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2019 IMEKO TC-4 INTERNATIONAL CONFERENCE ON
**METROLOGY FOR ARCHAEOLOGY
AND CULTURAL HERITAGE**
FLORENCE, ITALY / DECEMBER 4-6, 2019



FLORENCE 2019

PROCEEDINGS

UNIVERSITY OF FLORENCE
SAGAS DEPARTMENT
VIA S. GALLO, 10

ITALIAN GEOGRAPHIC
MILITARY INSTITUTE
VIA C. BATTISTI, 10



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2019 IMEKO TC-4 International Conference on

Metrology for Archaeology and Cultural Heritage

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PROCEEDINGS

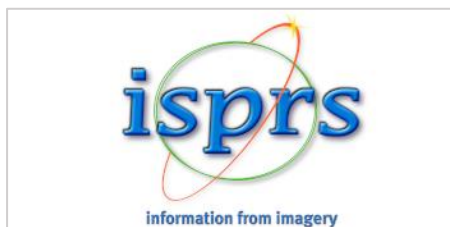
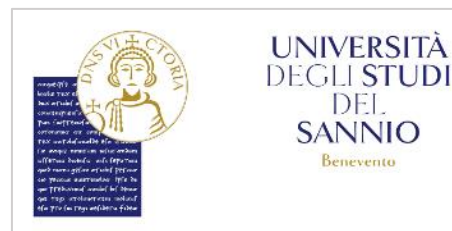
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Patronages



CONFERENCE PROGRAM

Wednesday, December 4

Special Session - Data Acquisition and Processing by Integrated Geomatic Techniques, Experiences and Open Issues - PART I

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: *Gabriele Bitelli, University of Bologna, Italy*

Maria Grazia D'Urso, DISA, University of Bergamo, Italy

- 1 An Updated Comparison on Contemporary Approaches for Digitization of Heritage Objects**
Efstathios Adamopoulos, Università degli Studi di Torino, Italy
Fulvio Rinaudo, Politecnico di Torino, Italy

 - 7 A methodology for semi-automatic documentation of archaeological elements using RPAS imagery**
Eduard Angelats, Centre Tecnològic de Telecomunicacions de Catalunya, Spain
M. E. Parés, Centre Tecnològic de Telecomunicacions de Catalunya, Spain
C. Mas-Florit, Universitat de Barcelona, Spain
M.A Cau-Ontiveros, Universitat de Barcelona, ICREA, Spain

 - 13 Modelling the Seventies: Image-Based Modelling to Investigate Landscape Change in a Mediterranean Mountain Area**
Manuel J.H. Peters, Politecnico di Torino, Italy, Uni. de Évora, Portugal, Uni. Leiden, The Netherlands
Tesse D. Stek, Universiteit Leiden, The Netherlands, Royal Netherlands Institute, Italy

 - 19 Evaluation of the Expected Data Quality in Laser Scanning Surveying of Archaeological Sites**
Mattia Previtali, Politecnico Milano, Italy
Lucia Díaz-Vilariño, Universidade de Vigo, Spain
Marco Scaioni, Politecnico Milano, Italy
Ernesto Frías Nores, Universidade de Vigo, Spain

 - 25 Rapid Mapping methods for archaeological sites**
Antonia Spanò, Politechnics of Turin, Italy
-

Special Session - IoT based Systems for the Structural Health Monitoring and the Analysis of Cultural Heritage Building and Archaeological Sites

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Carmelo Scuro, University of Calabria, Italy*

- 31 The Non-smooth tale of “Apennine Churches” stroked by the Central Italy Earthquakes of 2016**
Angela Ferrante, Polytechnic University of Marche, Italy
Ersilia Giordano, Polytechnic University of Marche, Italy
Francesco Clementi, Polytechnic University of Marche, Italy
Gabriele Milani, Politecnico di Milano, Italy
Antonio Formisano, University of Naples ‘Federico II’, Italy

- 37 Cultural Heritage and earthquake: the case study of San Francesco’s church in Amandola (Central Italy)**
Ersilia Giordano, Polytechnic University of Marche, Italy
Angela Ferrante, Polytechnic University of Marche, Italy
Francesco Clementi, Polytechnic University of Marche, Italy
Gabriele Milani, Politecnico di Milano,
Antonio Formisano, University of Naples ‘Federico II’, Italy

- 43 **An innovative structural health monitoring system for the preliminary study of an ancient anti-seismic construction technique.**
Carmelo Scuro, University of Calabria, Italy
Domenico Luca Carnì, University of Calabria, Italy
Francesco Lamonaca, University of Sannio, Italy
Renato Sante Olivito, University of Calabria, Italy
Gabriele Milani, University of Milan, Italy
- 48 **Automated procedure for the creation of finite element mesh: application to non-periodic historical masonry**
Simone Tiberti, University of Milan, Italy
Gabriele Milani, University of Milan, Italy
- 53 **SHM systems applied to the built heritage inventory at the territorial scale. A preliminary study based on CARTIS approach**
Renato Sante Olivito, University of Calabria, Italy
Saverio Porzio, University of Calabria, Italy
Carmelo Scuro, University of Calabria, Italy
Domenico Luca Carnì, University of Calabria, Italy
Francesco Lamonaca, University of Sannio, Italy
-

Thursday, December 5

Keynote Lecture: Conservation Science and Ethics in the Analytical Studies of Clay Cuneiform Tablets from Ancient Near Eastern Archives

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: Emma Angelini, Politecnico di Torino, Italy

- 59 **Conservation Science and Ethics in the Analytical Studies of Clay Cuneiform Tablets from Ancient Near Eastern Archives**
Yuval Goren, Ben Gurion University of the Negev, Israel
Erez Ben-Yosef, Tel Aviv University, Israel
Francisco Centola, Universidade de Évora, Portugal
Cécile Fossé, Ben Gurion University of the Negev, Israel, Universidade de Évora, Portugal
Yaron Katzir, BeGorenn Gurion University of the Negev, Israel
José Mirão, Universidade de Évora, Portugal
Ron Sha'ar, The Hebrew University of Jerusalem, Israel
Yitzhak Vassal, Tel Aviv University, Israel Antiquities Authority, Israel
Nicola Schiavon, Universidade de Évora, Portugal
-

Special Session on Advanced methodologies for diagnostic and preventive conservation of stone materials in subaerial and underwater environment

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: Mauro Francesco La Russa, University of Calabria, Italy

Paola Fermo, University of Milan, Italy

- 68 **SEM-EDS microanalysis in cultural heritage and archaeology: thickness effects and measurement strategy for ultrathin glass and metal fragments and particles**
Daniele Moro, Università di Bologna "Alma Mater Studiorum", Italy
Gianfranco Ulian, Università di Bologna "Alma Mater Studiorum", Italy
Giovanni Valdrè, Università di Bologna "Alma Mater Studiorum", Italy

73 Metals distributions within black crusts sampled on the facade of an historical monument: the case study of the Cathedral of Monza (Milan, Italy)

Valeria Comite, Università degli Studi di Milano, Italy
Jose Santiago Pozo-Antonio, University of Vigo, Spain
Carolina Cardell, University of Granada, Spain
Teresa Rivas, University of Vigo, Spain
Luciana Randazzo, Università della Calabria, Italy
Mauro Francesco La Russa, Università della Calabria, Italy
Paola Fermo, Università degli Studi di Milano, Italy

Special Session on Measuring Ancient Mortars and Concretes to Discover the Past

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Marco Lezzerini, University of Pisa, Italy*
Andrea Aquino, University of Pisa, Italy

79 Characterization of mortars of Giotto's Bell Tower for radiocarbon dating

Sara Calandra, (CNR-ICVBC), University of Florence, Italy
Serena Barone, University of Florence, INFN Florence Unit, Italy
Emma Cantisani, (CNR-ICVBC), Italy
Mariaelena Fedi, INFN Florence Unit, Italy
Carlo Alberto Garzonio, University of Florence, Italy
Lucia Liccioli, INFN Florence Unit, Italy
Barbara Salvadori, (CNR-ICVBC), Italy
Teresa Salvatici, University of Florence, Italy
Paola Ricci, University of Campania Luigi Vanvitelli, Italy

84 Calcarenite di Gravine Formation, a Row Material for the lime production

Agnese Emanuela Bonomo, University of Basilicata, Italy
G. Rizzo, University of Basilicata, Italy
G. Prosser, University of Basilicata, Italy

90 The production of binding materials in southern Florence area: stones and their properties (Greve in Chianti, Italy)

Andrea Aquino, Università di Pisa, Italy
Elena Pecchioni, Università di Firenze, Italy
Fabio Fratini, Consiglio Nazionale delle Ricerche, Italy
Emma Cantisani, Consiglio Nazionale delle Ricerche, Italy
Sonia La Felice, Consiglio Nazionale delle Ricerche, Italy
Tsegaye Abebe, Adhana Geological Consultancy Service, Italy
Claudia Principe, Consiglio Nazionale delle Ricerche, Italy
Marco Lezzerini, Università di Pisa, Italy

95 New Strategies in Mortar Characterization and Radiocarbon Dating

Giulia Ricci, University of Padova, Italy
Michele Secco, University of Padova, Italy
Fabio Marzaioli, (CIRCE), INNOVA SCaRL, Italy
Isabella Passariello, (CIRCE), INNOVA SCaRL, Campania Uni. "Luigi Vanvitelli", Italy
Filippo Terrasi, (CIRCE), INNOVA SCaRL, Campania Uni. "Luigi Vanvitelli", Italy
Gilberto Artioli, University of Padova, Italy

Special Session on Electromagnetic methods in Archaeology and Cultural Heritage applications - PART I

Room: Italian Geographic Military Institute - De Vecchi Hall

Chairs: *Giovanni Leucci, IBAM-CNR, Italy*
Rita Deiana, University of Padova, Italy
Raffaele Martorana, University of Palermo, Italy

- 100 The watch towers in Malta: a patrimony to preserve for the future**
Raffaele Persico, IBAM-CNR, University Uninettuno UTIU, Italy
Giovanni Leucci, IBAM-CNR, Italy
Sebastiano D'Amico, University of Malta, Malta
Lara De Giorgi, IBAM-CNR, Italy
Emanuele Colica, University of Malta, Malta
Maurizio Lazzari, IBAM-CNR, Italy
- 103 Matera European Capital of Culture 2019: NDT surveys in cave churches**
Lara De Giorgi, IBAM-CNR, Italy
Maurizio Lazzari, IBAM-CNR, Italy
Giovanni Leucci, IBAM-CNR, Italy
Raffaele Persico, IBAM-CNR, Italy
- 105 Remotely controlled aerial and underwater vehicles in support to magnetic surveys**
Salvatore Scudero, INGV, Osservatorio Nazionale Terremoti, Italy
Giovanni Vitale, INGV, Osservatorio Nazionale Terremoti, Italy
Antonino Pisciotta, INGV, Sezione di Palermo, Italy
Raffaele Martorana, Università degli studi di Palermo, Italy
Patrizia Capizzi, Università degli studi di Palermo, Italy
Antonino D'Alessandro, INGV, Osservatorio Nazionale Terremoti, Italy
- 109 Recent developments on portable XRF scanner**
Sergio Augusto Barcellos Lins, La Sapienza Università di Roma, INFN Roma Tre, Italy
Giovanni Ettore Gigante, La Sapienza Università di Roma, Italy
Roberto Cesareo, Università degli Studi di Sassari, Italy
Stefano Ridolfi, Ars Mensurae, Italy

General Session - PART I

Room: Italian Geographic Military Institute - Sala del Cortile

Chairs: *Marco Carpiceci, Sapienza University of Rome, Italy*
Marcantonio Catelani, University of Florence, Italy

- 114 Managing complex Synchrotron radiation FTIR micro-spectra from historic bowed musical instruments by chemometrics**
Silvia Grassi, Università degli Studi di Milano, Italy
Giacomo Fiocco, Università degli Studi di Pavia, Università di Torino, Italy
Claudia Invernizzi, Università degli Studi di Pavia, Uni. degli Studi di Parma, Italy
Tommaso Rovetta, Università degli Studi di Pavia, Italy
Michela Albano, Università degli Studi di Pavia, Italy
Patrizia Davit, Università di Torino, Italy
Monica Gulmini, Università di Torino, Italy
Chiaromaria Stani, Elettra-Sincrotrone Trieste, Italy
Lisa Vaccari, Elettra-Sincrotrone Trieste, Italy
Maurizio Licchelli, Università degli Studi di Pavia, Italy
Marco Malagodi, Università degli Studi di Pavia, Italy
- 120 First sampling of ceramic mixtures for Valle d'Aosta: research and perspectives related to the alpine settlement of Orgères (La Thuile-AO, Italy).**
Chiara Maria Lebole, University of Torino, Italy
Marco Russo, University of Torino, Italy
Alberto Spegis, University of Torino, Italy
Giorgio Di Gangi, University of Torino, Italy
- 125 Structural degradation measurement and diagnostics of historical masonry buildings.**
Valentino Sangiorgio, Politecnico di Bari, Italy
Silvia Martiradonna, Politecnico di Bari, Italy
Fabio Fatiguso, Politecnico di Bari, Italy
Giuseppina Uva, Politecnico di Bari, Italy

Special Session on Integrated Digital Survey Methodologies for the Knowledge and Enhancement of Architectural and Urban Heritage - PART I

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: *Marco Giorgio Bevilacqua, University of Pisa, Italy*

Assunta Pelliccio, University of Cassino, Italy

131 Integrated digital survey methodologies for the knowledge and enhancement of the ancient city walls. The “Curtain” of Santa Chiara in Cagliari (Italy)

Andrea Pirinu, University of Cagliari, Italy

Marco Utzeri, University of Cagliari, Italy

136 Historical data of laser scanning and photogrammetry for the knowledge and memory plan of Cultural Heritage

Gabriella Caroti, DICI, University of Pisa, Italy

Isabel Martínez-Espejo Zaragoza, DICI, University of Pisa, Italy

Andrea Piemonte, DICI, University of Pisa, Italy

142 SfM and Digital Modelling for Enhancing Architectural Archives Heritage

Roberta Spallone, Politecnico di Torino, Italy

Giulia Bertola, MODLab Arch, Italy

Francesca Ronco, MODLab Design, Italy

Special Session on Non-Invasive Systems and Techniques for "on-site" Monitoring and Diagnosis - PART I

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Emanuele Piuzzi, Sapienza University of Rome, Italy*

Livio d'Alvia, Sapienza University of Rome, Italy

149 A comparative evaluation of patch resonators layouts for moisture measurement in historic masonry units

Livio D'Alvia, Sapienza University of Rome, Italy

Eduardo Palermo, Sapienza University of Rome, Italy

Zaccaria Del Prete, Sapienza University of Rome, Italy

Erika Pittella, Sapienza University of Rome, Italy

Stefano Pisa, Sapienza University of Rome, Italy

Emanuele Piuzzi, Sapienza University of Rome, Italy

154 Integrated approach for non invasive diagnostic investigation at the Bishop's Palace of Frascati

Luisa Caneve, ENEA, Italy

Francesco Colao, ENEA, Italy

Massimiliano Guarneri, ENEA, Italy

Marialuisa Mongelli, ENEA, Italy

Valeria Spizzichino, ENEA, Italy

Massimo Francucci, ENEA, Italy

160 Mid-wave infrared imaging analysis of XVII century paintings on canvas of the Chigi Palace in Ariccia

Sofia Ceccarelli, Università degli Studi di Roma Tor Vergata, Italy

Noemi Orazi, Università degli Studi di Roma Tor Vergata, Italy

Fulvio Mercuri, Università degli Studi di Roma Tor Vergata, Italy

Stefano Paoloni, Università degli Studi di Roma Tor Vergata, Italy

Ugo Zammit, Università degli Studi di Roma Tor Vergata, Italy

Francesco Petrucci, Palazzo Chigi, Italy

166 Photogrammetry and structured light: comparison and integration of techniques in survey of the Corsini Throne at Corsini Gallery in Rome

Marialuisa Mongelli, ENEA, Italy

Giulia Chellini, ENEA, Italy

Silvio Migliori, ENEA, Italy

Antonio Perozziello, ENEA, Italy

Samuele Pierattini, ENEA, Italy

Marco Puccini, ENEA, Italy

Alessandro Cosma, Galleria Nazionale Corsini, Italy

Special Session on Electromagnetic methods in Archaeology and Cultural Heritage applications - PART II

Room: Italian Geographic Military Institute - De Vecchi Hall

Chairs: *Giovanni Leucci, IBAM-CNR, Italy*

Rita Deiana, University of Padova, Italy

Raffaele Martorana, University of Palermo, Italy

172 Structural detailing of buried Roman baths through GPR inspection

Luca Bianchini Ciampoli, Roma Tre University, Italy

Roberta Santarelli, Roma Tre University, Italy

Ersilia Maria Loreti, Sovrintendenza Capitolina ai Beni Culturali, Italy

Alessandra Ten, University of Roma La Sapienza, Italy

Andrea Benedetto, Roma Tre University, Italy

178 A 3D information framework for automated archaeological pottery archival

Luca Di Angelo, University of L'Aquila, Italy

Paolo Di Stefano, University of L'Aquila, Italy

Emanuele Guardiani, University of L'Aquila, Italy

Anna Eva Morabito, University of Salento, Italy

184 Hydrogeological and geotechnical modeling of the foundation soils of Maredolce Lake in Palermo, aided by geophysical surveys

Fabio Cafiso, University of Palermo, Italy

Alessandro Canzoneri, University of Palermo, Italy

Patrizia Capizzi, University of Palermo, Italy

Alessandra Carollo, University of Palermo, Italy

Raffaele Martorana, University of Palermo, Italy

Filippo Romano, University of Palermo, Italy

General Session - PART II

Room: Italian Geographic Military Institute - Sala del Cortile

Chairs: *Paolo Liverani, University of Florence, Italy*

Marcantonio Catelani, University of Florence, Italy

188 Metrological approach to the study of Central European regular cities

Maria Legut-Pintal, Wrocław University of Science and Technology, Poland

Anna Kubicka, Wrocław University of Science and Technology, Poland

193 Roman fragmentary painting: surveying technologies and methodological approaches.

Maria Legut-Pintal, Wrocław University of Science and Technology, Poland

Anna Kubicka, Wrocław University of Science and Technology, Poland

199 Thermoluminescence dating laboratory improvements tested on an archaeological rescue site in Trino, Vercelli province, Italy.

Laura Guidorzi, Università di Torino, INFN Sezione di Torino, Italy

Fulvio Fantino, TecnArt S.r.l., Italy

Elisabetta Durisi, Università di Torino, INFN Sezione di Torino, Italy

Marco Ferrero, Università di Torino, INFN Sezione di Torino, Italy

Alessandro Re, Università di Torino, INFN Sezione di Torino, Italy

Luisa Vigorelli, Università di Torino, Italy

Lorenzo Visca, Università di Torino, INFN Sezione di Torino, Italy

Monica Gulmini, Università di Torino, Italy

Giovanni Dughera, INFN Sezione di Torino, Italy

Giuseppe Giraud, INFN Sezione di Torino, Italy

Debora Angelici, TecnArt S.r.l., Italy

Elisa Panero, Ministero per i Beni e le Attività Culturali, Italy

Alessandro Lo Giudice, Università di Torino, INFN Sezione di Torino, Italy

Special Session on Integrated Digital Survey Methodologies for the Knowledge and Enhancement of Architectural and Urban Heritage - PART II

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: *Marco Giorgio Bevilacqua, University of Pisa, Italy*
Assunta Pelliccio, University of Cassino, Italy

205 Digital Survey and 3D Geometric Interpretation of Complex Vaulted Systems. Palazzo Valperga Galleani di Barbaresco in Turin

Marco Vitali, Politecnico di Torino, Italy
Fabrizio Natta, Politecnico di Torino, Italy

211 3D procedural modeling of complex vaulted systems: geometric rules vs SfM based modeling

Vincenzo Bagnolo, DICAAR, University of Cagliari, Italy
Raffaele Argiolas, DICAAR, University of Cagliari, Italy

217 Roots of 'Parametric Thinking' in Palladio's Villas. Surveying, interpreting and visual programming the plates from I quattro libri di architettura

Roberta Spallone, Politecnico di Torino, Italy
Michele Calvano, Politecnico di Torino, Italy

223 Integration and modelling of 3D data as strategy for structural diagnosis in Endangered Sites. The study case of Church of the Annunciation in Pokcha (Russia)

Sandro Parrinello, University of Pavia, Italy
Raffaella De Marco, University of Pavia, Italy

Special Session on Non-Invasive Systems and Techniques for "on-site" Monitoring and Diagnosis - PART II

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Emanuele Piuze, Sapienza University of Rome, Italy*
Livio d'Alvia, Sapienza University of Rome, Italy

229 Structural health monitoring of the Ninfeo Ponari by combined use of fibre optic sensors, photogrammetry and laser scanning

Michele Arturo Caponero, ENEA, Italy
Ernesto Grande, Univ. Guglielmo Marconi, Italy
Maura Imbimbo, Univ. of Cassino and Southern Lazio, Italy
Giuseppe Modoni, Univ. of Cassino and Southern Lazio, Italy
Marialuisa Mongelli, ENEA, Italy
Eugenio Polito, Univ. of Cassino and Southern Lazio, Italy

234 Archaeological application of centreless X-ray diffractometers for non-destructive pole figure measurements

Máté Sepsi, University of Miskolc, Hungary
Márton Benke, University of Miskolc, Hungary
Valéria Mertinger, University of Miskolc, Hungary

239 New, non-invasive texture measurement method for archaeology

Máté Sepsi, University of Miskolc, Hungary
Márton Benke, University of Miskolc, Hungary
Valéria Mertinger, University of Miskolc, Hungary

244 Diagnostic of historical vehicle's engines by acoustic emission techniques

Alejandro Roda-Buch, Haute Ecole Arc, Ecole Polytechnique Fédérale, Switzerland
Emilie Cornet, Haute Ecole Arc, Switzerland
Guillaume Rapp, Haute Ecole Arc, Switzerland
Brice Chalançon, Musée National de l'Automobile, France
Stefano Mischler, Ecole Polytechnique Fédérale, Switzerland
Laura Brambilla, Haute Ecole Arc, Switzerland

Special Session on Electromagnetic methods in Archaeology and Cultural Heritage applications - PART III

Room: Italian Geographic Military Institute - De Vecchi Hall

Chairs: *Giovanni Leucci, IBAM-CNR, Italy*

Rita Deiana, University of Padova, Italy
Raffaele Martorana, University of Palermo, Italy

- 249 **Ground Penetrating Radar investigation of the floor of Palazzo Vecchio's Great Hall**
Massimiliano Pieraccini, University of Florence, Italy
Lapo Miccinesi, University of Florence, Italy
Heidi Garcia Canizares, University of Florence, Italy
- 254 **Architectural survey and analysis of the costal tower of S. Maria dell'Alto in Nardò (Lecce, Italy).**
Francesco Gabellone, (ISPC-CNR) National Research Council, Italy
Ivan Ferrari, (ISPC-CNR) National Research Council, Italy
Alessandro Giuri, External collaborator, Italy
Francesco Giuri, (ISPC-CNR) National Research Council, Italy
- 259 **Effectiveness of electromagnetic conductivity mapping for delineating subsurface structures related to the Roman port of Emporiae**
Albert Casas, University of Barcelona, Spain
Pere Castanyer, Empúries. Museo d'Arqueologia, Spain
Mahjoub Himi, University of Barcelona, Spain
Raul Lovera, University of Barcelona, Spain
Lluís Rivero, University of Barcelona, Spain
Marta Santos, Empúries. Museo d'Arqueologia, Spain
Joaquim Tremoleda, Empúries. Museo d'Arqueologia, Spain
Rubén García, University of Barcelona, Spain
Aritz Urruela, University of Barcelona, Spain
- 265 **THE PIETRAGALLA PROJECT: FIRST RESULTS OF THE GEOPHYSICAL ACTIVITIES ON THE MONTE TORRETTA ARCHAEOLOGICAL SITE**
Luigi Capozzoli, CNR – IMAA, Italy
Vincenzo Capozzoli, Université Paris, 1 Panthéon-Sorbonne, France
Gregory De Martino, CNR – IMAA, Italy
Alain Duploux, Université Paris, 1 Panthéon-Sorbonne, France
Agnes Henning, Humboldt Universität zu Berlin, Germany
Enzo Rizzo, CNR – IMAA, Italy

Special Session on Data Acquisition and Processing by Integrated Geomatic Techniques, Experiences and Open Issues - PART II

Room: Italian Geographic Military Institute - Sala del Cortile

Chairs: Maria Grazia D'Urso, DISA, University of Bergamo, Italy
Grazia Tucci, DICEA, University of Florence, Italy

- 271 **Geomatics for Cultural Heritage conservation: integrated survey and 3D modeling**
Valeria Croce, DICI, University of Pisa, Italy
Gabriella Caroti, DICI, University of Pisa, Italy
Andrea Piemonte, DICI, University of Pisa, Italy
Marco Giorgio Bevilacqua, DESTEC, University of Pisa, Italy
- 277 **High-resolution 3D surveying in support of Cultural Heritage**
Francolini Chiara, University of Bologna, Italy
Gabriele Bitelli, University of Bologna, Italy
Beatrice Borghi, University of Bologna, Italy
Filippo Galletti, University of Bologna, Italy
- 282 **Terrestrial laser scanning points clouds for modeling masonry vaults**
Maria Grazia D'Urso, Department of Engineering and Applied Sciences, University of Bergamo, Italy
Valerio Manzari, Department of Civil and Mechanical Engineering, University of Cassino, Italy
Barbara Marana, Department of Engineering and Applied Sciences, University of Bergamo, Italy
- 288 **Additive manufacturing of marble statues: 3D replicas for the preservation of the originals**
Grazia Tucci, DICEA, University of Florence, Italy
Valentina Bonora, DICEA, University of Florence, Italy
Valerio Tesi, Soprintendenza Archeologia, Belle arti e paesaggio, Italy
Bernardo Pagnini, Freelance Architect, Italy

Special Session on Conservation and protection of natural and artificial stones used in historical buildings

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: Marco Lezzerini, University of Pisa, Italy

Rosaria D'Amato, ENEA, Italy

Andrea Aquino, University of Pisa, Italy

294 Performance of consolidants in marble and sandstone from Tuscany: a comparison

Andrea Aquino, Università di Pisa, Italy

Marco Lezzerini, Università di Pisa, Italy

299 Synthesis and characterization of nanosilica products for the consolidation of stones.

Neva Maria Elisabetta Stucchi, Università Ca' Foscari di Venezia, Italy

Elena Tesser, Iuav University of Venice, Italy

Fabrizio Antonelli, Iuav University of Venice, Italy

Alvise Benedetti, Università Ca' Foscari di Venezia, Italy

305 MATERA BUILDING STONES: CHEMICAL, MINERALOGICAL AND PETROPHYSICAL CHARACTERIZATION OF THE CALCARENITE DI GRAVINA FORMATION

Agnese Emanuela Bonomo, University of Basilicata, Italy

Marco Lezzerini, University of Pisa, Italy

G. Prosser, University of Basilicata, Italy

A. Munnecke, University of Erlangen-Nuremberg, Germany

R. Koch, University of Erlangen-Nuremberg, Germany

G. Rizzo, University of Basilicata, Italy

309 Intercalibration of hyperspectral and multispectral systems for Laser Induced Fluorescence imaging

Maria Federica Caso, ENEA, Italy

Luisa Caneve, ENEA, Italy

Valeria Spizzichino, ENEA, Italy

314 ARCHAOMETRIC STUDIES AND CONSERVATION SOLUTIONS FOR CORVIN'S CASTLE CIRCULAR TOWERS

Rodica-Mariana Ion, ICECHIM, Research Group, Valahia University of Târgoviște, Romania

Sorin Tincu, Corvin's Castle, Romania

Lorena Iancu, ICECHIM, Research Group, Valahia University of Târgoviște, Romania

Ramona Marina Grigorescu, ICECHIM, Research Group, Romania

Cristiana Radulescu, University of Târgoviște - ICSTM-UVT, Romania

Sofia Teodorescu, University of Târgoviște - ICSTM-UVT, Romania

Ioana Daniela Dulama, University of Târgoviște - ICSTM-UVT, Romania

Raluca Maria Stirbescu, University of Târgoviște - ICSTM-UVT, Romania

Ioan Alin Bucurica, University of Târgoviște - ICSTM-UVT, Romania

Mihaela Lucia Ion, "Atelierul de Creatie" NGO, Romania

Anca Irina Gheboianu, University of Târgoviște - ICSTM-UVT, Romania

318 A novel fibre optic sensor of relative humidity for application in cultural heritage

Rosaria D'Amato, ENEA, Italy

Michele Arturo Caponero, ENEA, Italy

Barbara Palazzo, ENEA, Italy

Gaetano Terranova, ENEA, Italy

Andrea Polimadei, ENEA, Italy

Friday, December 6

Special Session on Pigments and palettes through the Ages: science of painting techniques

Room: Italian Geographic Military Institute - De Vecchi Hall

Chairs: Vincenza Crupi, University of Messina, Italy

Valentina Venuti, University of Messina, Italy

324 Chemical-structural analysis of wooden painted specimens by clinical multi-slice computed tomography (MSCT) and surface-enhanced Raman scattering (SERS)

Sveva Longo, University of Messina, Sapienza University of Rome, Italy

Francesca Granata, University of Messina, Italy

Silvia Capuani, Sapienza University of Rome, Italy

Fortunato Neri, University of Messina, Italy

Enza Fazio, University of Messina, Italy

330 Scientific investigation of The Conversion of St Paul painting (Mdina, Malta)

Sebastiano D'Amico, University of Malta, Malta

Valentina Venuti, University of Messina, Italy

Emanuele Colica, University of Malta, Malta

Vincenza Crupi, University of Messina, Italy

Domenico Majolino, University of Messina, Italy

Giuseppe Paladini, University of Messina, Italy

Sante Guido, University of Trento, Italy

Giuseppe Mantella, Giuseppe Mantella Restauro Opere D'Arte, Italy

Rosarianna Zumbo, St Martin's College, Malta

POSTER SESSION

Room: Italian Geographic Military Institute

Chairs: *Lorenzo Ciani, University of Florence, Italy*

335 New insights about the consolidation of archaeological mortars located in underwater environment: the case study of the apsidal fishpond of Castrum Novum (Santa Marinella, Rome, Italy)

Mauro Francesco La Russa, University of Calabria, Italy

Luciana Randazzo, University of Calabria, Italy

Michela Ricca, University of Calabria, Italy

Daniela Pellegrino, University of Calabria, Italy

Daniele La Russa, University of Calabria, Italy

Alessandro Morrone, University of Calabria, Italy

Barbara Davidde, Ministero dei Beni e delle Attività Culturali e del Turismo, Italy

Flavio Enei, Museo del Mare e della Navigazione Antica, Italy

338 A combined petrographic and geochemical metrological approach to assess the provenance of the building limestone used in the Batalha Monastery (Portugal)

Yufan Ding, University of Évora, Portugal

José Mirao, University of Évora, Portugal

Pedro Redol, Mosteiro da Batalha, Portugal

Luis Dias, University of Évora, Portugal

Patricia Moita, University of Évora, Portugal

Emma Angelini, Politecnico di Torino, Italy

Sabrina Grassini, Politecnico di Torino, Italy

Nicola Schiavon, University of Évora, Portugal

343 Ground-penetrating Radar surveys in the Lecce Cathedral

Giovanni Leucci, IBAM-CNR, Italy

Ilaria Miccoli, IBAM-CNR, Italy

Lara De Giorgi, IBAM-CNR, Italy

Immacolata Ditaranto, IBAM-CNR, Italy

Giuseppe Scardozi, IBAM-CNR, Italy

346 The Epizefiri Archaeological Site in Locri (Reggio Calabria, Italy): Geophysical surveys for excavation project

Giovanni Leucci, CNR, Italy

Daniele Malfitana, CNR, Italy

Lara De Giorgi, CNR, Italy

Antonino Mazzaglia, CNR, Italy

Giovanni Fragalá, CNR, Italy

348 Geophysical investigations for the knowledge of the buried structures in the Basilica Julia at the Roman Forum

Giovanni Leucci, IBAM-CNR, Italy
Tommaso Ismaelli, IBAM-CNR, Italy
Lara De Giorgi, IBAM-CNR, Italy
Immacolata Ditaranto, IBAM-CNR, Italy
Giuseppe Scardozi, IBAM-CNR, Italy
Marco Galli, Sapienza Università di Roma, Italy
Carlo Inglese, Sapienza Università di Roma, Italy
Marika Griffo, Sapienza Università di Roma, Italy

351 Melite Civitas Romana Project: preliminary results from GPR survey

Robert Brown, Australian National University, Australia
David Cardona, Heritage, Malta
Lara De Giorgi, CNR, Italy
Giovanni Leucci, CNR, Italy
Ben Lowe, University of North Alabama, USA
Raffaele Persico, CNR, Italy
Davide Tanasi, University of South Florida, USA
Andrew Wilkinson, Flinders University, Australia

355 GIS to catalogue the shipment of naves lapidariae in Mediterranean Sea

Maurizio Delli Santi, CNR – ISPC, Italy

361 Geophysical surveys for the restoration of Branciforte Palace in Palermo

Patrizia Capizzi, University of Palermo, Italy
Raffaele Martorana, University of Palermo, Italy

365 A multidisciplinary non-invasive approach in geoarchaeology conducted on the archaeological area of Selinunte

Antonino Pisciotta, Istituto Nazionale di Geofisica e Vulcanologia, Italy
Raffaele Martorana, University of Palermo, Italy
Antonio Costanzo, Istituto Nazionale di Geofisica e Vulcanologia, Italy
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Patrizia Capizzi, University of Palermo, Italy
Antonino D'Alessandro, Istituto Nazionale di Geofisica e Vulcanologia, Italy
Sergio Falcone, Istituto Nazionale di Geofisica e Vulcanologia, Italy
Carmelo La Piana, Istituto Nazionale di Geofisica e Vulcanologia, Italy

369 The Basilica of Santa Caterina d'Alessandria in Galatina (Lecce, Italy): NDT surveys for the conservation project

Giovanni Leucci, CNR, Italy
Lara De Giorgi, CNR, Italy
Giancarlo De Pascalis, Università La sapienza Roma, Italy
Giuseppe Scardozi, CNR, Italy

371 The Monastery of Santa Chiara in Nardó (Lecce, Italy): GPR preliminary results

Giovanni Leucci, CNR, Italy
Lara De Giorgi, CNR, Italy
Giancarlo De Pascalis, Università La sapienza Roma, Italy
Francesco Giuri, CNR, Italy

374 Preliminary results from NDT-SPR survey on wooden beams

Giovanni Leucci, CNR, Italy
Lara De Giorgi, CNR, Italy

377 Geophysical surveys in the external areas of the Basilica of St Nicholas (Bari, Italy)

Giovanni Leucci, CNR, Italy
Lara De Giorgi, CNR, Italy
Raffaele Persico, CNR, Italy

- 380 **Characterization of the decay of a wooden trunk through electrical resistivity**
Lara De Giorgi, CNR, Italy
Giovanni Leucci, CNR, Italy
- 383 **Conservation purpose material testing of corrosion products on outdoor bronze statues in Museum Park of Hungarian National Museum**
Bubonyi Tamás, University of Miskolc, Hungary
Melinda Nagy, Hungarian National Museum, Hungary
Szilvia Gyöngyösi, University of Debrecen, Hungary
Laura Juhász, University of Debrecen, Hungary
Péter Barkóczy, FUX Co. Miskolc, Hungary
György Forgács, Forgax Alkotóműhely kft, Hungary
Bakonyi Eszter Szatmáriné, University of Fine Arts Budapest, Hungary
- 389 **Non-invasive characterization of ancient Cu-based coins using Raman spectroscopy**
Leila Es Sebar, Politecnico di Torino, Italy
Leonardo Iannucci, Politecnico di Torino, Italy
Yuval Goren, Ben Gurion University of the Negev, Israel
Peter Fabian, Ben Gurion University of the Negev, Israel
Emma Angelini, Politecnico di Torino, Italy
Sabrina Grassini, Politecnico di Torino, Italy
- 395 **Characterisation of Roman copper alloy artefacts and soil from Rakafot 54 (Beer Sheva, Israel)**
Manuel J.H. Peters, Politecnico di Torino, Italy, Universidade de Évora, Portugal, Ben-Gurion University of the Negev, Israel
Yuval Goren, Ben Gurion University of the Negev, Israel
Peter Fabian, Ben Gurion University of the Negev, Israel
José Mirão, Universidade de Évora, Portugal
Sabrina Grassini, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy
- 401 **The photogrammetric survey of Tomb II in Agios Athanasios, Thessaloniki**
Alessandra Turco, University of Salerno, Italy
- 406 **Metrological characterization of a textile temperature sensor**
Lorenzo Quartini, University of Florence, Italy
Andrea Zanobini, University of Florence, Italy
- 412 **A Machine Learning approach to aerial photointerpretation and mapping**
Ilaria Cacciari, "Nello Carrara" – CNR, Italy
Giorgio Franco Pocobelli, SAGAS, Università di Firenze, Italy
Salvatore Siano, "Nello Carrara" – CNR, Italy
- 417 **Architecture - Conceptual design in terms of the intuitive metrology method as an element of the natural development of the landscape and spatial context**
Jerzy Wojewodka, Silesian University of Technology, Poland
Julia Giżewska, Silesian University of Technology, Poland
- 423 **Measurement and analysis of visitors' trajectories in crowded museums**
Pietro Centorrino, Sapienza Università di Roma, Italy
Alessandro Corbetta, Eindhoven University of Technology, The Netherlands
Emiliano Cristiani, CNR, Italy
Elia Onofri, CNR, Italy
- 429 **A novel approach for in-situ assessment of the efficacy of biocides on building of historical interest by bioluminescence**
Eleonora Marconi, Università Roma Tre, Italy
Simonetta Tuti, Università Roma Tre, Italy
Maria Rosaria Fianza, Università Roma Tre, Italy
Fabio Leccese, Università Roma Tre, Italy
Adele Galetti, Leonardo S.r.l., Italy
Francesco Geminiani, Leonardo S.r.l., Italy

- 435 A novel approach for in-situ assessment of the efficacy of biocides on building of historical interest by bioluminescence**
Giuseppe Schirripa Spagnolo, Università degli Studi Roma Tre, Italy
Lorenzo Cozzella, Università degli Studi Roma Tre, Italy
Fabio Leccese, Università degli Studi Roma Tre, Italy
- 439 Multi-band infrared imaging for the characterization of underlying elements in the Santa Maria in Cosmedin altarpiece**
Sofia Ceccarelli, Università degli Studi di Roma Tor Vergata, Italy
Noemi Orazi, Università degli Studi di Roma Tor Vergata, Italy
Cristina Cicero, Università degli Studi di Roma Tor Vergata, Italy
Fulvio Mercuri, Università degli Studi di Roma Tor Vergata, Italy
Ugo Zammit, Università degli Studi di Roma Tor Vergata, Italy
Stefano Paoloni, Università degli Studi di Roma Tor Vergata, Italy
Anna Candida Felici, Università di Roma "La Sapienza", Italy
Francesca Matera, Private Restorer, Italy
Mariella Nuzzo, Ministero per i Beni e le attività Culturali, Italy
- 444 Using 3D scanning in the protection of industrial heritage- the example of Queen Luise Adit**
Krzysztof Herner, The Coal Mining Museum in Zabrze, Poland
- 449 Design and Implementation of a Mobile Robot for the Mechatronic Survey**
Erika Ottaviano, University of Cassino and Southern Lazio, Italy
Pierluigi Rea, University of Cassino and Southern Lazio, Italy
- 454 A new mortar from a strange ancient mortar**
Fabio Fratini, CNR, Italy
Silvia Rescic, CNR, Italy
Emma Cantisani, CNR, Italy
Elena Pecchioni, CNR, University of Firenze, Italy
Stefano Pasolini, Freelance restorer, Italy
Andrea Cagnini, OPD (Opificio delle Pietre Dure), Italy
- 459 Petrographic characteristics of the mortars from the Pisa's Cathedral apse**
Marco Lezzerini, University of Pisa, Italy
Marcello Spampinato, Freelance petrographer, Italy
Anton Sutter, Opera della Primaziale Pisana, Italy
Nadia Montevicchi, Freelance archaeologist, Italy
Andrea Aquino, University of Pisa, Italy
- 464 Quality Assurance for dosimetric measurements of mortar on polymineral fine grain fraction**
Kathya Bonilla, PH3DRA labs, Italy
Alessia D'Anna, PH3DRA labs, Italy
Sara Galvagno, PH3DRA labs, Italy
Anna Maria Gueli, PH3DRA labs, Italy
Stefania Pasquale, PH3DRA labs, Italy
Giuseppe Politi, PH3DRA labs, Italy
Giuseppe Stella, PH3DRA labs, Italy
- 469 Old anatomical models as makeshifts of measurements in medicine**
Emma Angelini, Politecnico di Torino, Italy
Andrea Gori, Museo Galileo, Italy
- 474 New insight on the 1st century BC paleo-sea level and related vertical ground movements along the Baia - Miseno coastal sector (Campi Flegrei, southern Italy)**
Pietro Aucelli, Università degli Studi di Napoli Parthenope, Italy
Claudia Caporizzo, Università degli Studi di Napoli Parthenope, Italy
Aldo Cinque, Università di Napoli 'Federico II', Italy
Gaia Mattei, Università degli Studi di Napoli Parthenope, Italy
Gerardo Pappone, Università degli Studi di Napoli Parthenope, Italy
Michele Stefanile, Università degli Studi di Napoli Parthenope, Italy

478 A petrographic study of the mortars from the Villa Reale di Marlia (NW Tuscany, Italy)

Marco Lezzerini, University of Pisa, Italy
Marcello Spampinato, Freelance Applied Petrographer, Italy
Nadia Montevicchi, Freelance Archaeologist, Italy
Luca Borgoni, Freelance Architect, Italy
Henric Grönberg, Villa Reale di Marlia, Italy
Andrea Aquino, University of Pisa, Italy

Special Session on Measuring in the past: ancient instruments between science and technology

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Emma Angelini, Politecnico di Torino, Italy*
Luisa Spairani, Gruppo Astrofili Eporediesi, Italy

483 A short tale of the short story of the sliding rule

Andrea Bacciotti, Politecnico di Torino, Italy

489 The sixteenth-century find “Treatise On Land Surveying Methods Using the Surveyor’s Cross”, by Francesco Paciotti, military and civil architect to the Duchy of Urbino: the technical evolution of a surveying tool.

Raffaella Marotti, Università degli Studi di Urbino "Carlo Bo", Italy

494 Measure by Measure they touched the heaven

Luisa Spairani, Gruppo Astrofili Eporediesi, Italy

499 Cleaning of historical scientific instruments: first analytical studies

Michela Albano, CISRiC, Università degli Studi di Pavia, Polytechnic of Milan, Italy
Giacomo Fiocco, CISRiC, Università degli Studi di Pavia, Università di Torino, Italy
Claudia Invernizzi, CISRiC, Uni. degli Studi di Pavia, Uni degli Studi di Parma, Italy
Maurizio Licchelli, CISRiC, Università degli Studi di Pavia, Italy
Marco Malagodi, CISRiC, Università degli Studi di Pavia, Italy
Raffaella Marotti, Università degli Studi di Urbino "Carlo Bo", Italy
Curzio Merlo, CISRiC, Università degli Studi di Pavia, Cr.Forma, Italy
Tommaso Rovetta, CISRiC, Università degli Studi di Pavia, Italy
Daniela Comelli, Polytechnic of Milan, Italy

505 Measuring instruments and protocols in Archaeomagnetic dating: Magneto-stratigraphy in Archaeology and Volcanology

Claudia Principe, CNR, Italy
Daniele Giordano, University of Turin, Italy
Sonia La Felice, CNR, Italy
Giulio Giovannetti, CNR, Italy
Marina Devidze, Tbilisi State University, Georgia

General Session - PART III

Room: Italian Geographic Military Institute - De Vecchi Hall

Chairs: *Lorenzo Ciani, University of Florence, Italy*

511 Presence and Applications of Bituminous Materials on the Ancient Vaccae Culture: a Nondestructive Spectroscopic Study

Javier Pinto, University of Valladolid, Spain
Carlos Sanz-Minguez, University of Valladolid, Spain
Carmelo Prieto, University of Valladolid, Spain

516 Computational modelling of the mechanical behaviour of the Pentelic Marble -Steel clamp system on the structures of the Athens Acropolis

Zacharias Vangelatos, University of California, USA
Michail Delagrammatikas, University of Athens, Greece
Olga Papadopoulou, University of Athens, Greece
Panayota Vassiliou, University of Athens, Greece

- 522 **Indirect Temperature Measurements for TL Signal Loss during Drilling**
Anna Maria Gueli, Università degli Studi di Catania & INFN-Sez CT, Italy
Stefania Pasquale, Università degli Studi di Catania & INFN-Sez CT, Italy
Giuseppe Politi, Università degli Studi di Catania & INFN-Sez CT, Italy
Giuseppe Stella, Università degli Studi di Catania & INFN-Sez CT, Italy
Carlo Trigona, Università degli Studi di Catania, Italy
- 527 **ERT investigation of tumuli: does the errors in locating electrodes influence the resistivity?**
Veronica Pazzi, University of Firenze, Italy
Lorenzo Ciani, University of Firenze, Italy
Luca Cappuccini, University of Firenze, Italy
Mattia Ceccatelli, University of Firenze, Italy
Gabriele Patrizi, University of Firenze, Italy
Giulia Guidi, University of Firenze, Italy
Nicola Casagli, University of Firenze, Italy
Marcantonio Catelani, University of Firenze, Italy

Special Session on Measurement and Instrumentation for the Preventive Conservation of Metallic Works of Art

Room: Great Hall, University of Florence, SAGAS Dep

Chairs: *Panayota Vassiliou, University of Athens, Greece*
Sabrina Grassini, Politecnico di Torino, Italy

- 533 **Micro-Raman investigation of dangerous corrosion products of archaeological bronzes from Tharros (Sardinia/Italy)**
Tilde de Caro, ISMN–CNR Rome, Italy
Leila Es Sebar, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy
- 538 **MA-XRF measurement for corrosion assessment on bronze artefacts**
Sergio Augusto Barcellos Lins, La Sapienza Università di Roma, INFN Roma Tre, Italy
Elisabetta Di Francia, INFN Roma Tre, Italy
Sabrina Grassini, Politecnico di Torino, Italy
Giovanni Ettore Gigante, La Sapienza Università di Roma, Italy
Stefano Ridolfi, Ars Mensurae, Italy
- 543 **Measurement Setup for the Development of PreCorroded Sensors for Metal Artwork Monitoring**
Marco Faifer, DEIB, Politecnico di Milano, Italy
Sara Goidanich, Chemistry “Giulio Natta” Politecnico di Milano, Italy
Christian Laurano, DEIB, Politecnico di Milano, Italy
Chiara Petiti, Chemistry “Giulio Natta” Politecnico di Milano, Italy
Sergio Toscani, DEIB, Politecnico di Milano, Italy
Michele Zanoni, DEIB, Politecnico di Milano, Italy
- 549 **A long-term corrosion investigation of bronze sculptures exposed outdoor**
Leila Es Sebar, Politecnico di Torino, Italy
Alessandro Re, Università di Torino and INFN, Italy
Marco Parvis, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy
Sabrina Grassini, Politecnico di Torino, Italy
- 554 **Provenance, manufacturing and corrosion behavior of Ancient Hellenistic coins from Egypt**
Panayota Vassiliou, School of Chemical Engineering, NTUA, Athens, Greece
Olga Papadopolou, School of Chemical Engineering, NTUA, Athens, Greece
Sabrina Grassini, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy

Special Session on Metrology for taphonomy: quantifying the alterations of skeletal remains in archaeology

Room: Parva Hall, University of Florence, SAGAS Dep

Chairs: *Francesco Boschini, Università degli Studi di Siena, Italy*
Simona Arrighi, Università di Bologna, Italy

560 A new geometric morphometrics-based shape and size analysis discriminating anthropogenic and non-anthropogenic bone surface modifications of an experimental data set

Antoine Souron, Université de Bordeaux, France
Alexandre Napias, Université de Bordeaux, France
Thomas Lavidalie, Université de Bordeaux, France
Frédéric Santos, Université de Bordeaux, France
Ronan Ledevin, Université de Bordeaux, France
Jean-Christophe Castel, Muséum d'histoire naturelle, Switzerland
Sandrine Costamagno, Université de Toulouse Jean Jaurès, France
Daniel Cusimano, Diablo Valley College, USA
Stephanie Drumheller, The University of Tennessee, USA
Jennifer Parkinson, University of San Diego, USA
Lee Rozada, Muséum national d'Histoire naturelle, France
David Cochard, Université de Bordeaux, France

566 The cut runs deep: linking the cut marks to the cutting tools

Francesco Boschini, Università degli Studi di Siena, Italy
Erika Moretti
Daniele Aureli, Université Paris Ouest Nanterre La Défense, France
Jacopo Crezzini, Università degli Studi di Siena, Italy
Simona Arrighi, Università di Bologna, Italy

571 Detection of sexual dimorphism in the human neurocranium at local scale

Antonieta Del Bove, IPHES, Universitat Rovira i Virgili (URV), Spain
Antonio Profico, University of York, UK
Carlos Lorenzo, IPHES, Universitat Rovira i Virgili (URV), Spain

577 Index of Authors

A Machine Learning approach to aerial photointerpretation and mapping

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Abstract – In the project “ARCHEO 3.0” a Machine Learning (ML) system for automatic contouring of the stratigraphic units of an archaeological excavation has been experimented. In this research, we have applied the same ML algorithm to aerial color photographs that represent very important tools in the study of ancient topography and landscape archaeology. Aerials of the Vulci necropolis, one of the most important cities of ancient Etruria, have been used. These photos, both vertical and oblique, have been chosen because the marks had been studied and analyzed in a recent PhD work in Ancient Topography. In particular, the traditional mapping method has been compared with the results obtained by means of automated ML algorithm. This experiment has demonstrated that the developed ML algorithm can be applied to aerial photographs for the recognition of archaeological traces, with interesting development prospects.

Keyword: Machine Learning, aerial photography, archaeological mapping, landscape archaeology, ancient topography, crop-marks, Vulci.

I. INTRODUCTION

In the framework of the project Archeo 3.0, funded by the Regione Toscana and developed by Consiglio Nazionale delle Ricerche, a Machine Learning (ML) algorithm for the automatic drawing of contours of stratigraphic units has been tested in archaeological excavation [1, 2]. Here we decided to extend the ML analysis to aerial color photographs that represent a very important tool in the study of ancient topography and landscape archaeology.

It is well known that buried archaeological structures produce visible marks on aerial photographs that, correctly interpreted, allow defining their shape and perimeter (contour).

There are different types of tracks: damp-marks, crop-marks, soil-sites, shadow-sites [3-5]. Crop marks are essential for our research because they are characterized by high color contrast. In fact, archaeological structures,

interacting with the rooting apparatus of the vegetation, can deeply influence its growth that can thus be reduced or enhanced. This difference can be easily recognized in aerial photographs considering the chromatic contrast. For example, in correspondence to the graves dug in the ground or defensive ditches, the vegetation will be taller and thicker, resulting in a dark green color; on the contrary, in correspondence with masonry structures or roads, plants will be lower and thinner resulting in light green or yellow (fig. 1).

In the traditional archaeological method, marks that are recognized in the photos are digitally drawn on a topographic map (CAD), a process that takes many days to generate the final results.

The aim of this project is the development of an automatic or semiautomatic system that allows speeding up the time of graphic restitution, drawing the outlines of the archaeological mark or helping the archaeologist in the interpretation with the delimitation of the areas affected by underground structures. These outlines, shown on the topographic map, will be crucial in protecting archaeological heritage.

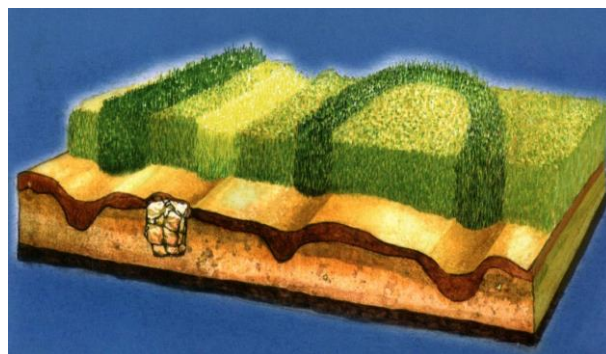


Fig. 1. The effect of buried archaeological features on the growth of crops.

II. MATERIALS AND METHODS

A. Aerial photography

In this research, aerial photos of the Vulci necropolis have been used. Vulci was one of the most important

cities of ancient Etruria from which, according to Latin writers, Servius Tullius, the sixth king of Rome, came from.

Both vertical and oblique photos of Vulci have been considered in a recent PhD work in Ancient Topography, in which the marks were studied and analyzed by means of a traditional mapping [6, 7]. These images were ideal candidates for testing the reliability and accuracy of the automatic (or semi-automatic) method based on ML algorithm. For this aim, a comparison with the automated results and the archaeological map, has been conducted (fig. 2).

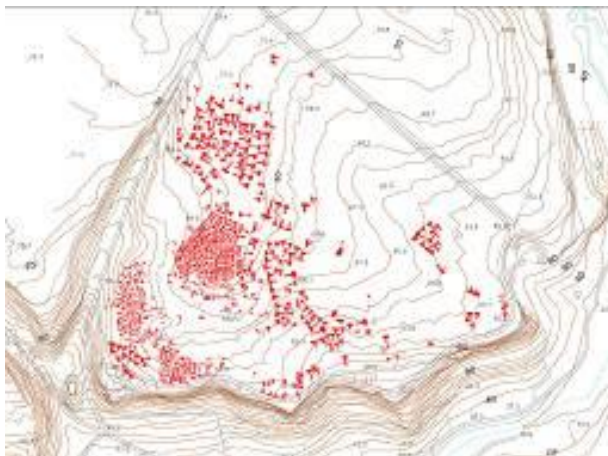


Fig. 2. Vulci. Poggio Mengarelli. Traditional method mapping of tombs (by G.F. Pocobelli).



Fig. 3. Vulci. Planimetric photography. Details of crop-marks of the shaft tombs.

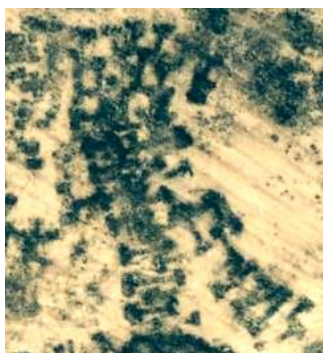


Fig. 4. Vulci. Planimetric photography. Details of crop-marks of the chamber tombs.



Fig. 5. Vulci. Oblique photography. Details of crop-marks of the chamber tombs.

In particular, it has been considered a 1996 vertical photo of a sector of Poggio Mengarelli (N of the ancient city) - used as a necropolis from the 8th to the 4th /3rd c. BC. It shows clearly many rectangular crop-marks, produced by underground shaft tombs (fig. 3), and “T” crop-marks of chamber tombs (fig. 4). The tombs were excavated in a very tender tufa bank, in which it was easy to make simple shaft tombs but also architecturally more complex graves, with a long ramp (dromos) descending to the rectangular atrium (i.e. the T recognizable by the traces) leading to the hypogeum chambers where aristocratic families were buried from the 7th c. BC onwards.

Some oblique photographs of the same necropolis sector have been also considered in this work. They were made at low altitude in 2001, in which the same traces were visible but with a different angle (fig. 5).

B. Machine Learning

A variety of problems are now currently solved with Machine Learning techniques. It ranges from detecting spam, to product recommendation as well as medical diagnosis and financial analysis. It not surprising that also in the archaeological domain, ML finds room for a plethora of applications [1, 2]. In this contest, one of the main aims of ML, is to group the unlabeled elements in a dataset depending on specific features (clusters): this task is commonly referred to as unsupervised learning. This approach is particularly interesting, since in archaeology, the features to be identified are generally partial or completely unknown.

Moreover, this approach results to be extremely promising because it requires minimal human intervention. This appears even more appealing in all the cases in which archaeology deals with images. In fact, a preliminary division (clustering) of the digital image can be performed by means of ML without providing the algorithm with any information on the image under test.

This can help the archaeologist in the identification of features that are not easily observable with the naked eye.

Among the numerous unsupervised ML algorithms for clustering, we have considered k -means clustering, due to its ease of use and robustness. This algorithm is able to partition the dataset (in this case the image) into a number of clusters established a priori by the operator.

The algorithm we have developed is based on three steps: in the first one, the operators set the number of clusters (k). In the next step, the color coordinates (e.g. RGB, HSL..), for each pixel of the image under test, are extracted, and k barycenters are defined in a random fashion. A barycenter is defined as a real location representing the center of a cluster. Every pixel is allocated to a cluster through reducing the in-cluster distance between all pixels. In other words, the pixel is assigned to its closest cluster center according to a distance function. For this aim, in the third step, a distance measure, based on Euclidean distance between the color coordinates of each pixel and the actual barycenters, is used for updating the clusters areas and hence the barycenter positions. The procedure is repeated until no further change occurs in the barycenter positions.

The outputs of the algorithm are k images in which all the non-zero pixels belong to a specific cluster. The k images are then combined, by assigning an 8-bit number to each pixel in a cluster, into a composite image (in false colors). This image is finally used with standard edge detection technique (such as Sobel or Canny filtering) to highlight the contours - in this case - of the tombs. It should be remarked that the results are subjective by the number of clusters set a priori. In this work, for the sake of homogeneity, all the images have been processed considering the same color coordinates and number of clusters (RGB, $k=3$).

III. RESULTS

In this research we have chosen to use only color photographs, deliberately excluding B/W photographs since the ML developed system works very well with color clusters. Moreover, historical B/W aerial photos are currently used in advanced experimentation conducted by Italian National Photographic Aerial Archive (AFN-ICCD) in Rome with Bruno Kessler Foundation (FBK) in Trento [8, 9].

Several areas from Poggio Mengarelli site (Vulci) have been considered for color clustering. The false color images obtained with RGB color coordinates and 3 clusters, for four areas have been presented in fig. 6. The aerial original image with overlaid the contours obtained at the end of the edge detection step, have been presented in figg. 7-10.

It results that the algorithm can recognize with a good degree of approximation the contours of the single tombs.

An in-depth analysis shows that the elaborations on aerial planimetric photographs are very detailed and with precise contours on many of the visible traces. In some

zones instead, in particular where the vegetation color is rather uniform, the system fails to distinguish the single tombs and the contour includes large sepulchral areas. In other cases, instead, where the human eye recognizes the regular forms of the graves, the computer is not able to detect marks.

We obtained a better result on the oblique photographs. The algorithm correctly distinguishes and highlights the profiles of the individual chamber tombs, with little loss of information.

The difference in terms of results could depend on the different degree of detail of the images. The coverage rate of vegetation affected the ability to read the tracks. The time of photo coverage is also important: in addition to different years, the oblique photos were taken at the end of June, with vegetation in the initial state of growth, while the planimetric photos in the second half of July.

On the other hand, we are not able to assess how much the difference in angle of coverage has favored the recognition of forms, perhaps helped by shadows and microrelief.

About mapping, we find a substantial correspondence with what is indicated with the traditional method, with a greater realism of the outline obtained with ML. The slight differences are due to the need to geometrically correct the oblique image, which is not necessary for planimetric photographs. The intervention of man, however, is still necessary to integrate what is not detected by the algorithm.

As far as the processing time, the results are excellent. With a standard laptop of the last generation, only few tens of seconds were needed to process with ML each photograph shown in this work.

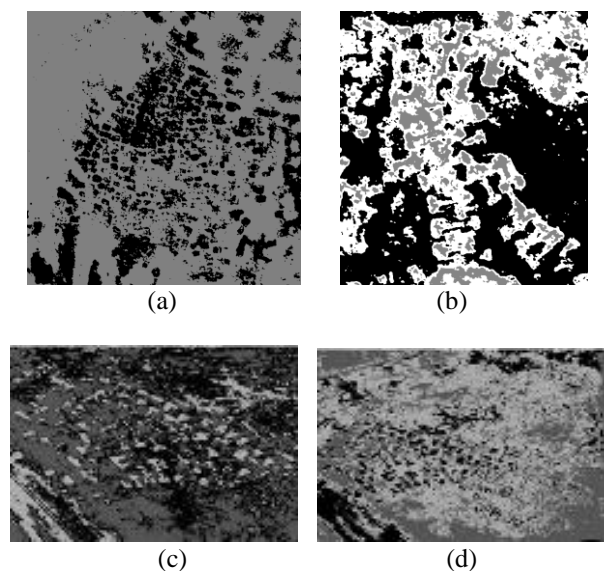


Fig. 6. Vulci. Poggio Mengarelli. a), b), c), d) False color images after color clustering with $k=3$ and RGB color coordinates.

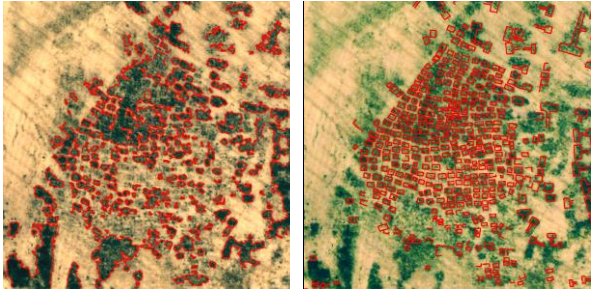


Fig. 7. Vulci. Poggio Mengarelli. Left) aerial original image with obtained contours overlaid; right) aerial original image with traditional method mapping of tombs.

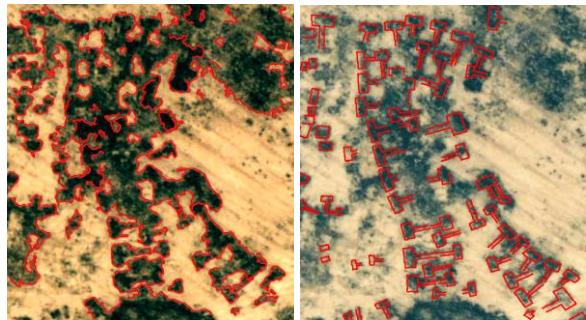


Fig. 8. Vulci. Poggio Mengarelli. Left) aerial original image with obtained contours overlaid; right) aerial original image with traditional method mapping.

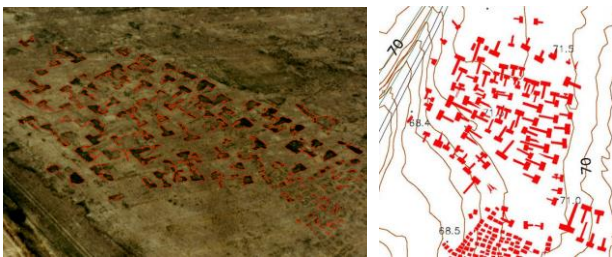


Fig. 9. Vulci. Poggio Mengarelli. Left) aerial original image with obtained contours overlaid; right) map with the traditional method of mapping of the marks.

IV. CONCLUSIONS

These preliminary experiments have demonstrated that ML developed in the framework of the ARCHEO 3.0 project for the identification of archaeological strata under excavation, with appropriate calibrations and corrections can also be applied to aerial photographs for the recognition of archaeological traces, with interesting development prospects.

Comparison with the traditional mapping method suggests that the ML system needs further improvements. Fig. 7 shows the mapping of 423 tombs with the traditional method, while the algorithm recognizes with a good degree of approximation the outline of 70 tombs

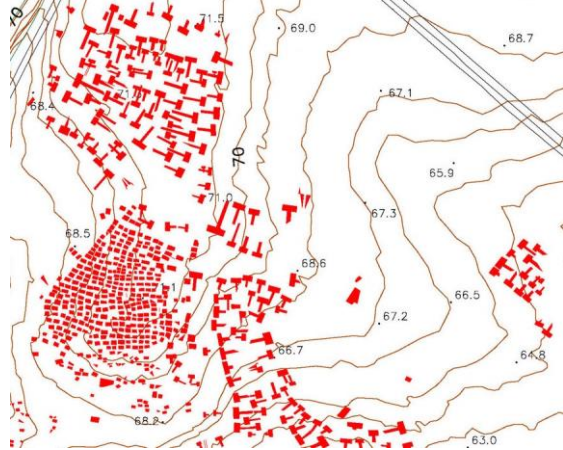


Fig. 10. Vulci. Poggio Mengarelli. Left) aerial original image with obtained contours overlaid; right) map with the traditional method of mapping of the marks.

(16.5%). The result obtained with fig. 8 is better: the algorithm defines 23 tombs while the human eye recognizes 71 shapes (32.4%). However, the limits of the areas where the vegetation is higher are defined very well. In these areas, the human eye can distinguish numerous tombs that the algorithm cannot define. However, it is also very important for the archaeologist to circumscribe the perimeter with the archaeological marks. As mentioned above, the best results have been obtained with the oblique photographs (figg. 9-10). The ML system recognizes 226 shapes while the traditional mapping detects 527 tombs (42.9%). The main reason for this result can be found in the different degree of growth of vegetation among the images used: lower in oblique photos, more luxuriant in the verticals. Instead, we cannot evaluate how much the angle of recovery has influenced the ability to recognize shapes through the microrelief shadows.

Failure to identify the traces recognizable by the human eye - one of the limits shown by the system - can be overcome by having the same image processed several times with different parameters, to create different levels of reading that, superimposed, can integrate any unwanted gaps.

Image definition is another element to be improved to achieve better results. The original photographs used in

this experiment are paper prints obtained with non-professional scanners at an average resolution (300 dpi). Increasing resolution with a suitable scanner could lead the ML algorithm to perform better. Other tests may be done: f.i. using images treated and corrected images with filters for the improvement of tone, contrast and colors, so as to increase the possibility of ML reading.

For the overall evaluation of the results obtained, the time taken to map the tracks is crucial. With the traditional method and the expensive technical equipment for cartographic restitution, certainly more precise and complete, it takes two days of work, while the ML system and a standard computer require only a few tens of seconds.

However, these initial tests can demonstrate it is foreseeable that ML algorithm, with the necessary calibrations, can greatly speed up the time of graphic restitution, helping the archaeologist to map, with an error of decimetric approximation, buried archaeological remains and to plan any excavation and protection of the archaeological heritage.

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