval swords. A particular aspect of the use of computerised tomography is the examination of cultural heritage made of wood (Zhang 2012: 221-225) and paintings on a wooden surface, as well as research on wax seals. A special multi-detector CT method examined the entire Egyptian mummies (Cesarani 2003: 596-606). In addition to testing the interior and material degradation, computerised tomography is also used for the purpose of digital storage and virtual display with the aim of museum archiving and dissemination (Abel 2011: 878-884). Here, we present the recent results from the systematic study of mortar samples using combined

X-ray and neutron computed tomography.

Keywords – computed tomography, X-rays, neutrons, 3D visualisation, cultural heritage

References:

Abel, R. L., Parfitt, S., Ashton, N., Lewis, S. G., Scott, B., and Stringer, C. 2011
Digital preservation and dissemination of ancient lithic technology with modern micro-CT, *Computers and Graphics (Pergamon)* 35(4) (2011): 878–884.

Cesarani, F., Martina, M.C., Ferraris, A., Grilletto, R., Boano, R., Marochetti, E.F., Donadoni, A.M., Gandini, G. 2003
Human Mummies, *Am. J. Roentgenol* 180 (2003): 597–606.

Griesser, M., Traum, R., Vondrovec, K., Vontobel, P., and Lehmann, E. 2012
Application of X-ray and neutron tomography to study antique Greek bronze coins with a high lead content, *Mater. Sci. Eng*. 37 (2012): 1–5.

Slavíková, M., Krejčí, F., Žemlička, J., Pech, M., Kotlík, P., and Jakůbek, J. 2012
X-ray radiography and tomography for monitoring the penetration depth of consolidants in Opuka - the building stone of Prague monuments, *Journal of Cultural Heritage* 13(4) (2012): 357–364.

Zhang, X., Blaas, J., Botha, C., Reischig, P., Bravin, A., and Dik, J. 2012
Process for the 3D virtual reconstruction of a microcultural heritage artifact obtained by synchrotron radiation CT technology using open source and free software, *Journal of Cultural Heritage* 13(2) (2012): 221–225.

ROMAN, LATE ANTIQUE AND BYZANTINE WINDOW GLASS FROM THE 3RD – 6TH CENTURY CE IN SERBIA: CHEMICAL CHARACTERISTICS, COMPOSITIONAL GROUPS AND PROVENANCE

ROMAN BALVANOVIĆ

Laboratory of Physics, Vinča Institute for Nuclear Sciences, University of Belgrade, Belgrade, Serbia

PERICA ŠPEHAR

University of Belgrade, Faculty of Philosophy, Department of Archaeology, Belgrade, Serbia

DRAGANA SPASIĆ-ĐURIĆ

National Museum, Požarevac, Požarevac Serbia

OLIVERA MILOVIĆ

National Museum, Požarevac, Požarevac, Serbia

MIHAILO MILINKOVIĆ

University of Belgrade, Faculty of Philosophy, Department of Archaeology, Belgrade, Serbia

broman@vinca.rs

The elemental composition of 74 windowpane glass fragments from Serbia have been analysed by PIXE/PIGE measurements, to date. The analysed samples come from the archaeological sites of Gradina on Jelica (39 pieces), Viminacium (1), Egeta (4), Pontes (2), Diana (2), Kosmaj (17), Mediana (7), and Mala Kopašnica (2), dated from the 2nd century CE to the late 6th/early 7th century CE.

In terms of their composition, the glass fragments are characterised by the concentrations of their major (SiO2 and Na2O), minor (CaO, Al2O3, Fe2O3, MgO, MnO and TiO2) and trace element (Sb2O3, ZrO2, CuO, PbO, NiO, and SnO) oxides. By a comparison with published contemporary glass groups from across the Mediterranean, their glass groups (or types) are determined.

Since the provenance of the found glass groups are known or supposed with reasonable probability, the provenance of the raw glass can be inferred. The raw glass used for manufacturing windowpanes in the 2nd – 6th century CE in the territory of today's Serbia came mostly from Egypt and, to a lesser extent, from the Levant.

The Roman glass in the period from the 1st to the 4th century CE is characterised by being often colourless, and of a chemical composition typical of clean sands, without many minerals. However, the 4th century saw a big change both in appearance and in the chemical composition, throughout the Mediterranean. The colours tended to become darker, often deep green, and the chemical composition shows the use of sands containing more minerals. This

indicates a change of sources of sand used for primary glass making.

A similar pattern is evidenced in Serbia during the 4th century CE. We present here both our measurements (Jelica, Viminacium, Pontes and Egeta) and the published data (Kosmaj, Kopašnica and Mediana), and explain the distribution of types of window glass in both space and time. We also show that while the compositions of window glass generally reflect the compositional patterns of other contemporary glass products (glassware, glass adornments and similar), there are also some specifics related to the windowpanes.

Keywords - glass, windowpane, compositional group, provenance, Serbia

References:

Balvanović, R. and Šmit, Ž. 2020
Sixth-century AD glassware from Jelica, Serbia—an increasingly complex picture of late antiquity glass composition, *Archaeological and Anthropological Sciences* 12, Article number: 94.
https://doi.org/10.1007/s12520-020-01031-3, IF 2.144 (5 godina, 2019)

Balvanović, R.V. and Šmit, Ž. 2022
Emerging Glass Industry Patterns in Late Antiquity Balkans and Beyond: New Analytical Findings on Foy 3.2 and Foy 2.1 Glass Types, *Materials* 2022, 15, Article number: 1086.
https://doi.org/10.3390/ma15031086

Balvanović, R., Šmit, Ž., Stojanović, M.M., Spasić-Đurić, D., Špehar, P. and Milović, O. 2022
Late Roman glass from Viminacium and Egeta (Serbia): glass-trading patterns on Iron Gates Danubian Limes, *Archaeological and Anthropological Sciences* 14, Article number: 79 (2022).
https://doi.org/10.1007/s12520-022-01529-y

Balvanović, R., Marić Stojanović, M. and Šmit, Ž. 2018
Exploring the unknown Balkans: early Byzantine glass from Jelica Mt. in Serbia and its contemporary neighbours, *J. Radioanalytical Nucl. Chem.* 317: 1175-1189.

Drauschke, J., and Greiff, S. 2010
Early Byzantine glass from Caričin Grad/Iustiniana Prima (Serbia): first results concerning the composition of raw glass chunks, in: *Glass along the silk road from 2000 BC to AD 1000*, eds. B. Zorn and A. Hilgner, Mainz: Verlag des Römisch-Germanischen Zentralmuseums, 53–67

Ivanišević, V. and Stamenković, S. (with a contribution by Greiff S) 2010
»Glass« Workshop from Caričin Grad (*Iustiniana Prima*), in: Glass along the Silk Road from 200 BC to AD 1000, eds. B. Zorn, A. Hilgner, Mainz, Germany: RGZM, 39-52.

Križanac, M. 2009
Glass from Early Byzantine Gradina on Mount Jelica (Serbia), in: Late Antique/Early Byzantine Glass in the Eastern Mediterranean, ed. E. Laflı, Izmir: Dokuz Eylül University, Faculty of Arts, Department of Archaeology, 265-284.

Stamenković, S. 2015
Glass production technology and production centres in Dacia Mediterranea, Doctoral Dissertation, University of Belgrade, Faculty of Philosophy, Department of Archaeology Belgrade (in Serbian).

Stamenković, S., Greiff, S. and Hartmann, S. 2015
Late Roman glass from Mala Kopašnica (Serbia) - forms and chemical analysis, in: *AIH V Annales du 20e Congrès de l' ASSOCIATIONINTERNATIONALE pour l'HISTOIRE du VERRE, Fribourg / Romont 7–11 septembre 2015*, eds. S. Wolf and A. Pury-Gysel, Romont: Verlag Marie Leidorf GmbH, 213-221.

Stojanović, M.M., Šmit, Ž., Glumac, M. and Mutić, J. 2015
PIXE–PIGE investigation of Roman Imperial vessels and window glass from Mt. Kosmaj, Serbia (Moesia Superior), *Journal of Archaeological Science: Reports* 1: 53–63. doi: 10.1016/j.jasrep.2014.11.01

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

904"652"(37)(048)

INTERNATIONAL Conference with Workshop Science for Conservation of the Danube Limes (1 ; 2022 ; Viminacium)
Mortar design for conservation – Danube Roman frontier 2000 years after [Elektronski izvor] : programme and abstracts / 1st International Conference with Workshop Science for Conservation of the Danube Limes, Viminacium, June 27th - July 1st, 2022 ; [editors Emilija Nikolić, Mladen Jovičić] ; [book illustration Nikola Korać]. - Belgrade : Institute of Archaeology, 2022 (Belgrade : Institute of Archaeology). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 10.

ISBN 978-86-6439-072-9

а) Археолошка налазишта, римска -- Србија -- Апстракти

COBISS.SR-ID 70334473