



CONFERENCE PROCEEDINGS



2025 IMEKO TC26 INTERNATIONAL CONFERENCE ON

METROLOGY for ARCHAEOLOGY and CULTURAL HERITAGE

BERGAMO, ITALY

OCTOBER 15-17, 2025



CONFERENCE PROGRAM

Wednesday, October 15

Session 1.1 - Geomatics for Archaeology and Cultural Heritage: multi-source and multi-scale data integration and processing in research and applications

Room: Conference Hall "Alberto Castoldi"

- 1 Integrated Workflow for 3D modelling of Historic Architecture: A Multi-Sensor Approach**
Vincenzo Saverio Alfio (Polytechnic University of Bari), Domenica Costantino (Polytechnic University of Bari), Mathab Fallah (Polytechnic University of Turin), Alfredo Restuccia Garofalo (Polytechnic University of Bari), Massimiliano Pepe (University "G. d'Annunzio" of Chieti-Pescara) and Paolo Piumatti (Polytechnic University of Turin)
- 7 UAS-based capacity building for enhancing minor archaeology**
Joel Aldrighettoni (University of Bergamo) and Maria Grazia D'Urso (University of Bergamo)
- 14 High-Resolution Photogrammetric Survey of a Romanesque Mosaic Floor: A Comparative Analysis of UAS and a Custom-Built Acquisition System**
Barbara Fazion (Politecnico di Milano), Daniele Treccani (Politecnico di Milano), Andrea Adami (Politecnico di Milano) and Luigi Fregonese (Politecnico di Milano)
- 20 New discoveries at the Castello Sforzesco in Milan: an integrated approach through 3D modelling and GPR survey**
Maurizio Porcu (Codevintec Italiana s.r.l.), Francesca Biolo (Politecnico di Milano) and Franco Guzzetti (Politecnico di Milano)
- 26 Integrating geomatic high-detail surveying and thermography for the documentation of historical masonry**
Anna Forte (Università di Bologna), Francesca Trevisiol (Università di Bologna), Giulia Fiorini (Università di Bologna) and Gabriele Bitelli (Università di Bologna)
- 32 Underground Surveying of the Porticus Minucia as a Basis for the Georeferencing of a Fragment of the Marble Plan of Rome (Forma Urbis Marmorea)**
Valerio Baiocchi (Sapienza University of Rome), Alessandri Luca (sapienza Università di Roma), Marta Baumgartner (Soprintendenza speciale Archeologia, Belle Arti e Paesaggio di Roma), Diego Blanco (archeogeos s.r.l.), Alessandro Bosman (CNR IGAG), Andrea Guaglianone (Independent researcher) and Felicia Vatore (Sapienza Università di Roma)

Session 1.2 - Non-destructive imaging and interferometric techniques for cultural heritage diagnostics and metrology

Room: Room 6 - First Floor

- 37 Infrared and Terahertz Imaging for the Analysis of a Fresco Sample**
Emma Vannini (INO-CNR, University of Florence), Iliana Catapano (IREA-CNR), Alice Dal Fovo (INO-CNR), Valentina Di Sarno (INO-CNR), Alessandra Rocco (INO-CNR), Pasquale Maddaloni (INO-CNR) and Raffaella Fontana (INO-CNR)
- 42 2D and 3D optical techniques for manuscript analysis: diagnostics based on data integration**
Nicole de Manincor (University of Verona), Sara Mazzocato (University of Verona), Dumitru Scutelnic (University of Verona) and Claudia Daffara (University of Verona)
- 47 Shearography and 3D scanning for assessing the strip lining in the case study: Pericles observes Phidias's artwork on the Parthenon, by Gaspare Landi**
Chiara Saltarelli (CNR-ISASI), Vito Pagliarulo (CNR-ISASI), Maria Rosaria Vigorito (Suor Orsola Benincasa University) and Melania Paturzo (CNR-ISASI)

- 53 Preliminary Tests of Millimetric Crack Detection in Ancient Wall Paintings using a Terahertz Radar**
Fulvia Gennari (Istituto Italiano di Tecnologia), Andrea Campostrini (Istituto Italiano di Tecnologia), Agnese Babini (Istituto Italiano di Tecnologia), Raffaella Lamuraglia (Istituto Italiano di Tecnologia), Giancarlo Ruocco (Istituto Italiano di Tecnologia), Valeria Giliberti (Istituto Italiano di Tecnologia), Arianna Traviglia (Istituto Italiano di Tecnologia) and Michele Ortolani (Istituto Italiano di Tecnologia)
- 57 Multidisciplinary approach of conservation of the fistulae aquariae from the archaeological site of Baiae**
Paola Fenelli (University of Studies Suor Orsola Benincasa, Naples), Alessandro De Rosa (University of Studies Suor Orsola Benincasa, Naples), Paola Cennamo (University of Studies Suor Orsola Benincasa, Naples), Giorgio Trojsi (University of Studies Suor Orsola Benincasa, Naples), Massimo Rippa (Institute of Applied Sciences and Intelligent Systems “E. Caianiello” of CNR, Pozzuoli) and Enrico Gallochio (Ministry of Cultural Heritage and Activities (MIC), Archaeological Park of Campi Flegrei)
- 63 From Europe to the UAE: A Multidisciplinary Approach to Studying Islamic and Arabic Manuscripts on European Papers**
Nagmeldeen Hamza (Department of Antiquities and Museums Ras Al Khaimah, United Arab Emirates) and Islam Shaheen (Grand Egyptian Museum)

Session 1.3 - Integrated Methods, Theories and Applications For Structural Health Monitoring And Assessment Of Ancient Constructions - PART I

Room: Room 7 - First Floor

- 69 STRUCTURAL ASSESSMENT OF THE PROPYLAEA CHURCH ARCHAEOLOGICAL REMAINS IN JERASH (JORDAN) USING 3D DISCRETE ELEMENT MODELLING**
Florin Cristinel Stan (Roma Tre University), Stefano De Santis (Roma Tre University), Sara Fares (Roma Tre University) and Gianmarco de Felice (Roma Tre University)
- 75 From scan to H-BIM: towards an automated workflow for cultural heritage vulnerability assessment**
Pietro Meriggi (Roma Tre University), Antonio Napolitano (Roma Tre University), Alessio Pasquali (Roma Tre University) and Luca Bianchini Ciampoli (Roma Tre University)
- 81 Using GPR to support structural interpretation of collapsed archaeological sites**
Roberta Santarelli (Sapienza University of Rome), Alessandra Ten (Sapienza University of Rome), Luca Bianchini Ciampoli (Roma Tre University), Andrea Benedetto (Roma Tre University) and Fabio Tosti (University of West London)
- 87 Digital Twin for Railway Infrastructure and Historic Stations: State of the Art, Technological Architecture, and Development Perspectives**
Gianmarco Pireneo (Telematic University Pegaso), Francesco Fabbrocino (Telematic University Pegaso), Carlo Olivieri (Telematic University Pegaso), Andrea Miano (Telematic University Pegaso) and Hamidreza Alavi (University of Cambridge)
- 92 Planning tools for historic centres reconstruction. An overview of Central Italy 2016 earthquake**
Margherita Giuffrè (Consiglio Nazionale delle Ricerche) and Francesco Fazzio (Università degli studi di Perugia)

Session 2.1 - From Composition to Conservation: Advanced Diagnostic Techniques for the Study of Ancient, Modern and Contemporary Painting Surfaces

Room: Conference Hall “Alberto Castoldi”

- 98 In situ non-invasive analyses of the painting “Cristo in Trono” (Amalfi, SA, Italy)**
Antonio Faggiano (University of Salerno), Chiara Gallo (Istemi S.r.l.), Oriana Motta (University of Salerno), Carmine Napoli (Istemi S.r.l.), Eduardo Caliano (Istemi S.r.l.), Antonino Fiorentino (University of Milan), Enza Cobalto (Comune di Amalfi, Assessorato per cultura e beni culturali, eventi e tradizioni), Maria Ricciardi (University of Salerno) and Antonio Proto (University of Salerno)
- 103 Analyzing and studying ancient polychrome surfaces using advanced imaging techniques: Tracing Original Composition to Modern Intervention**
Islam Shaheen (Sapienza University of Roma - Grand Egyptian Museum), Nagmeldeen Hamza (Grand Egyptian Museum-conservation center) and Mohammed Ragab (Grand Egyptian Museum)

108 Characterization of two vases from Centuripe

Bianca Irene Carnesale (University of Milan), Giacomo Biondi (CNR, ISPC), Mario Colella (University of Pavia), Federica Giacobello (University of Milan) and Letizia Bonizzoni (University of Milan)

113 Spectroscopic Investigation of a 17th-Century Illuminated Parchment from S. Maria di Montalto Church (Messina, Italy)

Giuseppe Paladini (University of Messina), Francesco Caridi (University of Messina), Domenico Majolino (University of Messina), Lorenzo Pistorino (University of Messina), Paola Cardiano (University of Messina), Alessandra De Caro (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali), Gloria Bonanno (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali), Arcangela Valenti (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali), Enza Anna Passerini (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali), Giuseppe Sampino (Soprintendenza BB.CC.AA) and Valentina Venuti (University of Messina)

Session 2.2 - How To Preserve Outdoor Cultural Heritage: State-Of-Art, Challenges and New Perspectives

Room: Room 6 - First Floor

118 Practical solutions to the biodeterioration dilemma: activity of *Dittrichia viscosa* extracts and its specialized metabolites on standard organism *Raphidocelis subcapitata*

Alessandro De Rosa (University of Studies Suor Orsola Benincasa, Naples), Marco Morelli (University of Naples Federico II), Marco Masi (University of Naples Federico II), Alessio Cimmino (University of Naples Federico II), Andrea Carpentieri (University of Naples Federico II), Gaia Marzia Silvestre (University of Naples Federico II), Antonino Pollio (University of Naples Federico II) and Paola Cennamo (University of Studies Suor Orsola Benincasa, Naples)

124 An integrated approach to the study of the architectural features of the theatre of Tyndaris

Marco Sfacteria (University of Messina), Stefania Tuccinardi (University of Messina) and Marta Venuti (University of Messina)

129 In-situ investigation of mortar fragments from the theatre of the archaeological area of Tindari (Sicily, Italy) through DRIFT and u-Raman techniques

Giuseppe Paladini (University of Messina), Francesco Caridi (University of Messina), Domenico Majolino (University of Messina), Gabriele Lando (University of Messina), Paola Cardiano (University of Messina) and Valentina Venuti (University of Messina)

133 Multi-Technique Characterization of Mural Paintings at the Santa Maria Gratia Plena Church in Bruzzano Vetere (Calabria, Southern Italy)

Lorenzo Pistorino (University of Messina), Francesco Caridi (University of Messina), Giuseppe Paladini (University of Messina), Pasquale Faenza (G. Rohlfs Museum of the Calabrian Greek Language), Domenico Majolino (University of Messina) and Valentina Venuti (University of Messina)

Session 2.3 - Integrated Methods, Theories And Applications For Structural Health Monitoring And Assessment Of Ancient Constructions - PART II

Room: Room 7 - First Floor

138 Historic centers between reconstruction and recovery. Urban planning considerations on a post-earthquake survey in Amatrice and Accumoli

Francesco Fazio (University of Perugia)

144 Remote Sensing for Heritage Conservation and Structural Monitoring: The case of Wolvesey Castle, Winchester

Efcharis Balodimou (University of West London), Nicoletta Bianchini (University of West London), Tamsin Withers (English Heritage, Engine House), Laden Husamaldin (University of West London), Moein Motavallizadeh Naeini (University of West London), Tesfaye Tessema (University of West London) and Fabio Tosti (University of West London)

- 150 **Experimental investigation of a masonry arch subjected to an asymmetric concentrated vertical load and validation via static and kinematic limit analysis**
Mario Fagone (University of Florence), Tommaso Rotunno (University of Florence), Natalia Pingaro (Politecnico di Milano) and Gabriele Milani (Politecnico di Milano)
- 155 **Optimization of CVAE parameters for the damage assessment of historic masonry buildings**
Ivan Roselli (ENEA) and Domenico Palumbo (ENEA)
- 160 **Time and frequency domain analysis of Etruscan pottery magnified videos**
Vincenzo Fioriti (ENEA), Eugenia Verrigni Petrei Castelli (ENEA), Alessandro Colucci (ENEA) and Ivan Roselli (ENEA)

Thursday, October 16

Session 3.1 - Damage and Radiological Risk Assessment: Diagnosis and Monitoring for the Restoration, Preventive Conservation, Usability and Maintenance of Cultural Heritage

Room: Conference Hall "Alberto Castoldi"

- 166 **Mineralogical Analysis of Viterbo Tuff Using X-Ray Diffraction and Raman Spectroscopy**
Giuliana Faggio (University Mediterranea of Reggio Calabria), Francesco Caridi (University of Messina), Daniele Chiriu (University of Cagliari), Stefania Da Pelo (University of Cagliari), Michele Guida (University of Salerno), Giacomo Messina (Università Mediterranea di Reggio Calabria), Maurizio Ponte (Università della Calabria), Silvestro Antonio Ruffolo (Università della Calabria), Domenico Majolino (University of Messina) and Valentina Venuti (University of Messina)
- 171 **Role of consolidants for limiting the radon exhalation rate in building materials of historical and artistic interest**
Francesco Caridi (University of Messina), Daniele Chiriu (University of Cagliari), Stefania Da Pelo (University of Cagliari), Giuliana Faggio (Università "Mediterranea" Calabria), Michele Guida (Università degli Studi di Salerno), Giacomo Messina (Università degli Studi di Salerno), Maurizio Ponte (Università della Calabria), Silvestro Antonio Ruffolo (Università della Calabria), Domenico Majolino (University of Messina) and Valentina Venuti (Università degli Studi di Messina)
- 176 **Historical urban centers built in tuff and indoor radon exposure**
Simona Mancini (University of Salerno), Serpil Aközcan Pehlivanoğlu (Kirkklareli University), Natasa Todorovic (University of Novi Sad), Albina Cuomo (C.U.G.RI.), Domenico Guida (C.U.G.RI.) and Michele Guida (University of Salerno)
- 181 **Natural radioactivity content, radiological hazard and mineralogy evaluation of Pumice stone from Lipari, Sicily, Southern Italy: a case study**
Lorenzo Pistorino (University of Messina), Francesco Caridi (University of Messina), Giuseppe Paladini (University of Messina), Antonio Francesco Mottese (Università Mediterranea, Reggio Calabria, Italy), Domenico Majolino (University of Messina) and Valentina Venuti (University of Messina)
- 187 **Radon exhalation, natural radioactivity content and radiological hazard assessment for the Viterbo tuff stone: a case study**
Francesco Caridi (University of Messina), Daniele Chiriu (University of Cagliari), Stefania Da Pelo (University of Cagliari), Giuliana Faggio ("Mediterranean" University of Reggio Calabria), Michele Guida (University of Salerno), Giacomo Messina ("Mediterranean" University of Reggio Calabria), Maurizio Ponte (University of Calabria), Silvestro Ruffolo (University of Calabria), Domenico Majolino (University of Messina) and Valentina Venuti (University of Messina)

Session 3.2 - Chromatic Heritage: Exploring the Science of Pigments, Stones and Art Conservation - PART I

Room: Room 6 - First Floor

193 [INVITED] Natural ultramarine in the Roman context of Volsinii (Bolsena, Italy): a multianalytical characterization

Martina Bernabale (Sapienza University of Rome), Anna Candida Felici (Sapienza University of Rome), Pierfrancesco Atanasio (Sapienza University of Rome), Luca Buccini (Sapienza University of Rome), Daniele Passeri (Sapienza University of Rome), Marco Rossi (Sapienza University of Rome), Paolo Binaco (Museo Territoriale del Lago di Bolsena) and Danilo Dini (Sapienza University of Rome)

198 Intelligent Workflow for Real Time and Automated Analysis of Historical Pigments

Irene Ferrara (Università degli Studi di Catania, Italia), Paola Benedetta Castellino (Università degli Studi di Catania, Italia), Salvatore Gallo (Università degli Studi di Catania, Italia), Anna Maria Gueli (Università degli Studi di Catania, Italia), Giuseppe Politi (Università degli Studi di Catania, Italia) and Giuseppe Stella (Università degli Studi di Catania, Italia)

203 3D Fluorescence Mapping: A promising Technique for the Analysis of the Degradation of Pigments

Stefania Porcu (University of Cagliari), Michela Podda (University of Cagliari), Giovanni Brodu (University of Cagliari), Stefano Columbu (University of Cagliari) and Daniele Chiriu (University of Cagliari)

Session 3.3 - Multiscale And Multitemporal High Resolution Remote Sensing and Non-Destructive Testing For Archaeology And Monumental Heritage: From Research To Preservation - PART I

Room: Room 7 - First Floor

208 New results from the GPR surveys at the area surrounding the Basilica at S. Croce in Gerusalemme, (Roma, Italy)

Salvatore Piro (ISPC CNR)

213 Multidisciplinary approach for the stability analysis of a historical hypogeum in the municipality of Cisternino in the Itria Valley (Puglia, Southern Italy), aimed at a refunctionalization and valorization of the site

Maurizio Lazzari (CNR ISPC, Potenza), Davide Palma (Geophysics to GeoEngineering), Pierpaolo Moretti (Geophysics to GeoEngineering) and Valentina Leopizzi (Independent archeologist researcher, Lecce)

219 GPR survey at the archaeological site of Heloros (Noto, Sicily)

Davide Tanasi (University of South Florida), Rosa Lanteri (Parco archeologico di Siracusa, Eloro, Villa del Tellaro e Akrai), Vincenzo di Fiore (ISPC-CNR), Michele Punzo (ISPC-CNR), Daniela Tarallo (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR), Lara De Giorgi (ISPC-CNR), Ivan Ferrari (ISPC-CNR), Francesco Giuri (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)

224 From Point Clouds to Cultural Landscapes: Open-Source Machine Learning Applications for Archaeological UAV LiDAR segmentation

Nicodemo Abate (CNR - ISPC), Antonio Minervino Amodio (CNR - ISPC), Maria Sileo (CNR - ISPC), Rosa Lasaponara (National Research Council - IMAA), Nicola Masini (CNR - ISPC), Gabriele Ciccone (CNR - ISPC) and Alessia Frisetti (CNR - ISPC).

229 Discovery and study of “S.S. Egypte” shipwreck using remote sensing techniques, off north harbour of Patras city, Greece

George Papatheodorou (University of Patras), Dimitrios Christodoulou (University of Patras), Xenophon Dimas (University of Patras), George Karelas (University of Patras) and Maria Geraga (University of Patras)

Session 4.1 - Old Solutions for New Problems: Innovative Multitechnical Strategies for Diagnostics on Peculiar Case Studies

Room: Conference Hall “Alberto Castoldi”

234 A matter of materiality: the use of multi-analytical methods for reinforcing urban heritage

Adi Sela Wiener (Bezalel Academy of Arts and Design, Jerusalem), Laura Medeghini (Sapienza University of Rome) and Gabriele Favero (Sapienza University of Rome)

240 Exploring the Application of Explainable Neural Networks for the Petrographic Classification of Ceramic Samples from the Levant

Sara Capriotti (Sapienza University of Rome), Alessio Devoto (Sapienza University of Rome), Donatella Genovese (Sapienza University of Rome), Silvano Mignardi (Sapienza University of Rome), Simone Scardapane (Sapienza University of Rome) and Laura Medeghini (Sapienza University of Rome)

246 Unlocking the Information Potential of Lake Pigments through SERS and Chemometrics

Adele Bosi (CNR-ISC), Camilla Marola (Sapienza University), Alessandro Ciccola (Sapienza University), Federico Marini (Sapienza University) and Claudia Fasolato (Sapienza University)

Session 4.2 - Chromatic Heritage: Exploring the Science of Pigments, Stones and Art Conservation - PART II

Room: Room 6 - First Floor

250 XRF and Raman Spectroscopic Study of Wall Polychromes in the Saltworks Castle in Wieliczka

Anna Klisińska-Kopacz (National Museum in Krakow), Pamela Grajny-Brzezińska (Cracow Saltworks Museum in Wieliczka), Tomasz Wilkosz (National Museum in Krakow), Michał Obarzanowski (National Museum in Krakow), Klementyna Ochniak-Dudek (Cracow Saltworks Museum in Wieliczka) and Julio M. del Hoyo Meléndez (National Museum in Krakow)

256 Quantitative approaches for Fiber Optics Reflectance Spectroscopy (FORS)

Ricardo Pedro Vicente Rojas (Sapienza University of Rome), Silvia Sotgiu (National Central Library of Rome), Véronique Cachia (National Central Library of Rome), Eugenio Delre (Sapienza University of Rome), Nicola Schiavon (Hercules Laboratory, University of Evora, Pal), Mauro Giustini (Sapienza University of Rome) and Mauro Missori (Institute of Complex Systems, CNR)

261 Multi-technique archaeometric investigation of a XVII century illuminated parchment belonging to the S. Maria di Montalto Church (Messina, Italy)

Giuseppe Paladini (University of Messina), Francesco Caridi (University of Messina), Domenico Majolino (University of Messina), Lorenzo Pistorino (University of Messina), Alessandra De Caro (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali, Italy), Gloria Bonanno (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali, Italy), Arcangela Valenti (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali, Italy), Enza Anna Passerini (Centro Regionale Progettazione e Restauro e per le Scienze Naturali ed applicate ai beni culturali, Italy), Giuseppe Sampino (Soprintendenza BB.CC.AA, Messina, Italy) and Valentina Venuti (University of Messina)

Session 4.3 - Multiscale And Multitemporal High Resolution Remote Sensing And Non-Destructive Testing For Archaeology And Monumental Heritage: From Research To Preservation - PART II

Room: Room 7 - First Floor

267 Archaeological Remote Sensing at the Villa of Sette Bassi: Vegetation Index Analysis with Pléiades Neo Imagery

Jessica Clementi (Sapienza University of Rome), Veronica Sanvito (Sapienza University of Rome), Stefano Roascio (Ministero della Cultura, Parco Archeologico dell'Appia Antica), Michele Reginaldi (Ministero della Cultura, Parco Archeologico dell'Appia Antica) and Paolo Mazzanti (Sapienza University of Rome)

273 Can Vandalism Reshape the Way We Perceive Cultural Heritage?

Fabrizio Terenzio Gizzi (CNR-ISPC), Cristina Cumbo (CNR-ISPC), Maria Rosaria Potenza (CNR-ISPC), Agata Maggio (CNR-ISPC), Antonio Minervino Amodio (CNR-ISPC) and Canio Alfieri Sabia (CNR-ISPC)

278 ERT geophysical survey for Landslide Risk Management in Coastal Areas: Case Studies of Brovinje and Havišće (Croatia)

Michele Punzo (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR), Giuseppe Cavuoto (ISPC-CNR), Vincenzo Di Fiore (ISPC-CNR), Daniela Tarallo (ISPC-CNR) and Giovanni Leucci (National Research Council).

282 Water leaks as a hidden risk to cultural heritage sites: application of the TEAMWIRE project and the geophysical challenges

Chiara Torre (University of Malta), Sebastiano D'Amico (University of Malta), Emanuele Colica (University of Malta), Julian Mamo (University of Malta), Lara De Giorgi (CNR-ISPC), Dora Francesca Barbolla (CNR-ISPC) and Giovanni Leucci (CNR-ISPC)

Session 5.1 - Monitoring techniques for cultural heritage damage assessment and control

Room: Conference Hall "Alberto Castoldi"

287 EO-based products for risk assessment of cultural and natural heritage against climate and pollution impact

Alessandro Sardella (CNR-ISAC), Ramiro Marco Figuera (SISTEMA GmbH), Stefano Natali (SISTEMA GmbH) and Alessandra Bonazza (CNR-ISAC)

292 Environmental monitoring of The Grotto of the Animals: a case study for the SENNSE IoT platform

Francesco Taurino (CNR - ISPC), Irene Muci (Università La Sapienza), Davide Zecca (CNR - ISPC), Cristiano Riminesi (CNR - ISPC), Grazia Tucci (Unifi, Firenze - Italia) and Alberto Bucciero (CNR - ISPC)

297 From Thermal Signatures to Conservation Insights: A Fixed Camera Network Approach for Heritage Structure Health Monitoring

Giandomenico Mastrantonì (Sapienza University of Rome), Jessica Clementi (Sapienza University of Rome), Antonio Molinari (Sapienza University of Rome), Ioannis Farmakis (Sapienza University of Rome) and Paolo Mazzanti (Sapienza University of Rome)

303 Multi-scale non-invasive techniques for assessing instability conditions: examples from the Val di Cornia parks system (Tuscany, Italy)

Tommaso Beni (University of Florence), Silvia Guideri (Parchi Val di Cornia S.p.A), Debora Brocchini (Parchi Val di Cornia S.p.A), Marta Coccoluto (Parchi Val di Cornia S.p.A), Diletta Borselli (University of Florence), Lorenzo Bonechi (National Institute for Nuclear Physics INFN), Sandro Gonzi (University of Florence), Irene Centauro (University of Florence), Anna Palamidessi (University of Florence), Vitaliano Ciulli (University of Florence), Raffaello D'Alessandro (University of Florence), Giovanni Gigli (University of Florence), Deodato Tapete (Italian Space Agency ASI), Veronica Tofani (University of Florence) and Silvia Bianchini (University of Florence)

309 Application of Digital Photogrammetry in Damage Mapping on Facades of Historical Buildings

Tallis Rubens (Universidade de São Paulo), Fabiana Oliveira (Universidade de São Paulo), Fabricio Costa (Oregon State University), Luciana Toledo (Pontifícia Universidade Católica de Campinas) and Ana Elisabete Jacintho (Pontifícia Universidade Católica de Campinas)

Session 5.2 - Advances and innovation in ancient building materials studies: interfacing Archaeology, Science, and Technology

Room: Room 6 - First Floor

315 Geophysical Survey in the Presbytery of Tarragona Cathedral

Albert Casas (Universitat de Barcelona), Josep M^a Macias (Institut Català d'Arqueologia Clàssica), Mahjoub Himi (Universitat de Barcelona), Andreu Muñoz-Virgili (Institut Català d'Arqueologia Clàssica), Aritz Urruela-García (Universitat de Barcelona), Andreu Muñoz-Melgar (Museu Diocesà de Tarragona), Albert Casas-Ponsatí (Universitat de Barcelona).

320 València la Vella (Spain) and Late Antique Mortars: A Regional Geochemical Approach

Manel Górriz I Villar (Universitat de València), Mirco Ramacciotti (Universitat de València), Iván Pérez Torralba (University of Valencia), Angel Morales Rubio (University of Valencia), Iván Fumadó-Ortega (Universitat de València), José María Macias Solé (Catalan Institute of Classical Archaeology), Albert Ribera (Catalan Institute of Classical Archaeology) and Gianni Gallelo (Universitat de València)

326 Multi-Technique Characterization of Mortars from Gammarth Villa (Tunisia)

Manel Górriz I Villar (Universitat de València), Mirco Ramacciotti (Universitat de València), Iván Fumadó Ortega (Universitat de València), Hamden Ben Romdhane (Institut National du Patrimoine, Tunis, Tunisia.), Angel Morales Rubio (University of Valencia) and Gianni Gallelo (University of Valencia)

- 333 **XRD and PCA analysis of historic mortars from the Venetian Fortress of Bergamo (Italy)**
Renato Pelosato (Università degli Studi di Bergamo), Isabella Natali Sora (Università degli Studi di Bergamo), Virna Maria Nannei (Università degli Studi di Bergamo) and Giulio Mirabella Roberti (Università degli Studi di Bergamo)
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Session 5.3 - General Session - PART I

Room: Room 7 - First Floor

- 339 **The Advent of Complex Metallurgy**
Yuval Goren (Ben-Gurion University of the Negev), Yotam Asscher (University of Haifa), Sarel Shalev (University of Haifa) and Danny Rosenberg (University of Haifa)
- 345 **Characterization of Early 20th Century Measurement Instruments: A Heritage Approach**
Emma Angelini (Politecnico di Torino), Margherita Bongiovanni (Politecnico Torino), Leila Es Sebar (Politecnico di Torino) and Federico Di Iorio (Fondazione Centro per la Conservazione ed il restauro dei Beni Culturali (La Venaria Reale))
- 351 **Preliminary Investigation into pre-Industrial Salt Production: an experimental approach**
Martina Sciortino (University of Trento), Alessia Santiglia (University of Milan), Monica Azzarone (University of Milan), Laura Magnano (Università Cattolica), Giorgio Baratti (Università Cattolica), Laura Santagostini (University of Milan) and Vittoria Guglielmi (University of Milan).
- 357 **Preserving the Past with Gamma Rays: Real Case Studies from the Montecassino Abbey Collection**
Beatrice D'Orsi (ENEA), Rocco Carcione (ENEA), Iliana Di Sarcina (ENEA), Jessica Scifo (ENEA), Teresa Rinaldi (Sapienza University of Rome), Nicola Tangari (University of Cassino and Southern Lazio) and Alessia Cemmi (ENEA)
- 362 **Assessing material compatibility for restoration: An innovative approach to compare hydraulic properties of repair and historic mortars**
Salvatore Menta (University of Catania), Antonio Stroschio (University of Catania), Gaetano Ortolano (University of Catania), Roberto Visalli (University of Catania) and Cristina Maria Belfiore (University of Catania)
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Session 6.1 - Archaeobotany and Palynology as Tools for Reconstructing Past Biodiversity, Ecosystems, and Landscapes

Room: Conference Hall "Alberto Castoldi"

- 367 **Natural vs anthropogenic constraints address changes of plant biodiversity in Italy during the Holocene**
Cristiano Vignola (Sapienza University of Rome), Alessia Masi (Sapienza University of Rome) and Laura Sadori (Sapienza University of Rome)
- 372 **The Long-Term Human-Mediated Success of Olive Trees in the Central Mediterranean: A Multiproxy Perspective**
Laura Sadori (Sapienza University of Rome), Jordan Palli (University of Tuscia, Viterbo), Sabina Fiolna (Freie Universität of Berlin), Monica Bini (University of Pisa), Federico Cappella (Sapienza University of Rome), Adam Izdebski (Max Planck Institute, Jena, Germany, Jagiellonian University in Krakow, Poland, University of Warsaw, Poland), Alessia Masi (Sapienza University of Rome), Scott Mensing (University of Nevada, Reno), Lorenzo Nigro (Sapienza University of Rome), Gianluca Piovesan (University of Tuscia, Viterbo) and Giovanni Zanchetta (University of Pisa)
- 376 **Measuring Millennial Biodiversity with Pollen: Archaeo-Data from Southern Italy**
Eleonora Clò (University of Modena and Reggio Emilia), Anna Maria Mercuri (University of Modena and Reggio Emilia), Jessica Zappa (University of Modena and Reggio Emilia), Cristina Ricucci (University of Modena and Reggio Emilia), Lorenzo Braga (University of Modena and Reggio Emilia) and Assunta Florenzano (University of Modena and Reggio Emilia)
- 382 **ARBOREA – A new georeferenced database for plant macro-remains from archaeological sites in Central Italy**
Claudia Moricca (Sapienza University of Rome), Erasmo Di Fonso (Sapienza University of Rome), Rachele Nicolini (Sapienza University of Rome) and Laura Sadori (Sapienza University of Rome)

Session 6.2 - General Session - PART II

Room: Room 6 - First Floor

- 386 Biofilms on limestones specimens: laboratory tests implementing a non-destructive approach**
Davide Ripamonti (Università degli Studi di Milano), Emanuele Frabasile (Università Degli Studi di Milano), Alessia Marzanni (Università di Bolzano), Chao Gao (Norwegian University of Science and Technology), Chiara Bertolin (Norwegian University of Science and Technology), Villa Federica (Università degli Studi di Milano) and Nicola Gherardo Ludwig (Università degli Studi di Milano)
- 392 Multi-technical non-invasive analysis to prevent deterioration in varnish-coated oil-paintings**
Alice Dal Fovo (Istituto Nazionale di Ottica, CNR), Laura Maestro-Guijarro (Instituto de Química Física Blas Cabrera, CSIC), Paula Maria Carmona-Quiroga (Instituto de Ciencias de la Construcción Eduardo Torroja, CSIC), Raffaella Fontana (Istituto Nazionale di Ottica, CNR), Francesca Rosi (Istituto di Scienze e Tecnologie Chimiche, CNR), Martina Alunni Cardinali (ISTC-CNR, Perugia, Italy; Università di Perugia, Italy), Aldo Romani (Università di Perugia, Italy), Lucia Comez (Istituto Officina dei Materiali, CNR), Cristiano Riminesi (Istituto di Scienza del Patrimonio Culturale, CNR), Magdalena Iwanicka (Faculty of Fine Arts, Nicolaus Copernicus University in Toruń, Poland), Piotr Targowski (Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń, Poland), Magdalena Kowalska (Nicolaus Copernicus University in Toruń, Poland), Aggelos Philippidis (Institute of Electronic Structure and Laser, FORTH, Heraklion, Crete, Greece), Paraskevi Pouli (Institute of Electronic Structure and Laser, FORTH, Heraklion, Crete, Greece), Marta Castillejo (Instituto de Química Física Blas Cabrera, CSIC) and Mohamed Oujja (Instituto de Química Física Blas Cabrera, CSIC)
- 397 Mediterranean eustatic and climatic variations vs the Phoenician-Punic settlement/abandonment phases**
Alessandro Paladini (Independent archeologist researcher) and Maurizio Lazzari (CNR ISPC, Potenza)
- 403 Evolution of anthropic coastal landscapes and ground deformation in the Campi Flegrei caldera (southern Italy) since Roman times: insights from multi-technique surveys**
Claudia Caporizzo (Università Telematica Pegaso), Gaia Mattei (Università degli Studi di Napoli Parthenope), Pietro P.C. Aucelli (Università degli Studi di Napoli Parthenope) and Gerardo Pappone (Università degli Studi di Napoli Parthenope)
- 409 APPLICATION OF PARTICLE IMAGE VELOCIMETRY (PIV) TO DETECT THERMALLY-INDUCED AIRFLOWS IN ARTWORK DISPLAY CASES**
Barbara Marchetti (Università degli Studi eCampus), Matteo Moglie (Università degli Studi eCampus) and Francesco Corvaro (Università Politecnica delle Marche)

Friday, October 17

Session 7.1 - Vibroacoustic metrological characterization for archaeology and cultural heritage - PART I

Room: Conference Hall "Alberto Castoldi"

- 414 Minimization of environmental acoustic effects: an intangible design element of Greek theatres**
Fabrizio Barone (University of Salerno) and Marco Casazza (University of Salerno)
- 420 Vibroacoustic landscape and defensive network: metrology for the characterization of potential communication systems in Medieval Basilicata until the Longobard-Norman transition**
Rosa Fiorillo (University of Salerno), Marco Casazza (University of Salerno) and Fabrizio Barone (University of Salerno)
- 425 The Sound Emission of the Bell Tower of the Salerno Cathedral in Medieval Europe between Architectural Structure and Bell Construction Techniques**
Fabrizio Barone (University of Salerno), Rosa Fiorillo (University of Salerno) and Marco Casazza (University of Salerno)

- 430 **A Case Study of Road Traffic Noise Intrusion Simulation in an Italian Archaeological Site**
Claudio Guarnaccia (University of Salerno), Aurora Mascolo (University of Salerno) and Domenico Rossi (University of Salerno)
- 436 **The Roman Bridge on the Savuto River: understanding its dynamical structural behavior through the adaptive DFEM method**
Fabrizio Barone (University of Salerno), Salvatore Antonio Fornaro (Studio di Architettura Fornaro), Armando Di Maio (Studio di Architettura Di Maio, Napoli, Italy) and Marco Casazza (University of Salerno)

Session 7.2 - Virtual environments and Cultural Heritage: tools, new technologies, and future perspectives - PART I

Room: Room 6 - First Floor

- 442 **Gradient-Based Analysis of Vertical Displacements in Urban 3D LiDAR Models Using SAR Data**
Alessandro Di Benedetto (University of Salerno), Margherita Fiani (University of Salerno) and Salvatore Barba (University of Salerno)
- 448 **Cultural Heritage visualization through Generative AI: a Unity-based plugin for real-time 3D object creation**
Attilio Della Greca (University of Salerno), Ilaria Amaro (University of Salerno), Giovanni Nocerino (University of Naples Federico II) and Paola Barra (Parthenope University of Naples)
- 453 **Federated Digital Twins and XR for Cultural Heritage: A Collaborative Framework**
Gizealew Alazie Dagnaw (University of L'Aquila) and Henry Muccini (University of L'Aquila)
- 458 **Mobile games for the Revival of Archeological Parks in Campania: A Pilot Experience Bridging Virtual Environments and Cultural Heritage**
Francesco Colace (University of Salerno), Constanza Fiorella Duarte Petti (Universidad abierta Interamericana), Angelo Lorusso (University of Salerno), Michele Pellegrino (University of Salerno) and Domenico Santaniello (University of Salerno)
- 464 **Towards an Operational Protocol for Virtual Tours in Complex Cultural Sites: The Norman Castle of Aci Castello**
Paolino Trapani (University of Catania), Eleonora Pappalardo (University of Catania), Anna M. Gueli (University of Catania) and Filippo Stanco (University of Catania)

Session 7.3 - Advanced Metrological Approaches for the Study and Transmission of Prehistoric Material Culture

Room: Room 7 - First Floor

- 470 **High-Resolution 3D Digitization and Analysis of the Mesolithic Site of Latnija (Malta)**
Davide Tanasi (University of South Florida), Alex Fawbush (University of South Florida), Kaitlyn Kingsland (University of South Florida), Dario Calderone (LMU-Munich), Eleanor Scerri (Max Planck Institute of Geoanthropology), Nicholas Vella (University of Malta) and Huw Groucutt (University of Malta)
- 474 **Preliminary Results of the Integrated 3D Digitization of the Prehistoric Artifacts Exhibited at the Museum of Archaeology of the University of Catania**
Paolino Trapani (University of Catania), Marianna Figuera (University of Catania), Simona V. Todaro (University of Catania), Anna M. Gueli (University of Catania) and Filippo Stanco (University of Catania)
- 479 **Colourant pigments used for pottery decoration in Northeastern Africa during the Neolithic period: An analysis using Raman spectroscopy and Microscopy**
Sakura Sanada (Tokyo Metropolitan University, Graduate School of Humanities)
- 485 **RTI and virtualRTI: tools and methodologies for documenting prehistoric engraved artifacts**
Angelo Lorusso (University of Salerno), Michele Pellegrino (University of Salerno), Domenico Santaniello (University of Salerno) and Francesco Colace (University of Salerno)
- 491 **Digital Strategies for the Protection and Valorization of Prehistoric Landscapes: 3D Metrology at Cozzo del Pantano (Sicily)**
Davide Tanasi (University of South Florida), Alew Fawbush (University of South Florida), Stephan Hassam (Randolph Macon College) and Dario Calderone (LMU-Munich)

Session 8.1 - Vibroacoustic metrological characterization for archaeology and cultural heritage - PART II

Room: Conference Hall “Alberto Castoldi”

- 495 Geometry of a Medieval Town in the Context of Political Religious Governance of the Territory**
Fabrizio Barone (University of Salerno), Rosa Fiorillo (Università di salerno), Armando Di Maio (Studio di Architettura Di Maio, Napoli, Italy) and Marco Casazza (University of Salerno)
- 501 Non-invasive dating of historical church bells through vibroacoustic matching of musical temperaments**
Marco Casazza (University of Salerno), Rosa Fiorillo (University of Salerno) and Fabrizio Barone (University of Salerno)
- 506 A new protocol for the reconstruction of the auditory ambiance in Palaeolithic sites: first results from Grotta Paglicci (Apulia – Southern Italy)**
Jacopo Crezzini (University of Siena), Adriano Farina (University of Bologna), Enrico Armelloni (University of Parma), Riccardo Salvini (University of Siena), Annamaria Ronchitelli (University of Siena), Stefano Ricci (University of Siena) and Francesco Boschini (University of Siena)
- 511 Sensorial identity of ruins: Vibroacoustic features of the roofless medieval Chapel of Madonna del Fieno (Fisciano, Italy)**
Elide Nastri (University of Salerno) and Paolo Todisco (University of Salerno)

Session 8.2 - Virtual environments and Cultural Heritage: tools, new technologies, and future perspectives - PART II

Room: Room 6 - First Floor

- 515 Hidden Monuments Revealed: 3D Digitization of the Benedictine Monastery of Catania and its Stratified Spaces**
Simone Pio Barbagallo (University of Catania), Maura Fugazzotto (University of Catania), Lucrezia Longhitano (University of Catania), Roberta Occhipinti (University of Catania), Dario Allegra (University of Catania), Germana Barone (University of Catania), Paolo Mazzoleni (University of Catania) and Filippo Stanco (University of Catania)
- 520 Adaptive Immersive Experiences: Comparative Study on Villa Regina**
Liliana Cecere (University of Salerno), Francesco Colace (University of Salerno), Muhammad Khan (University of the West of England), Angelo Lorusso (University of Salerno), Domenico Santaniello (University of Salerno) and Carmine Valentino (University of Salerno)
- 526 Gamified AR and supervised AI for Cultural Heritage: The Amiternum Site Experience**
Federico Martusciello (Università degli Studi dell’Aquila), Henry Muccini (Università degli Studi dell’Aquila) and Alfonso Forgione (Università degli Studi dell’Aquila)
- 532 From Surveying Techniques to a 3D GIS Geodatabase**
Barbara Marana (University of Bergamo) and Giorgio Ubbiali (Diemme Strumenti)

POSTER SESSION

Room: University of Bergamo

- 538 How do climate change-driven renewable energy infrastructures affect the visual perception of landscapes? An exploratory empirical study**
Canio Alfieri Sabia (CNR ISPC), Maria Rosaria Potenza (CNR ISPC), Agata Maggio (CNR ISPC), Antonio Minervino Amodio (CNR ISPC) and Fabrizio Terenzio Gizzi (CNR ISPC)
- 543 Implementation of Management Facilitators in Historic Buildings: Integration of BIM and GIS for Pathology Monitoring**
Crislandy Kaline Barreiro Marques (Universidade Estadual de Campinas), Rafael Fernandes Dionízio (Universidade Estadual de Campinas) and Eloísa Dezen Kempter (Universidade Estadual de Campinas)

- 548 Tracing Construction Phases at the Roman Villa Horta da Torre (Fronteira, Portugal): Insights from mortars aggregates**
Mizuki Takahashi (University of Évora), Cristina Galacho (University of Évora), André Carneiro (University of Évora) and Patricia Moita (University of Évora)
- 553 Walls of the Castle of Alcácer do Sal – Contribution to the Study of Mortars in Military Architecture**
Maria Almeida (University of Évora), Maria Pinheiro-Alves (University of Évora), Patrícia Moita (University of Évora) and Cristina Galacho (University of Évora)
- 559 Protecting the Past, Shaping the Future. High School Students Test Nanocomposites on Archaeological samples**
Beatrice Calosso (ENEA), Rosaria D’Amato (ENEA), Valentina Nigro (ENEA) and Gaetano Terranova (ENEA)
- 564 An integrated approach for the systematic monitoring of the indoor air quality and microclimatology at churches located in the Central Mediterranean region**
Antonio Proto (University of Salerno), Francesca Cannizzaro (University of Messina), Maria Ricciardi (University of Salerno), Maria Letizia Amadori (University of Urbino), Jgor Arduini (University of Urbino), Oriana Motta (University of Salerno), Paola Donato (University of Messina), Alfred Micallef (University of Malta), Sebastiano D’Amico (University of Malta), Adriana Alescio (St John’s Foundation), Luigi Mondello (University of Messina) and Danilo Sciarrone (University of Messina)
- 569 Application of 3D Ultrasonic Tomography in Cultural Heritage: The Case of the Ustica Sculpture**
Alessandra Carollo (University of Palermo), Patrizia Capizzi (University of Palermo), Raffaele Martorana (University of Palermo), Marco Vincenzo Majani (University of Palermo) and Franco Foresta Martin (National Institute of Geophysics and Volcanology)
- 573 Integrated Geophysical Prospection at the Roman Villa of Agosta (Comacchio, Italy): first results**
Jessica Clementi (Sapienza Università di Roma) and Enzo Rizzo (Università di Ferrara)
- 577 Micro-geophysical investigations for structural diagnostics at Coratelli Mill**
Lara De Giorgi (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 582 ERT surveys at the Necropolis of Baucina (Palermo)**
Lara De Giorgi (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 587 Virtual reconstruction of the Ducal Palace of Oliveto Lucano (Basilicata, Italy)**
Maurizio Delli Santi (ISPC-CNR) and Massimiliano Passarelli (CNR - NANOTEC)
- 591 Post-earthquake structural assessment using Ground Penetrating Radar (GPR): preliminary insight for guidelines from literature review**
Antonio Minervino Amodio (Institute of Heritage Science (ISPC)), Giovanni Leucci (Institute of Heritage Science (ISPC)) and Fabrizio Terenzio Gizzi (Institute of Heritage Science (ISPC))
- 596 Dust Detector for Museum Environment Based on Raspberry-Pi**
Mariagrazia Leccisi (Università degli Studi Roma Tre), Giuseppe Schirripa Spagnolo (Università degli Studi Roma Tre) and Fabio Leccese (Università degli Studi Roma Tre)
- 602 The Theatre of Marcellus: between historical memory and digital innovation**
Roberto Barni (Sapienza Università di Roma), Marika Griffò (Sapienza Università di Roma), Carlo Inglese (Sapienza Università di Roma) and Simone Lucchetti (Sapienza Università di Roma)
- 608 Reconstructing Galileo’s Inclined Plane Experiments: Problems of Time Measurements.**
Giuseppe Schirripa Spagnolo (Università Roma Tre), Giorgia Satta (Università degli Studi Roma Tre), Federico Fina (Università degli Studi Roma Tre), Ilaria De Angelis (Università degli Studi Roma Tre) and Fabio Leccese (Università degli Studi Roma Tre)
- 614 Analysis of hypogea environments based on ambient vibration data: application to a case study on the Palatine hill**
Iolanda Gaudiosi (Consiglio Nazionale delle Ricerche), Maurizio Simionato (Consiglio Nazionale delle Ricerche), Daniel Tentori (Consiglio Nazionale delle Ricerche), Michele Livani (Consiglio Nazionale delle Ricerche), Salvatore Piro (Consiglio Nazionale delle Ricerche), Marco Mancini (Consiglio Nazionale delle Ricerche), Francesco Stigliano (Consiglio Nazionale delle Ricerche) and Massimiliano Moscatelli (Consiglio Nazionale delle Ricerche).

- 620 Historic Roofless Masonry Structures: The role of Environmental Factors that Contribute to Decay and Collapse**
Nicoletta Bianchini (University of West London), Efcharis Balodimou (University of West London), Tesfaye Tessema (University of West London), Laden Husamaldin (University of West London) and Fabio Tosti (University of West London)
- 626 Augmented Reality for Knowledge Transfer of Historical Masonry Vaulting Techniques**
Davide Prati (University of Bergamo), Orsolya Gaspar (Penn State University) and Vittorio Paris (University of Bergamo)
- 632 Structural Investigation through Digital Modeling of Two Domes by Ferdinando Crivelli**
Virna Maria Nannei (University of Bergamo), Vittorio Paris (University of Bergamo), Davide Prati (University of Bergamo), Monica Resmini (University of Bergamo) and Giulio Mirabella Roberti (University of Bergamo)
- 638 Multitemporal SAR data for prospection, monitoring and preservation of Cultural Heritage**
Antonio Corbo (Sapienza University of Rome), Antonio Napolitano (Sapienza University of Rome, Roma Tre University), Deodato Tapete (Italian Space Agency), Andrea Benedetto (Roma Tre University) and Alessandro Jaia (Sapienza University of Rome)
- 644 Spectroscopic and Micro-Elemental Analysis of some 20th-Century Paintings: Identifying Diagnostic Pigments**
Andrea Bergomi (Università degli Studi di Milano), Valeria Comite (Università degli Studi di Milano), Chiara Andrea Lombardi (Università degli Studi di Milano), Mattia Borelli (Università degli Studi di Milano), Giulia Galli (Università degli Studi di Milano), Gianluca Carabelli (Università degli Studi di Milano), Paola Fermo (Università degli Studi di Milano) and Antonino Fiorentino (Università degli Studi di Milano)
- 649 Optical methods for violin diagnostic**
Vito Pagliarulo (CNR-ISASI), Massimo Rippa (CNR-ISASI), Chiara Saltarelli (CNR-ISASI), Antimo Di Meo (CNR-ISASI), Dimitru Scutelnic (Dept. of Computer Science, University of Verona), Claudia Daffara (Dept. of Computer Science, University of Verona) and Melania Paturzo (CNR-ISASI)
- 654 Active Thermography Analysis of Wall Paintings in the Early Christian Basilica Complex of Cimitile (Italy)**
Antimo Di Meo (Institute of Applied Sciences and Intelligent Systems “E. Caianiello” of CNR, Pozzuoli (Na), Italy.), Maria Palma Recchia (Superintendency for Archaeology, Fine Arts and Landscape for the Metropolitan Area of Naples, Italy.) and Massimo Rippa (Institute of Applied Sciences and Intelligent Systems “E. Caianiello” of CNR, Pozzuoli (Na), Italy.)
- 659 3D modelling for the historical reconstruction of an archaeological site: the temple of Iuvanum**
Vincenzo Saverio Alfio (Polytechnic University of Bari), Domenica Costantino (Polytechnic University of Bari), Ahmed Kamal Hamed Dewedar (University “G. d’Annunzio” of Chieti-Pescara), Massimo Leserri (Polytechnic University of Bari), Caterina Montanaro (Polytechnic University of Bari), Donato Palumbo (University “G. d’Annunzio” of Chieti-Pescara), Massimiliano Pepe (University “G. d’Annunzio” of Chieti-Pescara) and Alfredo Restuccia Garofalo (Polytechnic University of Bari)
- 665 High-Resolution 3D Surveying to Support Museum Inclusiveness Strategies**
Gabriele Bitelli (Università di Bologna, DICAM), Anna Forte (Università di Bologna, DICAM) and Andrea Tirincanti (Museo del Territorio di Riccione)
- 671 Metal finds from the Etruscan site of Spina (Ostellato - FE - Italy), 2023 field: preliminary results**
Colin Ongari (University of Ferrara), Elena Marrocchino (University of Ferrara), Negar Eftekhari (University of Ferrara) and Carmela Vaccaro (University of Ferrara)
- 677 Medieval church bell sound generation for vibroacoustic landscape studies**
Marco Casazza (University of Salerno) and Fabrizio Barone (University of Salerno)
- 682 Hard vibroacoustic metrology for intangible cultural heritage: The case of church bells tuning**
Rosa Fiorillo (Università di Salerno), Marco Casazza (Università degli Studi di Salerno) and Fabrizio Barone (Università degli Studi di Salerno)
- 686 Preliminary results obtained by a non-destructive multi-analytical approach applied to a self-portrait by Giuseppe Sabatelli, son of Prof. Luigi Sabatelli professor at Brera Academy, and to an inscription by Natale Longoni on a shaving bowl lid**
Giulia Galli (University of Milan), Chiara Andrea Lombardi (University of Milan), Chiara Nenci (Accademia di Belle Arti di Brera), Carlo Mariani (Architect), Paola Fermo (University of Milan) and Valeria Comite (University of Milan)

- 691 **Geophysical data acquisition for a non-invasive diagnosis at the Convitto Palmieri in Lecce**
Dora Francesca Barbolla (ISPC-CNR), Lara De Giorgi (ISPC-CNR), Ivan Ferrari (ISPC-CNR), Francesco Giuri (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 696 **Integrating Historical Sources and Infrared Thermography for Detection of Seismic Damage in Architectural Heritage**
Fabrizio Terenzio Gizzi (CNR-ISPC), Edoardo Gherardi (CNR-IMAA), Maria Rosaria Potenza (CNR-ISPC) and Maria Sileo (CNR-ISPC)
- 700 **Tracking the research landscape of Infrared Thermography in Architectural Heritage: A Data-Driven View**
Fabrizio Terenzio Gizzi (CNR-ISPC), Maria Rosaria Potenza (CNR-ISPC), Maria Sileo (CNR-ISPC) and Antonio Minervino Amodio (CNR-ISPC)
- 706 **Geophysical survey in the area of aguglia d'agosta (Priolo Gargallo, Sicily)**
Lara De Giorgi (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 712 **Geophysical survey at the coastal tower of S. Caterina (Lecce, Italy)**
Lara De Giorgi (ISPC-CNR), Giancarlo De Pascalis (Università di Roma La Sapienza), Ivan Ferrari (ISPC-CNR), Francesco Giuri (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 716 **ERT survey at the Roman Bath in Sagalassos (Turkey)**
Lara De Giorgi (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 720 **THE ARCHAEOLOGICAL SITE OF ANGLONA (MT): GEOPHYSICAL SURVEYS TO UNDERSTAND THE SETTLEMENT DISPOSITION**
Lara De Giorgi (ISPC-CNR), Dora Francesca Barbolla (ISPC-CNR) and Giovanni Leucci (ISPC-CNR)
- 724 **Archeology of the future and the simulacrum for heritage As-Becoming solutions**
Fernando Birello de Lima (State University of Mato Grosso), Simone Helena Tanoue Vizioli (University of São Paulo), Luciana Paelas Mascaro (Federal University of Mato Grosso) and Amanda Kirchesch Castrillon Mendes (Federal University of Mato Grosso)
- 730 **Digital Built Heritage Representation and Documentation: A Systematic Mapping of Platforms and Hybrid Models**
Maisa Almeida (University of São Paulo), Marcela Noronha (Postdoctoral Fellow at the Faculty of Civil Engineering, Architecture and Urban Design, UNICAMP), Marcio Fabricio (Full Professor at the University of São Paulo, Architecture and Urbanism Institute (IAU USP)) and Alfonso Ippolito (Full Professor at the DSDRA, Sapienza University of Rome)
- 736 **The First 21st Century Comprehensive Restored Plan of Hadrian's Villa and its Metrological Analysis**
Michael Ytterberg (Drexel University)
- 742 **From Visual Perception to Automated Detection: Integrating NDVI, SCP, and AI for the Identification of Archaeological Surface Markers**
Filomena Papaleo (Università degli Studi di Genova) and Simone Giosuè Madeo (Università degli Studi di Genova)
- 747 **Application of Charged Particle Activation Analysis (CPAA) in archaeology**
Chaturvedula S. Sastri (Scientist (retired) - (Guest at CNRS-CEMHTI, Orleans, France)), Thierry Sauvage (CNRS, CEMHTI UPR 3079, Orleans), Olivier Wendling (CNRS, CEMHTI UPR 3079, Orleans), Aurélien Bellamy (CNRS, CEMHTI UPR 3079, Orleans), William Hate (CNRS, CEMHTI UPR 3079, Orleans), Paul Sigot (CNRS, CEMHTI UPR 3079, Orleans), Frédéric Foucher (CNRS, CEMHTI UPR 3079, Orleans) and Christian Humburg (Medical doctor)
- 753 **Multi-technique integrated analysis to discover the invisible on the Camponeschi Monument in L'Aquila**
Luisa Caneve (ENEA), Valeria Spizzichino (ENEA), Massimiliano Guarneri (ENEA), Federico Angelini (ENEA), Roberto Chirico (ENEA), Elena De Panfilis (GSSI) and Speranza Falciano (GSSI)
- 759 **Digital Heritage Conservation: The SENNSE IoT Platform as a Structured Approach for Cultural Heritage Monitoring Projects**
Davide Zecca (ISPC-CNR, Lecce, Italy), Irene Muci (Università La Sapienza, Rome, Italy), Francesco Valentino Taurino (ISPC-CNR, Lecce, Italy), Mohamed Ali Jaziri (ISPC-CNR, Lecce, Italy) and Alberto Bucciero (ISPC-CNR, Lecce, Italy)
- 764 **Modeling Memory: Ethical Reuse and AI Training with Archaeologist-Produced 3D Reconstructions**
Simone Pio Barbagallo (University of Catania), Davide Tanasi (University of South Florida) and Filippo Stanco (University of Catania)

- 769 **Digital Documentation and Virtual Accessibility of Prehistoric Artefacts: Case Studies from Sicilian Museums**
Dario Calderone (Ludwig Maximilians Universität, Munich), Davide Tanasi (University of South Florida), Enrico Greco (Institute for the Advanced Study of Culture and the Environment, University of South Florida, Tampa (FL), USA), Stephan Hassam (Randolph-Macon College, Ashland (VA), USA) and Madeleine Kraft (Digital Exploration, University of South Florida, Tampa (FL), USA)
- 774 **Preliminary findings from a non-invasive and micro-invasive multi-analytical study of the painting “Posa della Prima Pietra” by Ismaele Teglio Milla (1853)**
Paola Fermo (University of Milan), Valeria Comite (University of Milan), Chiara Andrea Lombardi (University of Milan), Mattia Borelli (University of Milan), Andrea Bergomi (University of Milan), Letizia Bonizzoni (University of Milan), Francesca Sabatini (University of Milano-Bicocca), Giulia Galli (University of Milan), Gianluca Carabelli (University of Milan) and Daniele Bolleri (University of Milan)
- 779 **Virtual Reconstruction of the Temple of Olympian Zeus in Syracuse: A Journey in the Metaverse between History and Technology**
Nicolò Di Marco (University of Catania), Elvia Maria Letizia Giudice (University of Catania) and Filippo Stanco (University of Catania)
- 784 **Surface Features of the Giovanni Rasori marble monument (1840, Milan): chemical characterization of degradation and past restoration interventions**
Andrea Bergomi (University of Milan), Paola Fermo (University of Milan), Chiara Andrea Lombardi (University of Milan), Michela Pirovano (Alma Mater Studiorum - Università di Bologna), Antonino Fiorentino (University of Milan), Mattia Borelli (University of Milan), Mario Colella (Università degli Studi di Pavia) and Valeria Comite (University of Milan)

XRD and PCA analysis of historic mortars from the Venetian Fortress of Bergamo (Italy)

Renato Pelosato *, Isabella Natali-Sora *, Virna Maria Nannei and Giulio Mirabella Roberti

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Abstract – Mortars from the 16th-century Venetian Fortress of Bergamo (Italy) were investigated using X-ray diffraction (XRD). Samples were taken from the bastions of San Pietro and Valverde, areas affected by severe degradation and targeted in a recent conservation initiative. XRD qualitative phase analysis and semi-quantitative analysis were performed on 59 samples collected from 9 cores extracted at different locations. XRD analysis identified calcite, hydrocalumite- and hydrotalcite-type compounds, brucite, aragonite, plombierite, and a substantial amorphous fraction in the binder, while aggregates consist mainly of quartz and carbonate-rich sands. The large dataset of abundances of phases in the 59 samples was analyzed via principal component analysis (PCA). PCA results indicate a homogeneous distribution of mineral phases across the dataset, with no significant clustering by depth or sampling location, supporting the interpretation of a consistent binder composition throughout the investigated sections.

I. INTRODUCTION

In 1561, the Serenissima Repubblica di Venezia began the challenging task of constructing a fortress to defend Bergamo, its westernmost city, from the rival Ducato di Milano. This fortress, with 11 bulwarks, 5 platforms, 4 main gates, and a perimeter of approximately 5 kilometres, has become a landmark in Bergamo (Figure 1) [1]. During the 19th century, the fortress underwent modifications to allow public access to the ramparts and to connect Porta Sant'Agostino with Porta Sant'Alessandro by road, while retaining its original structure. A small section of the San Pietro bulwark was demolished in 1908 to make way for Via Beltrami [2]. Given the historical and urban significance of the site for Bergamo, the municipality nominated the fortress for the World Heritage List as part of the transnational site “The Venetian Works of Defence between 16th and 17th centuries: Stato da Terra - Western Stato da Mar” acknowledged in 2017 [3]. In 2015, to support the UNESCO nomination, Bergamo's municipality, responsible for maintenance, collaborated with the University of Bergamo and the volunteer organisation Orobicambiente OdV to develop a

conservation strategy to ensure proper upkeep of this stone landscape. The initial project involved an extensive survey of the southern wall sections, identifying key preservation issues in the best-preserved area. From 2019, a second project focused on the northern walls, which were severely degraded due to overgrowth. Those areas are particularly afflicted by severe degradation from unchecked vegetation growth. Laser scanning, photogrammetry, and investigations — encompassing historical, archaeological, geological, petrographic, physical-chemical, and numerical studies — were conducted, targeting the Valverde and San Pietro bastions. A pilot site for cleaning and consolidation protocols was also established [4].

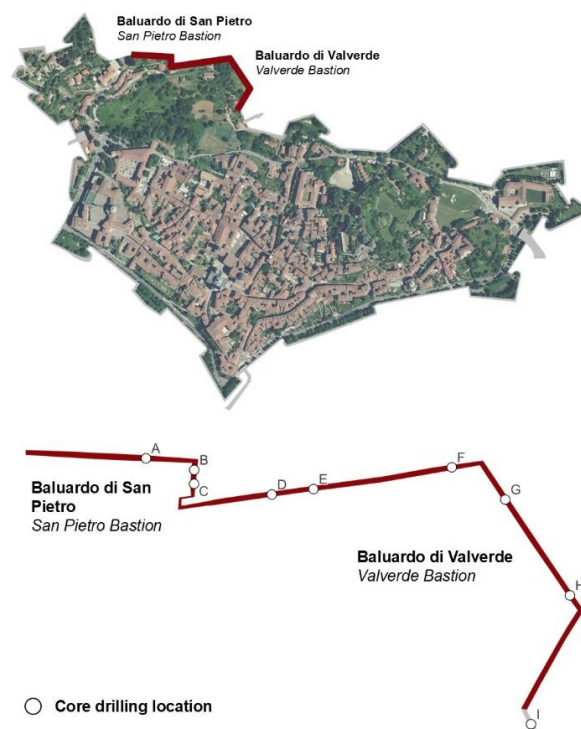


Fig. 1. Plan of the Venetian Fortress of Bergamo, indicating the sampling locations.

During geological surveys, nearly horizontal core samples were extracted from the masonry at the wall base,

allowing verification of wall thickness and providing samples to evaluate the masonry's consistency and composition beyond the surface [4].

II. MATERIALS AND METHODS

Horizontal drillings through the masonry thickness were carried out at an approximate height of 1.50 m above the ground (Figure 2). 9 cores (named from A to I) were extracted, with lengths spanning from 2 to 4 m.



Fig. 2. Core drilling in the masonry carried out by Ecogeo srl.

From the cores, containing parts of mortar, rocks and other fill materials used in the construction, 44 specimens were extracted at different position in the cores, ground and analysed individually. From 3 of the cores, extracted from different zones in the wall (namely core B, D and H) bulk samples, consisting of approximately 250 g of mortar, were collected. Five aliquots were measured for each bulk sample (for a total of 15 XRD patterns) to obtain data on the average mortar composition in the groups.

A. X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis was carried out on the mortar specimens using an X-Ray powder diffractometer Bruker D8 Advance. Measurements were performed in the $\theta/2\theta$ configuration using Cu K α radiation ($\lambda = 1.5418 \text{ \AA}$), at a voltage of 40 kV and with a current of 40 mA. The diffracted signal was collected using a Lynxeye XE-T[®] solid-state detector with a 5° window. The scan range was 2-70 °2 θ with a step size of 0.01 °2 θ and a measuring time of 19 s/step. Millimetre-sized aggregates were separated from the materials before the measurements, then the samples were ground in an agate mortar. Patterns from the 59 samples of mortar (binder and aggregates) were collected and analysed for the identification of the phases. The patterns were analysed using DIFFRACPLUS EVA[®] version 5.1.0.5 software equipped with the ICDD-PDF

(International Centre for Diffraction Data - Powder Diffraction Files) database (version 2024). XRD pattern analysis allowed the identification of the mineralogical phases and the quantification of the abundance of the phases in each sample, by means of semi-quantitative analysis performed with the RIR (Reference Intensity Ratio) method as implemented within the EVA[®] software. RIRs are a general, instrument-independent constant for use in quantitative phase analysis by the X-ray powder diffraction internal standard method [5]. When the reference standard is corundum, RIR is known as I/Ic. These constants are collected in the ICDD-PDF database. Also, the amorphous content of each sample was determined using the DIFFRACPLUS EVA[®] internal algorithm in the interval 5-70 °2 θ .

B. Principal Component Analysis (PCA)

Multivariate analysis, in the form of principal component analysis, was performed to determine the possible existence of patterns in the mineralogical composition distribution across samples. The input data were the phase abundances obtained from semi-quantitative XRD phase analysis. The 44 measurements of the small mortar samples and the 15 measurements from the bulk samples were analysed separately. Prior to PCA, the abundance data were normalized to include the amorphous fraction, then the obtained values were mean-centered and scaled to unit variance to balance the influence of mineral phases with different abundance ranges. PCA was carried out on the covariance matrix using the software OriginLab OriginPro[®] 2025b.

III. RESULTS AND DISCUSSION

XRD diffraction analysis was carried out to evaluate crystallinity and identify the phase composition in the mortar. The abbreviations used in the paper for the mineralogical phases are reported in Table 1. The mortars show good cohesion and are predominantly white or light grey colour. The phase composition of all 59 samples was estimated via the RIR (Reference Intensity Ratio) method as implemented within the EVA[®] software.

A. Phases identification in bulk samples

The mineralogical characterization of the bulk samples from cores B, D and H shows that all three mortars mainly consists of: calcite (CaCO₃), quartz (SiO₂), phyllosilicates such as muscovite (KAl₂(Si₃AlO₁₀)(OH)₂) and clinocllore ((Mg,Fe)₅Al(Si₃Al)O₁₀(OH)₈), brucite Mg(OH)₂, aragonite (CaCO₃), hydration products such as hydrocalumite (Ca₄Al₂O₆(CO₃)_{0.5}(OH)·10.75H₂O) and hydrotalcite (Mg₆Al₂(CO₃)(OH)₁₆·4H₂O), inosilicates such as plombierite (Ca₅H₂Si₆O₁₈·6H₂O), and albite (NaAlSi₃O₈). In addition to the crystalline compounds, the mortar contains a large fraction of amorphous phase (18 ÷ 25 wt%). The phases were quantified, and the composition is reported in the heat map of Figure 3 comprising the 15

measurements of the 3 mortars.

Among the identified phases, the following compounds were attributed to the aggregate fraction: quartz (Qu), muscovite (Mu), clinochlore (Cl) and albite (Al), while hydrocalumite (Ca-Hy), hydrotalcite (Mg-Hy), brucite (Br), and plombierite (Pl) are attributed to the binder fraction of the mortar, together with the amorphous fraction (Am).

Table 1. mineralogical phases names, formulae and abbreviations.

Phase Name	Chemical Formula	Abbr.
Calcite	CaCO_3	Ca
Quartz	SiO_2	Qu
Muscovite	$\text{KAl}_2(\text{Si}_3\text{AlO}_{10})(\text{OH})_2$	Mu
Hydrocalumite	$\text{Ca}_4\text{Al}_2\text{O}_6(\text{CO}_3)_{0.5}(\text{OH}) \cdot 10.75\text{H}_2\text{O}$	Ca-Hy
Aragonite	CaCO_3	Ar
Brucite	$\text{Mg}(\text{OH})_2$	Br
Clinochlore	$(\text{Mg},\text{Fe})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$	Cl
Jennite	$\text{Ca}_9\text{Si}_6\text{O}_{18}(\text{OH})_6 \cdot 8\text{H}_2\text{O}$	Je
Hydrotalcite	$\text{Mg}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$	Mg-Hy
Albite	$\text{NaAlSi}_3\text{O}_8$	Al
Plombierite	$\text{Ca}_5\text{H}_2\text{Si}_6\text{O}_{18} \cdot 6\text{H}_2\text{O}$	Pl
Vaterite	CaCO_3	Va
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	Do
Ettringite	$\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}(\text{H}_2\text{O})_{24}$	Et
Amorphous	-	Am

Calcite (Ca) instead, was attributed to both the binder and the aggregate fraction. In the binder fraction, calcite is present as the result of the usual carbonatation reaction of portlandite ($\text{Ca}(\text{OH})_2$) in the hardening reaction of lime binders: $\text{Ca}(\text{OH})_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$. Meanwhile, a large fraction of the aggregates is constituted by a typical calcareous local black sand. Petrographic observations (not reported here) and XRD measurements on a fragment of the black sand confirm this mineralogical composition. (see Section III-B).

The XRD phase quantification in the bulk samples suggests good control of the mix design for the mortars. Indeed, in all the bulk samples of core B, D and H, the same 10 phases could be detected. Small differences are to be found in the higher amount of quartz and the absence of plombierite in the sample from core B, a slightly larger abundance of calcite in core D, and a larger amount of hydrated phases and of the amorphous fraction in core H (Figure 3).

B. Phases identification in individual mortar samples

The analyses of the specimens collected throughout all the cores in small portions (a few cm^3) show as expected a much larger variation in the number of phases and in their amounts. The corresponding heatmap is reported in Figure 4.

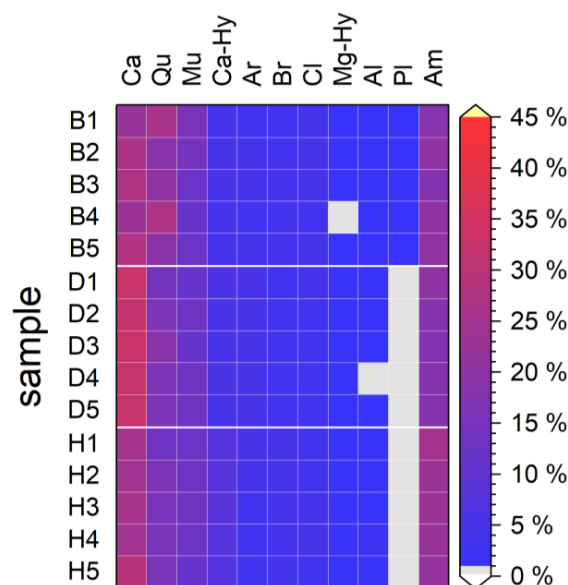


Fig. 3. Heat map of wt% composition of bulk mortar samples. On the top axis the phases are reported with abbreviations detailed in section III.A. (amount increases from blue to red according to the colour scale reported on the right; gray: < 1%, white: phase not detected; yellow: > 45%).

The identified compounds are: calcite (CaCO_3), quartz (SiO_2), muscovite ($\text{KAl}_2(\text{Si}_3\text{AlO}_{10})(\text{OH})_2$) and clinochlore ($(\text{Mg},\text{Fe})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$), brucite ($\text{Mg}(\text{OH})_2$), aragonite (CaCO_3), hydrocalumite ($\text{Ca}_4\text{Al}_2\text{O}_6(\text{CO}_3)_{0.5}(\text{OH}) \cdot 10.75\text{H}_2\text{O}$), hydrotalcite ($\text{Mg}_6\text{Al}_2(\text{CO}_3)(\text{OH})_{16} \cdot 4\text{H}_2\text{O}$), plombierite ($\text{Ca}_5\text{H}_2\text{Si}_6\text{O}_{18} \cdot 6\text{H}_2\text{O}$) and albite ($\text{NaAlSi}_3\text{O}_8$). Also, jennite ($\text{Ca}_9\text{Si}_6\text{O}_{18}(\text{OH})_6 \cdot 8\text{H}_2\text{O}$) a crystalline form of calcium silicate hydrate, vaterite (CaCO_3), a metastable polymorph of calcium carbonate, dolomite ($\text{CaMg}(\text{CO}_3)_2$) and ettringite ($\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12}(\text{H}_2\text{O})_{24}$) were detected sporadically in a few samples. The amount of the amorphous fraction (Am) was quantified in a range from 14 to 27% by weight of the analysed fragments (only exception is sample D30pn with $\text{Am} < 3\%$). Many of the fragments show a consistent composition, not far from that of the bulk samples, but a few outliers were also observed. Those are to be explained partially by the choice of the operator to collect and analyse specimens with a peculiar visual aspect. Examples of those kinds of samples are sample A-10, F-05a, F-09 and G-08 that contain a large amount of brucite (to be found concentrated in a collection of white lumps evenly distributed in the mortar). Samples D-28a, F-05a, F-09, H-36b and I-11 have a large amount

of aragonite. Samples H-16, I-13a and in a lesser extent I-13b and G-08, contain a large fraction of jennite.

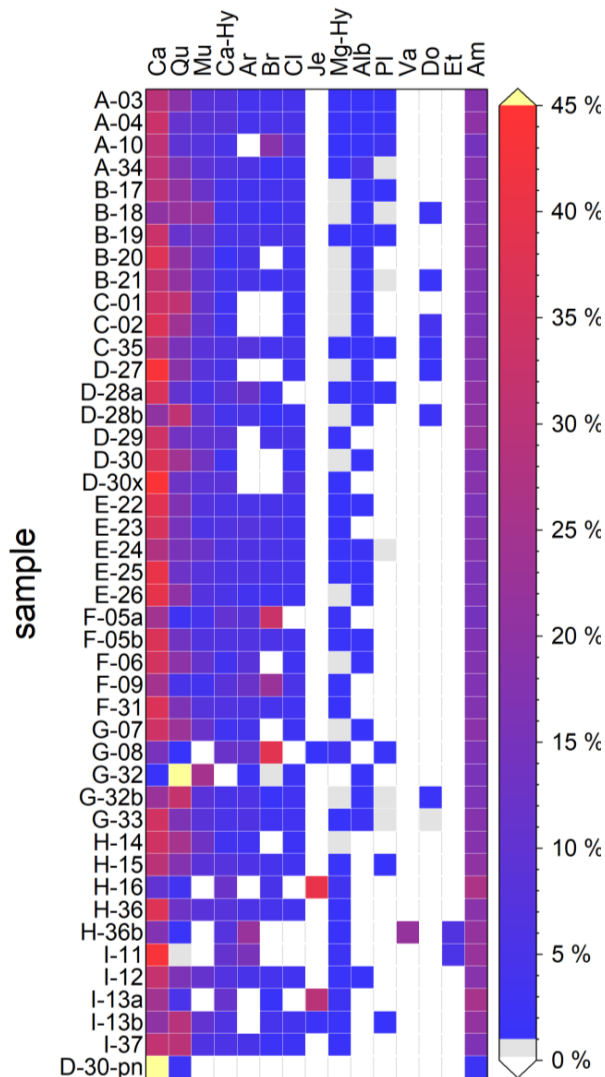


Fig. 4. Heat map of wt% composition of individual mortar samples. On the top axis the phases are reported with abbreviations detailed in section III.B. (amount increases from blue to red according to the colour scale reported on the right; gray: < 1%, white: phase not detected; yellow: >45%).

Unlike the other specimens, sample D-30pn was intentionally chosen to include a large fragment of black sand aggregate, therefore it does not reflect the mortar composition. The analysis shows that it is mainly constituted of calcite, supporting the claim in Section III-A about the distribution of calcite in both the binder and the aggregate.

C. PCA analysis

PCA analysis was performed on the bulk samples and on

the individual samples separately.

Starting from the bulk samples, in Figure 5 the biplot is presented. The vectors represent the mineralogical phases and reflect the co-variance of the phases in the specimens; the first two principal components account for nearly 69% of the total variance. The half-filled circles represent the scores of the individual samples and reflect their composition. The shaded shapes represent the 95% confidence ellipsoids.

The loading graph shows that the amorphous content (Am), hydrotalcite (Mg-Hy) and hydrocalumite (Ca-Hy) phases and brucite (Br) amounts are positively correlated, being phases that develop in the hydration of the binder. PCA reveals a strong correlation between aragonite and calcite. The matter is complicated by the fact that calcite is part of both the carbonated binder and the calcareous aggregate.

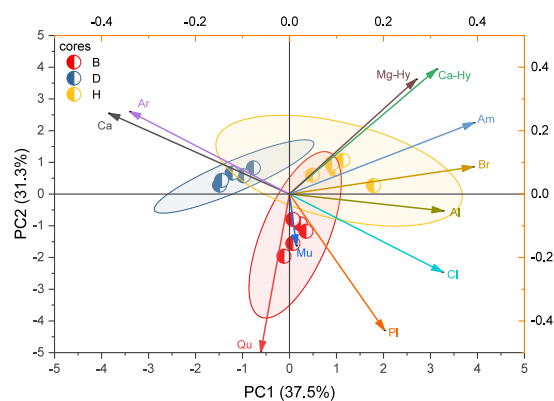


Fig. 5. Biplot of PCA analysis of phases abundance in bulk samples of cores B, D and H.

Literature suggests that aragonite is commonly formed as a metastable phase in hydraulic lime binders [6] [7] [8], therefore it is expected to be found in association with the calcite produced during the hardening and ageing of the binder. Further analysis could be required to disentangle these contributions. The differences in phase composition that were noticeable in the heatmap emerge also from the bi-plot. A slight clustering is observed among samples, based on core origin, (core B, core D and core H). core H is more associated with hydration products and amorphous content. In contrast, and quartz (Qu) and muscovite (Mu) show negative loadings, indicating a stronger presence in cores B and D. Overall, despite some internal dispersion, the confidence ellipses overlap significantly, indicating no distinct clustering by sampling location. This supports the interpretation of a relatively homogeneous phase distribution across the two studied bastions

PCA performed on individual small samples reveals a more scattered distribution of mineral phases compared to previous analyses on composite samples. This discrepancy likely reflects the influence of local heterogeneities and sampling bias in small-scale specimens, which may not

capture the full compositional spectrum of the mortar. In contrast, composite samples—obtained by averaging multiple aliquots—tend to smooth out local variations, resulting in more stable phase correlations. The biplot relative to the PCA analysis based on cores (representative of the different drilling positions) is presented in Figure 6.

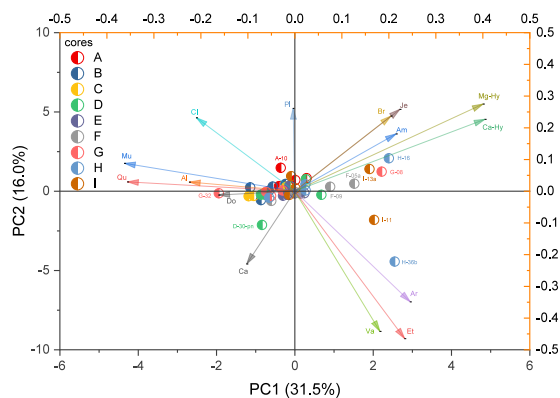


Fig. 6. Bi-plot of PCA analysis of phases abundances in individual samples, grouped by core (A to I).

In this situation, the first two principal components only account for 47.5 % of the total variance, indicating the complexity of the phase relations in the dataset.

The loading graph highlights the strong internal correlation of the hydrated phases in the binder (Am, Ca-Hy, Mg-Hy, Br and Je) and among the aggregate-related phases (Qu, Mu, Al, Do), and their strong negative correlation. This pattern is likely due to sampling bias, where binder-rich or aggregate-rich mortar samples were selected. Calcite, being present in both the subsets, ends up poorly correlated, while the metastable carbonates vaterite and aragonite show a strong association.

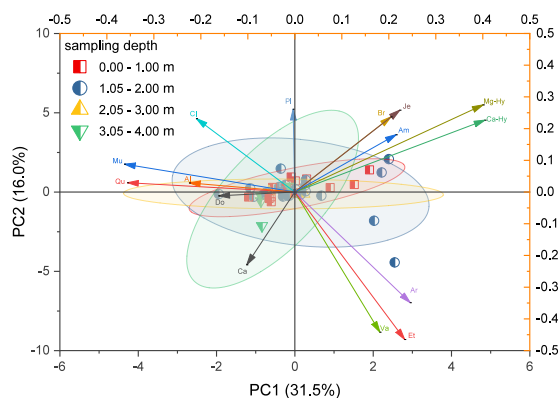


Fig. 7. Bi-plot of PCA analysis of phases abundances in individual samples, grouped by sampling depth (1 to 4m).

The sample scores, here grouped by the core, are largely clustered in the centre, with no dispersion whatsoever. The confidence ellipsoids are not shown for sake of clarity, since they are nearly completely overlapped to each other.

The few individual samples that stand-out are indicated on the graph and are those mentioned above in Section IIIB for having a peculiar composition.

The bi-plot reported in Figure 7 groups the samples for sampling depth (0.00-1.00 m, 1.05 – 2.00m, 2.05-3.00 m, 3.05-4.00 m). No clustering is apparent either, as witnessed by the complete overlapping of the confidence ellipsoids.

IV. CONCLUSIONS

The historic mortars of the wall of Venetian Fortress of Bergamo were analysed by means of X-ray diffraction and the results were analysed using PCA. Mineral phases present in the mortar were identified and associated with the binder and aggregate fractions. The main crystalline compounds are calcite, quartz, muscovite, hydrocalumite-type and hydrotalcite-type compounds, brucite, aragonite, plombierite, clinocllore and albite. Also, jennite, vaterite, dolomite and ettringite were identified occasionally. Additionally, the mortar contains a large fraction of amorphous phases (between 14 and 27 wt%). The results of PCA on composite samples—obtained by averaging multiple aliquots—tend to smooth out local variations, resulting in more stable phase correlations. Overall, the PCA analysis confirms a relatively homogeneous mineralogical composition across the cores, indicating that the binder composition remains consistent across the examined portions of the wall.

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