2018 IEEE INTERNATIONAL CONFERENCE ON

METROLOGY FOR ARCHAEOLOGY AND CULTURAL HERITAGE

METROARCHAEO 2018

CASSINO, ITALY - OCTOBER 22-24, 2018

PROCEEDINGS

MetroArchaeo CASSINO 2018

2018 EUROPEAN YEAR OF CULTURAL HERITAGE #EuropeForCulture

UNIVERSITÀ DEGLI STUDI DI CASSINO E DEL LAZIO MERIDIONALE SOL PER NOCTEM

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Welcome Message from the Chairpersons

On behalf of the Organizing Committee, we wish to welcome you to the *2018 IEEE International Conference on Metrology for Archaeology and Cultural Heritage - MetroArchaeo2018*.

The combined use of numerical approaches and metrology in archaeology and, more generally, in the study of cultural heritage, is a firmly established reality in contemporary research, which is undergoing rapid evolution both in the scale, type and scope of applications. Metrology includes both theoretical and practical aspects with reference to measurements, whatever their uncertainties are, and in whatever fields of science or technology they occur. The characterization, valorisation and preservation of cultural heritage are therefore deeply related to metrological issues, for the collection, interpretation and validation of data, through the use of different analytical tools, physical-chemical and mechanical techniques, digital technologies, new ICT tools.

The *2019 IEEE International Conference on Metrology for Archaeology and Cultural Heritage - MetroArchaeo2018* aims to gather a wide range of scholars and heritage scientists working in universities and research centres, museums, galleries, libraries, archives, small and medium enterprises. *MetroArchaeo2018* is conceived as an occasion to foster exchanges of ideas and information, to establish connections and collaborations, and to share innovative solutions in the field of measurements applied to cultural heritage, among material scientists, chemists, physicists, engineers, archaeologists, conservators, restorers.

Following the positive experience of the first four editions held in Benevento (2015-2016), Turin (2017) and Lecce (2017), this year's conference has been organized in Cassino, a town that houses the testimonies of a prestigious historical and cultural tradition, spanning from Roman antiquity to Middle Ages, up to modern times. Cassino's origins lie in a Volscan settlement later passed under the control of the Samintes, and then of the Romans, who established a fortified colony there at the end of the 4th century BC. Traces of the Roman era survive in the archaeological area located at the foot of Montecassino, showing the remains of the ancient Casinum: a Roman amphitheatre, a theatre, the mausoleum of the Roman matron Ummidia Quadratilla, the so-called «nymphaeum Ponari» (belonging to the University of Cassino). Immediately above the archaeological area stands the Abbey of Montecassino, which is one of the most renowned Benedictine monasteries in the world. It was founded by St. Benedict in 529 on the remnants of a pre-existing Roman fortification, and destroyed four times: by the Longobards around 577, by the Saracens in 883, by an earthquake in 1349 and the last time in 1944, when it was bombed by the Allies at the end of Word War II. The present-day Cathedral was reconstructed after its most recent destruction according to the 17^{th}-18^{th} century design. The Abbey also hosts a museum and a library with a valuable collection of precious manuscripts and historical books. Cassino is also a reference point for contemporary art: CAMUSAC (Cassino Museum of Contemporary Art), a new structure created in 2013, houses a permanent private collection gathered over a period of more than twenty-five years, and the University itself also holds a significant collection of works by important contemporary artists.

The activities aimed at the conservation, protection, enhancement and use of cultural heritage, through the development and application of innovative methods and technologies, have a consolidated academic, scientific and entrepreneurial tradition, recognized both at a national and international level, in the territory of southern Lazio. The University of Cassino stands out for its commitment in this sector, with a number of initiatives involving a wide range of skills, projects, collaborations in progress with other research institutions, and industries.

Cassino is therefore a perfect frame for a conference designed to encourage discussion and networking among scientists coming from all over the world, and to promote new interactions and collaborations among established scholars and new researchers working in different areas and interested in the use of measurements in the study of cultural heritage.

MetroArchaeo2018 hosts three plenary lectures and 25 oral, poster and demo sessions aiming to give a complete and multidisciplinary picture of the applications of measurements and data treatments to the characterization and safeguard of archaeological and historic heritage.

With the aim of providing a common ground for researchers to share their findings about metrology applied to archaeology and cultural heritage, *MetroArchaeo2018* includes a significant number of special sessions, intended to group the different applications of metrology to archaeology and cultural heritage into thematic strands, and to allow coherent and targeted discussions.

The program includes three keynote lectures, which will be delivered by John Bintliff, from Leiden University (The Netherlands) and the University of Edinburgh (UK), Rodney Ast, from the University of Heidelberg (Germany), and Anna Maria Mercuri, from the University of Modena and Reggio Emilia (Italy).

Awards will be assigned to a number of outstanding papers, posters and demos.

The social programme includes a Welcome party, to be held at the University Rectorate, and a social dinner at "La Cocincina" restaurant.

The organisation of the conference was a very complex task, due to the large interest in the wide range of topics listed in the call for papers. A generous and tireless scientific and organising committee was involved in drafting the technical program, arranging accommodation for the speakers, managing the administrative aspects, and setting up the social programme. *We are very grateful to all of them* for their outstanding work, as well as to the reviewers who have contributed to guarantee the quality of the scientific program. We also wish to thank the public and private organizations which have kindly accepted to support the meeting in different ways.

The *2018 IEEE International Conference on Metrology for Archaeology and Cultural Heritage* is about to begin. We hope you will enjoy the company of colleagues and experts as well as the natural and artistic beauties of Cassino! Please, let us have *your comments and remarks*: we all, metrologists, archaeologists, geologists, heritage scientists, colleagues and friends, know that criticism is the best way to improve quality, and to achieve lasting excellences.

On behalf of the Organizing Committee

Pasquale Daponte

Marilena Maniaci

MetroArchaeo 2018 Committee

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MetroArchaeo 2018 Keynote Speakers

Keynote Monday, October 22, 2018

Regional Surface Survey: From pictures via grab-samples to a quantified sub-discipline

John Bintliff
Leiden University, The Netherlands
University of Edimburgh, UK

ABSTRACT. Landscape Archaeology began in the imagination, grew from firsthand qualitative description, and matured into a continuously innovating field of ever - increasingly detailed measurement of ancient surface artefacts and their spatial context. This paper will illustrate this evolution of regional surface survey techniques and discuss current challenges to further progress in rigorous analysis of past human presence as recorded on the present landscape.

John Bintliff (London, England, 1949) is Emeritus Professor of Classical and Mediterranean Archaeology at Leiden University, the Netherlands, and Emeritus Professor at the University of Edinburgh, UK. He studied Archaeology and Anthropology at Cambridge University, where he also completed his PhD in 1977 on the (pre)history of human settlement in Greece. He was Senior Lecturer in Archaeology at Bradford University, where he taught from 1977, then moved to Durham University as Reader in Archaeology in 1990, where he taught till moving to Leiden in 1999. In 1988 he was elected a Fellow of the Society of Antiquaries. Since 1978 he has been co-directing (with Cambridge University) the Boeotia Project, an interdisciplinary programme investigating the evolution of settlement in Central Greece, widely-recognised as one of the most significant regional research programmes in the Mediterranean region. His interests include social theory and the application of neuroscience to the Humanities.

Keynote Tuesday, October 23, 2018

Advanced Technologies and the Written Heritage

Rodney Ast
University of Heidelberg, Germany

ABSTRACT. Technology has improved the way we decipher, organize, and retrieve elements of historical written records. High resolution images as well as methods in multi-spectral (MSI) and reflectance transformation imaging (RTI) have made it easier to study inscribed historical artifacts without actually taking them in hand. Large datasets of textual transcriptions can be subjected to pattern recognition via search engines far more efficiently than in the past, when scholars relied primarily on printed texts and indices for organizing and analyzing their historical sources. Although, over the last several decades, efforts have tended to focus largely on the storage and retrieval of these datasets, recent attention has shifted to methods of processing image data, in the interest of advancing, for example, the study of paleography. The result has been increased interest in the application of neural networks and machine learning for image recognition processes.

This talk surveys a variety of the technologies currently in use in ancient studies. It focuses, on a practical level, on their current limitations, while pointing, on the conceptual level, to the potential they have to transform scientific practice even further. How all these tools can make us better humanists should be at the heart of technological development, and this talk also serves as a reminder of ways in which they have and can continue doing this.

Rodney Ast has a PhD in Classics from the University of Toronto. He is Senior Research and Teaching Associate in the Institute for Papyrologyat the University of Heidelberg. His main areas of interest are Greek and Latin documentary and literary papyrology and palaeography; the cultural and social history of Graeco-Roman Egypt; Egyptian archaeology; digital papyrology. Besides authoring works on Greek and Latin papyrological and inscriptional texts, he is involved in digital initiatives (papyri.info, Digital Corpus of Literary Papyri, pappal.info) and takes part in excavations at Amheida (Dakhla Oasis) and Berenike (Eastern Desert).

Keynote Wednesday, October 24, 2018

Why, what and how can archaeobotany measure the past? Cultural landscapes of the Mediterranean and Saharan areas

Anna Maria Mercuri
University of Modena and Reggio Emilia, Italy

ABSTRACT: Today as in the past, plants are everywhere around us, they are different and have special needs to grow, are members of the ecosystems and have been included in our culture as natural resources since the beginning of human history on the world. For all these reasons plants are excellent bioindicators of environmental quality and human behaviour, and Archaeobotany is the science that has developed the ability to measure the related characters and processes based on plant records unearthed from archaeological sites.
The talk introduces principles, methods and objects of the archaeobotanical research, with special focus on pollen analysis. The Mediterranean case studies are reported to demonstrate that Archaeobotany is able to reconstruct cultural landscapes: They are the Bronze Age Terramara's culture, the Roman Peasants in southern Tuscany, the Roman to Medieval farmhouse of Piazza Armerina in Sicily. The Saharan case studies are described to show how the same data can give both palaeoenvironmental and ethnobotanical information on the transformations of this desert: They are the Sai Island in Sudan, the necropolis of Gobero in Niger, and the Wadi Teshuinat area in southern Libya. The talk concludes on the site of Takarkori from which an unexpected exploitation of wild cereals has opened a new perspective on the sustainable resources for the future.

Anna Maria Mercuri, biologist and palynologist, Associate Professor of Systematic Botany at the Università di Modena e Reggio Emilia, Italy; teacher of 'Applied Palynology and Botany', coordinator of the Italian Working Group of Palynology and Palaeobotany for the Italian Botanical Society (GPPSBI, since 2012); she designed the archaeobotanical network BRAIN (https://brainplants.unimore.it), published > 200 research papers, and organised three international conferences on palynology and archaeobotany in Modena. Her scientific interests include aerobiology, the relationship between plant landscapes and human activities, and the human impact and vegetation history in the Mediterranean Basin and the Sahara.

CONFERENCE PROGRAM

Monday, October 22

Special Session on Non-invasive systems and techniques for "on site" monitoring and diagnosis - PART I

Room: Aula Magna, Cassino University Campus
Chairs: *Emanuele Piuzzi, Sapienza, University of Rome, Italy*
Livio D'Alvia, Sapienza, University of Rome, Italy

1 **Effect of Applied Pressure on Patch Resonator - Based Measurements of Moisture Level for Cultaral Heritage Materials**
Livio D'Alvia, 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
Zaccaria Del Prete, Sapienza, University of Rome, Italy

6 **Multidisciplinary approach for the study of the Ptolemaic coffin of Ankhhapy from the egyptian collection of MANN in Naples**
Alessia Volino, Università degli Studi Suor Orsola Benincasa, Italy
Maria Rosaria Barone Lumaga, Università degli Studi di Napoli Federico II, Italy
Paola Cennamo, Università degli Studi Suor Orsola Benincasa, Italy
Giancarlo Fatigati, Università degli Studi Suor Orsola Benincasa, Italy
Giorgio Trojsi, Università degli Studi Suor Orsola Benincasa, Italy

12 **Acoustic Characterization of Outcropping Stratigraphic Units**
Andrea Azelio Mencaglia, Institute of Applied Physics "Nello Carrara", Italy
Ilaria Cacciari, Institute of Applied Physics "Nello Carrara", Italy
Giorgio Franco Pocobelli, Cooperativa Archeologia, Italy
Salvatore Siano, Institute of Applied Physics "Nello Carrara", Italy

17 **Non-destructive Diagnostics of Architectonic Elements in San Giuseppe Calasanzio's Church in Cagliari: a Test-case for Micro-geophysical Methods within the Framework of Holisti/integrated Protocols for Artefact Knowledge.**
Luca Piroddi, University of Cagliari, Italy
Giulio Vignoli, University of Cagliari, Italy
Antonio Trogu, University of Cagliari, Italy
Gian Piero Deidda, University of Cagliari, Italy

22 **Use of Ground Penetrating Radar for Assessing Interconnections between Root Systems of Different Matured Tree Species**
Livia Lantini, University of West London, UK
Rich Holleworth, University of West London, UK
Daniel Egyir, University of West London, UK
Iraklis Giannakis, University of West London, UK
Fabio Tosti, University of West London, UK
Amir M. Alani, University of West London, UK

Special Session on Artificial intelligence for measurements in cultural heritage - PART I

Room: B 2.07 Hall, Cassino University Campus
Chairs: *Francesco Colace, University of Salerno, Italy*
Mario Molinara, University of Cassino and Southern Lazio, Italy

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General Session PART I

Room: 1.09 Hall, Cassino University Campus
Chairs: *Maria Grazia D'Urso, University of Cassino and Southern Lazio, Italy*
Marco Laracca, University of Cassino and Southern Lazio, Italy

Tuesday, October 23

Special Session on Metrological approaches to the study of ancient and medieval written Heritage - PART I

Room: Aula Magna, Cassino University Campus

Chairs: *Gianluca Del Mastro, Università degli Studi di Napoli Federico II, Italy*

84 **The secrets of Herculaneum papyri revealed by synchrotron based techniques: writing and ink composition**

Silvia Romano, Institute for Microelectronics and Microsystems, Italy
Ana Sofia Leal, Institute for Microelectronics and Microsystems, Italy
Emmanuel Brun, ESRF, France
Daniel Delattre, CNRS-IRHT, France
Vito Mocella, Institute for Microelectronics and Microsystems, Italy

87 **Document analysis at AGH University of Science and Technology**

Tomasz Łojewski, AGH University of Science and Technology, Poland

92 **Scripta volant: measuring the purple spots biodeterioration of historical parchments by an interdisciplinary approach**

Nicoletta Perini, University of Rome Tor Vergata, Italy
Maria Cristina Thaller, University of Rome Tor Vergata, Italy
Alessandro Rubechini, Archivio Segreto Vaticano, Città del Vaticano
Fulvio Mercuri, University of Rome Tor Vergata, Italy
Silvia Orlanducci, University of Rome Tor Vergata, Italy
Luciana Migliore, University of Rome Tor Vergata, Italy

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

Room: B 2.07 Hall, Cassino University Campus

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

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Roberta Spallone, Politecnico di Torino, Italy
Marco Vitali, Politecnico di Torino, Italy

102 **Spatial Data Analysis in Archaeology: A comparison of two available methods for site location**

Rafał Bieńkowski, Polish Academy of Science, Poland
Marta Lorenzon, The University of Helsinki, Finland
Agnieszka Kaliszewska, Polish Academy of Science, Poland
Krzysztof Leśniewski, Polish Academy of Science, Poland

106 **Assessment of workflows for creating 3D semantic libraries: a study on medieval bell towers in the central region of Sicily**

Cettina Santagati, University of Catania, Italy
Raissa Garozzo, University of Catania, Italy
Melissa Lengies, Carleton University, Ottawa
Graziana D'Agostino, University of Catania, Italy
Mariateresa Galizia, University of Catania, Italy

112 **Geochemical and petrographic analysis on the stones and integrated digital survey of the Cathedral of Sant'Antioco di Bisarcio (Ozieri, Italy)**

Stefano Columbu, Università di Cagliari, Italy
Marco Lezzerini, Università di Pisa, Italy
Giorgio Verdiani, Università di Firenze, italy

Special Session on Artificial intelligence for measurements in cultural heritage - PART II

Room: 1.09 Hall, Cassino University Campus

Chairs: *Francesco Fontanella, University of Cassino and Southern Lazio, Italy*
Mario Molinara, University of Cassino and Southern Lazio, Italy

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Fabio Clarizia, University of Salerno, Italy
Francesco Colace, University of Salerno, Italy
Massimo De Santo, University of Salerno, Italy
Marco Lombardi, University of Salerno, Italy
Francesco Pascale, University of Salerno, Italy
Domenico Santaniello, University of Salerno, Italy

122 **Ancient Coin Classification Using Graph Transduction Games**
Sinem Aslan, ECLT - CCHT, Ca' Foscari University of Venice, Italy, Ege University, Turkey
Sebastiano Vascon, ECLT - CCHT, Ca' Foscari University of Venice, Italy
Marcello Pelillo, ECLT - CCHT - DAIS, Ca' Foscari University of Venice, Italy

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Andrea Felicetti, (DII) Università Politecnica delle Marche, Italy
Alessandra Albiero, CNR, Italy
Roberto Gabrielli, CNR, Italy
Roberto Pierdicca, (DICEA) Università Politecnica delle Marche, Italy
Marina Paolanti, (DII) Università Politecnica delle Marche, Italy
Primo Zingaretti, (DII) Università Politecnica delle Marche, Italy
Eva Savina Malinverni, (DICEA) Università Politecnica delle Marche, Italy

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Marco Lombardi, University of Salerno, Italy
Francesco Pascale, University of Salerno, Italy
Domenico Santaniello, University of Salerno, Italy

Special Session on Using multivariate analyses to interpret lithic variability: contributions and limitations

Room: Aula Magna, Cassino University Campus
Chairs: *Alice Leplongeon, Muséum national d'Histoire naturelle, France*
Elena A.A. Garcea, University of Cassino and Southern Latium, Italy

136 **Objectifying processes: The Multivariate analyses of the Acheulean Tools in the Western Europe**
Paula García-Medrano, British Museum, UK
Elías Maldonado-Garrido, British Museum, UK
Nick Ashton, British Museum, UK
Andreu Ollé, (IPHES), Spain

140 **Raw material exploitation and lithic variability at the MSA site of Gotera, Southern Ethiopia: technological and quantitative approaches combined**
Elena Carletti, "La Sapienza" University of Rome, Italy
Marianna Fusco, "La Sapienza" University of Rome, Italy
Andrea Zerboni, "La Sapienza" University of Rome, Italy
Marina Gallinaro, "A. Desio" Università degli Studi di Milano, Italy
Enza Elena Spinapolice, "La Sapienza" University of Rome, Italy

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Special Session on Cultural Heritage: Measurement of Immeasurable Values - PART I

Room: B 2.07 Hall, Cassino University Campus
Chairs: *Magdalena Żmudzińska-Nowak, Silesian University of Technology, Poland*

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Magdalena Żmudzińska-Nowak, Faculty of Architecture Silesian University of Technology, Poland

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Krzysztof Herner, The Coal Mining Museum in Zabrze, Poland

157 **Enforced oblivion. The heritage site and it's intangible heritage tangled with the political narrative and social memory of the nations**
Beata Piecha-van Schagen, Coal Mining Museum, Poland

Special Session on Pondera Online: An international network for ancient and byzantine metrology

Room: B 2.07 Hall, Cassino University Campus
Chairs: *Charles Doyen, FNRS / UCLouvain, Belgium*
Maria Letizia Caldelli, Sapienza - Università di Roma, Italy

Special Session on Full Coverage Geophysical Prospection on Protohistoric and Roman Central Settlements in Italy

Room: 1.09 Hall, Cassino University Campus
Chairs: *Frank Vermeulen, Ghent University, Belgium*

Special Session on Geomatic Techniques for Integrated 3D Data Acquisition, Metric Validation and Management - PART II

Room: Aula Magna, Cassino University Campus
Chairs: *Gabriele Bitelli, Alma Mater Studiorum, University of Bologna, Italy*
Maria Grazia D'Urso, University of Cassino and Southern Lazio, Italy

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Special Session on Cultural Heritage: Measurement of Immeasurable Values - PART II

Room: B 2.07 Hall, Cassino University Campus
Chairs: *Magdalena Żmudzińska-Nowak, Silesian University of Technology, Poland*

Special Session on Non-invasive systems and techniques for "on site" monitoring and diagnosis - PART II

Room: 1.09 Hall, Cassino University Campus
Chairs: *Emanuele Piuzzi, Sapienza, University of Rome, Italy*
Livio D'Alvia, Sapienza, University of Rome, Italy

308 **Photogrammetric survey to support Non Destructive Tests at St. Alexander Catacombs in Rome**
Marialuisa Mongelli, Department of Energy technologies ICT DIVISION ENEA, Italy
Irene Bellagamba, Department of Energy technologies ICT DIVISION ENEA, Italy
Antonio Perozziello, Department of Energy technologies ICT DIVISION ENEA, Italy
Samuele Pierattini, Department of Energy technologies ICT DIVISION ENEA, Italy
Silvio Migliori, Department of Energy technologies ICT DIVISION ENEA, Italy
Andrea Quintiliani, Department of Energy technologies ICT DIVISION ENEA, Italy
Giovanni Bracco, Department of Energy technologies ICT DIVISION ENEA, Italy
Angelo Tatì, Department of Energy technologies USER DIVISION ENEA, Italy
Paola Calicchia, Institute of Marine Engineering CNR-INM, Italy

314 **Frequency Domain Analysis of the Minerva Medica Temple by means of the Motion Magnification Methodology**
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Ivan Roselli, ENEA, Italy
Gerardo De Canio, ENEA, Italy

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Eduardo Caliano, Istemi s.a.s, Italy
Carmine Napoli, Istemi s.a.s, Italy
Nicolino Messuti, Istemi s.a.s, Italy
Rosangela Faieta, Istemi s.a.s, Italy

325 **Structural Health Monitoring System for Masonry Historical Construction**
Francesco Lamonaca, University of Sannio, Italy
Renato S. Olivito, University of Calabria, Italy
Saverio Porzio, University of Calabria, Italy
Domenico Luca Carnì, University of Calabria, Italy
Carmelo Scuro, University of Calabria, Italy

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Ricardo Tadeu Lopes, PEN/COPPE/UFRJ, Brazil
Soraia Rodrigues Azeredo, PEN/COPPE/UFRJ, Brazil
Roberto Cesareo, University di Sassari, Italy
Regulo F. Jordan, Museo Señora de Cao and Fundacion Wiese, Peru
Arabel Fernandez, Museo Señora de Cao and Fundacion Wiese, Peru
Angel Bustamante, Universidad Nacional Mayor de San Marcos, Peru

Wednesday, October 24

General Session - PART II

Room: Aula Magna, Cassino University Campus
Chairs: *Marilena Maniaci, University of Cassino and Southern Lazio, Italy*
Eugenio Polito, University of Cassino and Southern Lazio, Italy

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Elisabetta Di Francia, Politecnico di Torino, Italy
Andrea Bussetto, Politecnico di Torino, Italy
Tilde De Caro, CNR, Italy
Marco Parvis, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy
Sabrina Grassini, Politecnico di Torino, Italy

340 **Looking for the full scan: S. Zenone chapel**
Marco Carpiceci, Sapienza University Rome, Italy
Andrea Angelini, Institute for the Technologies Applied to Cultural Heritage National Research Council of Italy, Italy

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Special Session on Metrological approaches to the study of ancient and medieval written Heritage - PART II

Room: 1.09 Hall, Cassino University Campus
Chairs: *Lucio Del Corso, University of Cassino and Southern Lazio, Italy*

POSTER SESSION

Room: B 2.11 Hall, Cassino University Campus
Chairs: *Marco Laracca, University of Cassino and Southern Lazio, Italy*
Cristina Corsi, University of Cassino and Southern Lazio, Italy

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Special Session on Non-Destructive Analytical Approaches applied to the Study of Ancient Stone Materials

Room: Aula Magna, Cassino University Campus
Chairs: *Giulio Lucarini, University of Cambridge, UK*
Andrea Manzo, University of Naples L'Orientale, Italy

Special Session on Archaeopalynology for the reconstruction of environmental and cultural landscapes

Room: B 2.07 Hall, Cassino University Campus
Chairs: *Assunta Florenzano, University of Modena and Reggio Emilia, Italy*
Sebastián Pérez-Díaz, Spanish National Research Council, CSIC, Spain

489 **Archeobotanical investigations in the ancient city of Gonfienti, Italy (Bronze Age, Iron Age)**
Francesco Ciani, University of Florence, Italy
Davide Attolini, University of Florence, Italy
Cristina Bellini, University of Florence, Italy
Miria Mori Secci, University of Florence, Italy
Tiziana Gonnelli, University of Florence, Italy
Pasquino Pallecchi, Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Firenze e le province di Pistoia e Prato, Italy
Marta Mariotti Lippi, University of Florence, Italy

494 **Woodland-use in Tyrrhenian southern Tuscany during the Middle Ages (mid-7th-13th century AD)**
Mauro Paolo Buonincontri, University of Siena, Italy
Pierluigi Pieruccini, University of Turin, Italy
Carmine Lubritto, University of Campania "Luigi Vanvitelli", Italy
Marta Rossi, University of Siena, Italy
Davide Susini, University of Siena, Italy
Paola Ricci, University of Campania "Luigi Vanvitelli", Italy
Giovanna Bianchi, University of Siena, Italy
Gaetano Di Pasquale, University of Naples "Federico II", Italy

500 **Palynological approach to reconstruct cultural landscape evolution: case studies from South Italy**
Assunta Florenzano, Università di Modena e Reggio Emilia, Italy

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General Session - PART III

Room: 1.09 Hall, Cassino University Campus
Chairs: *Assunta Pelliccio, University of Cassino and Southern Lazio, Italy*
Lucio Del Corso, University of Cassino and Southern Lazio, Italy

505 **On the Suppression of Mixed Gaussian and Impulsive Noise in Color Images**
Damian Kusnik, Silesian University of Technology Insitute of Informatics, Poland
Bogdan Smolka, Silesian University of Technology Institute of Automatic Control, Poland

511 **The Environmental Monitoring Campaign of the Museum of the Faculty of Archaeology of the Sohag University (Egypt)**
Ahmed Elsayed, Politecnico di Torino, Italy
Luca Lombardo, Politecnico di Torino, Italy
Marco Parvis, Politecnico di Torino, Italy
Emma Angelini, Politecnico di Torino, Italy
Sabrina Grassini, Politecnico di Torino, Italy

517 **Measuring and leveling roman aqueducts to estimate their flows**
Claudio Alimonti, Sapienza University Rome, Italy
Valerio Baiocchi, Sapienza University Rome, Italy
Giorgia Bonanotte, Sapienza University Rome, Italy
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Comparison and deformation analysis of five 3D models of the Paleolithic wooden point from the Ljubljanica River

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***Abstract*—The article describes the comparison and analysis of five 3D models of the hunting tool from the Ljubljanica River found near Sinja Gorica. The 40,000 years old Palaeolithic point, discovered by underwater archaeologists during a preventive archeological survey, was made out of yew wood. Five 3D models of the point were taken over the period of ten years, two before and three after the conservation process. The comparison of the 3D models serves two purposes. The primary goal is to evaluate the changes of the artifact that occurred during this period and, specifically, to compare its shape before and after the treatment. Conservation of waterlogged wood is still a delicate and somewhat uncertain process in regards to the long term survivability of such artifacts. The second goal is to asses which software tools are currently available for such comparison, what are technical problems that need to be addressed, and how to effectively present or visualize the sometimes small but critical changes of shape.**

***Index Terms*—3D models, 3D model analysis, CloudCompare, deformation monitoring, deformation analysis, palaeolithic wooden point, Ljubljanica River**

I. Introduction

In 2008 underwater archaeologists discovered a pointed object made of Yew wood (*Taxus sp.*) in the Ljubljanica river near Sinja Gorica in Slovenia. Its shape is reminiscent of Palaeolithic leaf-shaped stone and bone points. Two wood samples were dated using the AMS ^{14}C method. Te first gave an age estimate of >43,970 years (Beta-252943), while a repeat measurement gave 38,490±330 BP (OxA-19866). At the same time, dendrological examinations were conducted and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) was performed to determine which chemical elements were on the point. After analyzing the wooden point from different points of view it became clear that the point was carved by Homo Neanderthalensis or Homo Sapiens [1].

This wooden point is so far just one of only eight known wooden paleolithic artifacts found in Europe: Clacton-on-Sea, GB 1911 (424-374ka date secondary [2]; Lehringen, Germany 1948 (115-125ka by stratigraphy) [3]; Abric Romani, Spain 1992 (45-49ka secondary) [4]; Schöningen, Germany 1995 (337-300ka secondary) [5]; Mannheim, Germany 2004 (∼18ka BP AMS) [6]; Sinja Gorica, Slovenia 2008 (∼40ka BP AMS) [1]; Poggetti Vecchi, Italy 2012 (∼171ka secondary by UDM) [7]; Aranbaltza [8], Spain 2014 (∼90ka secondary by OSL) [9].

After this lucky find and after the artifact's true importance was finally determined, it's preservation was necessary. It is well known that the conservation of waterlogged wooden artifacts is very challenging. The conservation process of waterlogged wood can induce substantial changes to the shape and size of the artifacts [10]. However, it was decided to conserve the paleolithic wooden point using conventional methods by treat the artifact with melamine and was sent to the Römisch-Germanischen Zentralmuseum in Mainz where the preservation procedure was performed.

Protection of the world's archaeological cultural heritage

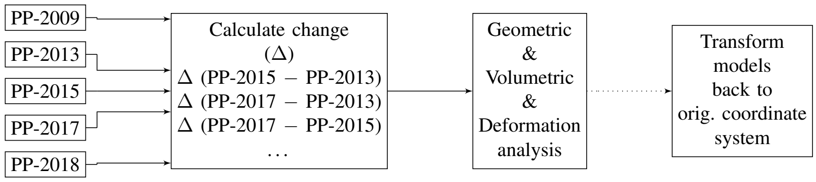


Fig. 1. Flowchart of the key steps used in model deformation analysis of 3D models

(CH) has become a special responsibility of scientific and state institutions in the 21.st Century. Artifacts made from organic materials (e.g. wood, leather, textiles etc.) are especially prone to degradation and are therefore rare archeological finds. CH artifacts are constantly exposed to natural and human-made influences that can compromise their cultural value. Archaeologists and other CH professionals are faced with the problem of protecting and analyzing these artifacts as well as preserving them for future generations. In order to do so, they need reliable data on their state of preservation.

Based on our extensive experience in underwater archaeology and with waterlogged wood [11] we knew that such artifacts, when they are excluded from its natural environment and deposits, can even under expertly performed conservation processes undergo unwanted changes (i.e. bending and other shape deformations, changes of cross-section, size, volume, color, texture etc.). Having at our disposal 3D models of the studied artifact we could quantify these changes. Our hypothesis was, therefore, that we will be able to measure and control the changes that the 40,000 years old paleolithic wooden point has undergone since its discovery and exclusion from its natural environment and deposits in the Ljubljanica River and to highlight in this way the danger of unwanted changes in artifacts of terrestrial and underwater CH after being extracted from their original environment and after the conservation processes.

Since the essential element in this study are the 3D models of the artifact [12], this article serves also as an illustration and case study of how computer technology, computer tools and methodologies are used in the interdisciplinary context of CH [13].

II. Data, tools and methods

Five 3D models of the paleolithic wooden point are available to us. The first 3D model was made in 2009 (PP-2009), a year after the artifact's discovery. The point was scanned again in 2013 (PP-2013) before undergoing a conservation treatment by melamine. Until the conservation process was started, the wooden point was stored in distilled water in a cool and dark environment. After the conservation process the artifact is stored in requested museum climate conditions and was scanned again in 2015 (PP-2015), 2017 (PP-2017), and finally using a Micro-CT scanner in 2018 (PP-2018). The 3D models PP-2013 (scanner ATOS III), PP-2015 (scanner ATOS III) and PP-2017 (scanner ATOS TRIPPLE SCAN) were stored in *.ply* format by the Kompetenzbereich Wissenschafliche IT des Romisch-Germanischen Zentralmuseums in collaboration with i3mainz, the Institut for Raumbezogenen Informations- und Messtechnik der Hochschule Mainz, University of Applied Science (Germany) (PP-2015 and PP-2017). The models PP-2009 (ZScanner 800) by Intri d.o.o. (Slovenia) and PP-2018 (Micro XCT 400) by the Slovenian National Building and Civil Engineering Institute Ljubljana, were stored in *.stl* format.

Our particular goal is to compare and analyze vertices and polygons of five 3D models in *.ply* and *.stl* formats to compute the differences in dimensions, volumes and cross-sections of the models (Fig. 1). The comparative analysis of the data and parameters of all 3D models was performed with CloudCompare version 2.9.1. (see: *http://www.danielgm.net/cc/*), an open source graphical computer program (Fig. 2).

CloudCompare (CC) can process 3D point clouds and triangular meshes. It was originally designed to perform comparisons between two dense 3D point clouds (such as the ones acquired with a laser scanner) or between a point cloud and a triangular mesh. It relies on a specific octree data structure dedicated to this task. Later, it was extended to a more generic point cloud (C2M and M3C2) processing software, including many advanced algorithms (i.e. registration, resampling, color/normal/scalar fields handling, statistics computation, sensor management, interactive or automatic segmentation, display enhancement, etc.), (see: *https://en.wikipedia.org/wiki/CloudCompare*). To date, this software tool has been used primarily in mechanical engineering, in the automobile industry, geology, medicine and by design and construction companies, especially for quality control of products or materials and in determining differences and errors between 3D models. While the attention of 3D model research in archeology has been focused so far on visualization and reconstruction, systematic comparisons of different 3D models, for deformation analysis and deformation monitoring of artifacts, have not been very common so far.

The five 3D models of the point were imported into CC and subjected to geometric comparisons and volumetric measurements. Many different algorithms can be used to compare 3D models including the popular ICP [14]. CC provides a set of basic tools for manually editing and rendering of 3D point clouds and triangular meshes. It also offers various advanced processing algorithms [15]. A dynamic color rendering system helps the user to visualize the per-point scalar fields in an efficient way. The *.ply* and *.stl* formats are the most appropriate for further comparison and processing of 3D cloud points in CC since they can be compared without any compromises and differences. However, we prefer the *.ply* format since a larger

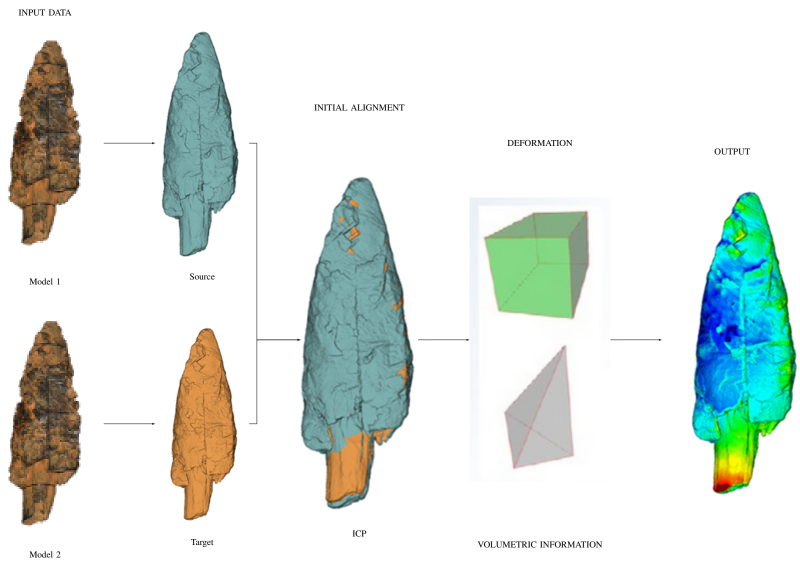


Fig. 2. The process of comparing 3D models (CloudCompare). Source: volumetric tetrahedral mesh. Target: volumetric shape defined by voxels. ICP: Iterative Closest Point Algorithm

set of comparisons is available in CC. Since the model PP-2018 was initially stored in two separate 3D clouds—due to the limited size of the work space of the scanner—we had to combine and integrate both files into a single one.

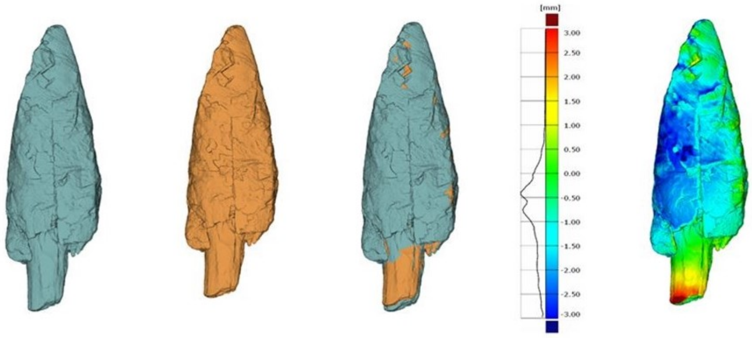
We first performed the registration of input data. The basis for determining the transformation parameters of the photogrammetric 3D model was the 3D point cloud consisting of scanned points. This was followed by the calculation of the distance between the cloud points and the planes of the 3D model (Fig. 1). Measurements expressed in μm, μm^2 and μm^3 of models of the point using CC and statistical comparisons of data were performed. The comparisons were made between models PP-2009 and PP-2013 (before preservation), between PP-2013 and PP-2015 (end of preservation), between PP-2013 and PP-2017, between PP-2015 and PP-2018, between PP-2017 and PP-2018 and between PP-2009 and PP-2018.

III. Results

The most striking comparison is between models PP-2013 and PP-2015, this is just before and after the conservation process of the wooden point was finished (Fig. 3 and Table I). The pronounced change of the point occurred during the treatment. A larger deviation in dimensions in the PP-2013 model is due to the above-mentioned circumstances (irrigation, swelling, adding consolidation, etc.). All volumetric measurements indicate that the selected preservation method has a strong (decisive) effect on the tip deformation process. Two years after the conservation was concluded (2017), the process of deviation due to the conservation process has stabilized and apparently subsided. Changes in dimensions in the PP-2015, PP-2017 and PP-2018 models show a certain moderation, not stabilization. This may also be due to the final stage of preservation (intensive heat and then controlled natural drying) and the use of selected consolidating agents (eg. melamine resin). CT scanning of the artifact (PP-2018) warned that the internal structure of the point was severely degraded and that certain parts were not evenly preserved. We can conclude that the uncontrolled operation of internal peak forces with a different degree of dynamics and response in the longitudinal, radial and tangential direction of archaeological wood is still underway. Two years after the end of preservation, the point is thinner by 1.14% (0.2 mm), shorter by 0.62% (0.9 mm) and narrower by 0.5% (0.3 mm). Archaeologists were confronted with similar problems also with the Clacton Spear Point (England) and the Neanderthal wooden tools from Aranbaltza (Spain) [8].

The deformation monitoring of the point was carried out with the C2M (cloud-mesh) algorithm. The results of the comparison of all five models (Table I) show that during the entire ten year monitoring period the artifacts length was reduced by 3.3% (5.171 mm), width by 3.31% (1.655 mm) and thickness by 11.3% (2.890 mm), while the volume of the point decreased by 9.60% or 6.781 mm^3. Due to intensive irrigation (preparation for canning) of the point, the second model (PP-2013) indicates swelling of the wood and the dimension of the point increased (length + 3.44%, width + 1.41% and thickness 12.53%). Since the end of the conservation in 2015, the process of deformation and change of dimension has slowed down and the artifact is now mostly stable. Still, shrinkage of the point continued and between 2015 and 2018 the length of the point decreased by 1.49%, the width by 4.42% and the thickness by 4.89%. There was also some bending and deformation, both at the base and at the tip of the point. Since wood is a natural organic material, some oscillations in dimensions are normal and expected. This is a sign that the consolidant does not fix the wood into an unnatural shape, but instead lets it "breathe".

Although the first signs of deformation of the point were



PP-2013			PP-2015			Δ (PP-2015 − PP-2013) / PP-2013
Length:	160,958	μm	Length:	152,709	μm	-5.12%
Width:	52,274	μm	Width:	50,594	μm	-3.21%
Thickness:	28,810	μm	Depth:	23,956	μm	-17.20%
Volume:	80,404	μm^3	Volume:	66,383	μm^3	-17.44%

Fig. 3. Comparison between models PP-2013 and PP-2015. On top from left to right: PP-2013, PP-2015 and difference between the two models.

TABLE I
VOLUMETRIC COMPARISON OF THREE 3D MODELS OF THE PALEOLITHIC WOODEN POINT FROM THE LJUBLJANICA RIVER

	PP-R2008	PP-2009	PP-2013	PP-2015	PP-2017	PP-2018
	0	1	2	3	4	5
	μm	μm	μm	μm	μm	μm
Length	160000	155606	160958	152709	151768	150435
Width	51000 48000	50014	52274	50594	50348	48359
Thickness	25000 24000	25579	28810	23856	23585	22689
	+-μm / %	+-μm / %	+-μm / %	+-μm / %	+-μm / %	+-μm / %
Length+-% (l)		α	+5352 +3,44%	-897 -1,86%	-3838 -2,47%	-5171 -3,3%
			α	-8249 -5,12%	-9190 -5,74%	-10523 -6,54%
				α	-941 -0,62%	-2274 -1,49%
					α	-1333 -0,88%
Width+-% (b)		α	+2260 +1,41%	+580 +1,2%	+334 +0,68%	-1655 -3,31%
			α	-1680 -3,21%	-1926 -3,68%	-3915 -7,49%
				α	-246 -0,49%	-2235 -4,42%
					α	-1989 -3,95%
Thickness+-%		α	+3230 +12,63%	-1724 -6,74%	-1995 -7,8%	-2890 -11,3%
			α	-4954 -17,2%	-5225 -18,34%	-6121 -21,3%
				α	-217 -1,14%	-1167 -4,89%
					α	-896 -3,80%
	μm^3	μm^3	μm^3	μm^3	μm^3	μm^3
Volume		70653,6	80404,1	66382,8	65238,9	63871,9
	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %	+-μm^3 / %
Volume +-%		α	+9751 +13,80%	-4271 -6,05%	-5414 -7,66%	-6781 -9,60%
			α	-14022 -17,44%	-15166 -18,86%	-16532 -20,56%
				α	-1145 -1,72%	-2511 -3,78%
					α	-1367 -2,1%

partially indicated in the PP-2015 model, the deformation process of the point at the tip and at the base can be clearly identified in the PP-2018 model. The measurements show that two shape deformation processes (Fig. 4) are taking place: bending and shrinkage of the point. The bending of the point is more prominent, indicated by the shift of the cross section contours at the tip and at the base (Fig. 5).

The C2M algorithm found in the PP-2018 model some bending at the tip of the point, which was not observed until then. 3D CT scans additionally highlighted the possibility that the deviation at the tip of the point is the result of two opposing internal processes in the upper and middle part of the artifact. The first is shrinkage, the second is bending. These two processes were intensified as indicated by PP-2018. Color comparison of the middle part of the point (Fig. 4) additionally indicates that the wood is unevenly shrinking which causes bending of the upper part of the point. In addition, the coloring of PP-2018 manifests that the base of the point is bending out of the point's central axis.

IV. DISCUSSION

Comparison of five 3D models confirms our initial hypothesis that the paleolithic point underwent changes after its discovery and exclusion from its natural environment in the deposits of the Ljubljanica River. After ten years, the length, width and thickness of the point, as well as its volume, were reduced. The largest changes occurred during the process of conservation. These dimensional changes may well be within the expected changes during the prevailing methods of conservation of waterlogged wood. But since the dimensional changes were not completely uniform, this resulted also in changes of shape. We believe that periodic monitoring of the paleolithic point is necessary since advancing changes of shape may lead to breakage of the artifact, as unfortunately exemplified by the Clacton wooden paleolithic point [2].

The changes that we identified using the CloudCompare software tool highlight the need for careful, thoughtful, responsible and planned conservation and protection of CH objects. Especially for those rare high CH valuable artifacts which due to the special features of their composition (such as organic materials) are more exposed to the risk of deformation.

We presented the changes between the 3D models using tables with numerical data (Tab. I), color coded 2D images from several orthogonal viewpoints (Fig. 4), and with 2D

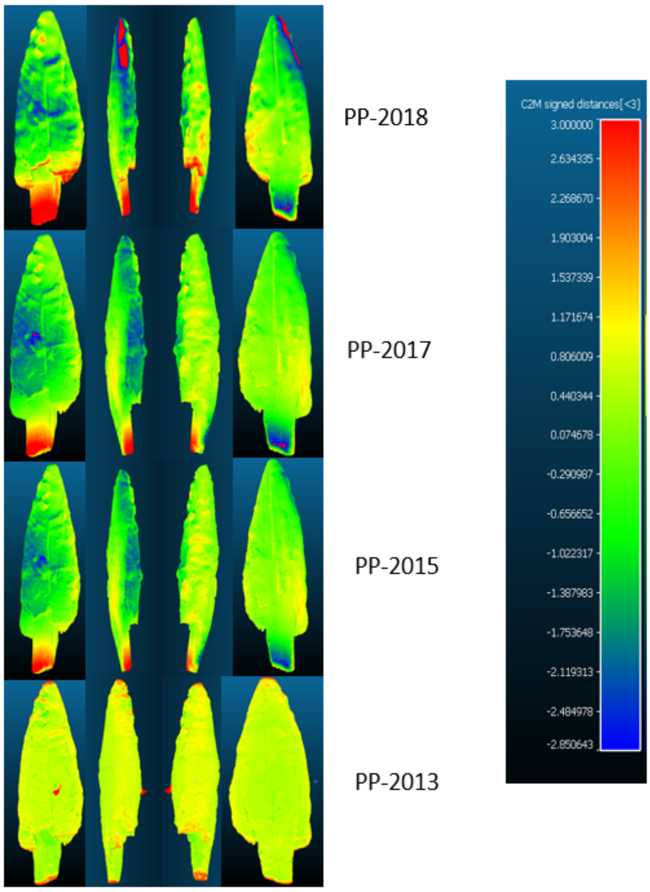


Fig. 4. The deformation process of the Paleolithic point after 2009. The colors show by how much the given models (PP-2013, PP-2015, PP-2017, PP-2018) differ from PP-2009 in millimeters, as indicated by the color chart. Colors at the base of the point of the top three models indicate extension on one side and compression on the opposite side, reflecting that the base part is bending off the center axis.

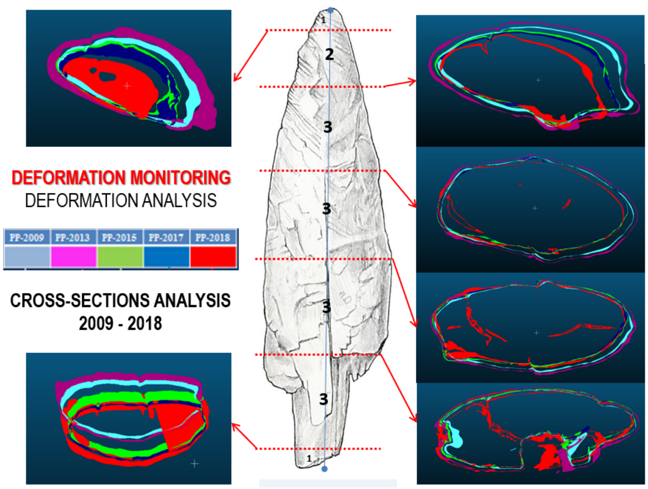


Fig. 5. Changes of the point at five different cross-sections (2009-2018). The cross sections are not shown at the same scale to better see the details.

cross-sections (Fig. 5), which often requires tedious close observation and comparison. Innate property of the human visual system, however, is to detect differences through motion. Having at our disposal 3D models of the artifact from different time periods, one could present the changes as variations on a common shape, using blend animation to show the change smoothly into another by interpolation.

This case study illustrated the need for a closer interdisciplinary cooperation between archeology and computer science on a technological and methodological level. An important shift in the relationship between archeology and computer science as well as their co-responsibility for CH at the national and international level are two documents, namely The London Charter (2009) (see: *http://www.londoncharter.org/*) for the computer-based visualization of CH and the Seville Principles of Virtual Archeology (2011) (see: *http://smartheritage.com/seville-principles/seville-principles*). Among the eight fundamental principles of the Seville document, the principle of **interdisciplinarity** is laid down, which requires modern archeology to include the use of new technologies related to computer visualization of the remains of archaeological heritage in all archaeological research.

A. Recommendations

Open-source 3D graphical software tools (e.g. CloudCompare, Meshlab, Blender, etc. [9]) and technologies for recording of 3D data (e.g. structured light scanners, multi-image photogrammetry) have brought in recent decades radical changes to the field of archeology. Archaeologists now have a greater degree of authority in evaluating, reconstructing, reading, describing and documenting artifacts. 3D models, replicas and virtual models of artifacts allow us to study, compare and analyze them while keeping the original intact.

The software (CC – CloudCompare) and the applied algorithms confirmed their suitability and usefulness in analytical shape monitoring. They also confirmed to be an appropriate basis for further archaeological analyses and interpretations of 3D models of CH artifacts. Expectations for greater precision of artifact measurements and also for reconstruction and preparation of models for later visualization were also fulfilled. Open source tools, such as CC, can provide archaeologists with the necessary reliable data for further analysis and interpretation at a low cost. It also provides them with more reliable and accurate information (up to μm) by measuring x, y, and z points of artifacts. CC could be an important standard for future archaeological treatment of artifacts and analysis of degradation.

The collected findings and lessons highlighted by the comparison of 3D models of the Paleolithic wooden point from the Ljubljanica River indicate that a careful and responsible approach is required by archaeologists as well as by computer scientists which should be reflected also by forming guidelines that should be set by national state institutions. Only in this way credible preservation and presentation of artifacts, such as the 40,000 year old wooden point, one of only eight known wooden paleolithic artifacts found in Europe, can be preserved for the future. Efficient use of 3D graphic software tools [16] presents both the archaeological and computer science professions with a number of new challenges. Our research has highlighted the following challenges [13]:

- inclusion of 3D scanning, modeling and measurement techniques already during initial archaeological field research,
- standardization of 3D models in *.ply* or *.bin* formats,
- establishment of national and transnational digital collections of 3D artifact models (digital glyptothek),
- using CloudCompare etc. and similar open source software in analytical and preventive archaeology,
- permanent monitoring of dimensional changes and deformation processes of artifacts using 3D models,
- definition of standard procedures for 3D deformations analysis in the treatment and protection of worldwide archaeological CH.

Our case study fully confirmed the appropriateness of the computer and information technologies and tools in modern archeology. In accordance with the London Charter and the Seville Principles, it would be appropriate to include the suggested approach for the analytical treatment of 3D models with open-source computer graphic tools in national guidelines that define and regulate methods, procedures and techniques for finding archaeological remains and the use of technical means in it.

Based on the presented case study, we found that CC is an appropriate tool for:

- accurately determining the dimensions of artifact, its volume and the texture characteristics;
- volumetric measurements and their basic statistical treatment;
- graphic processing and comparison of a point cloud or a triangulation network of 3D model artifact points;
- comparing two or more 3D models to perform deformation monitoring in archeology.

CC can provide for different types of 3D data (LiDAR, TLS and GIS) means of processing and analysis that can not be achieved reliably with analogue tools. But CC is inadequate for all 3D data formats. The most suitable formats are PLY and BIN. Since CC is on top of it an open source program we recommend its use in archeology.

For periodical monitoring of 3D shape of a particular artifact we advise the persistent use of the same device. For deformation (volumetric) analysis, 3D recorders ATOS III and ATOS TRIPPLE SCAN are advisable. For small artifacts (up to 15 cm) Mini XCT 400 are ideal for deformation and degradation analysis. It is advisable that for each artifact a specially made clamp or cradle is constructed so that the artifact can be consistently locked in the same position during 3D scanning.

B. Conclusions

It is obvious that in the future the protection of underwater cultural heritage will be impossible to imagine without digitized collections of 3D models, the visualization of artifacts, virtual museums, new analytic methods, deformation analysis, deformation monitoring etc. In that way, artifacts will be safely stored but will live globally.

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REFERENCES

[1] Andrej Gaspari, Miran Erič, and Boštjan Odar. A Paleolithic Wooden Point from Ljubljansko barje (Slovenia). In Jonathan Benjamin, Clive Bonsall, Catriona Pickard, and Anders Fischer, editors, *Submerged Prehistory*, pages 186–192. Oxbow Books, Oxford UK, 2011.

[2] Lu Allington-Jones. The Clacton spear: The last one hundred years. *Archaeological Journal*, 172(2):273–296, 2015.

[3] Hartmut Thieme. Lower Palaeolithic hunting spears from Germany. *Nature*, 385(6619):807, 1997.

[4] Eudald Carbonell and Zaida Castro-Curel. Palaeolithic wooden artefacts from the Abric Romani (Capellades, Barcelona, Spain). *Journal of Archaeological Science*, 19(6):707–719, 1992.

[5] Werner H Schoch, Gerlinde Bigga, Utz Böhner, Pascale Richter, and Thomas Terberger. New insights on the wooden weapons from the Paleolithic site of Schöningen. *Journal of human evolution*, 89:214–225, 2015.

[6] Gaelle Rosendahl, Karl-Wilhelm Beinhauer, Manfred Loescher, Kurt Kreipl, Rudolf Walter, and Wilfried Rosendahl. The oldest bow in the world? An interesting piece from Mannheim, Germany. *Anthropologie*, 110(3):371–382, 2006.

[7] Biancamaria Aranguren, Anna Revedin, Nicola Amico, Fabio Cavulli, Gianna Giachi, Stefano Grimaldi, Nicola Macchioni, and Fabio Santaniello. Wooden tools and fire technology in the early Neanderthal site of Poggetti Vecchi (Italy). *Proceedings of the National Academy of Sciences*, page 201716068, 2018.

[8] Joseba Rios-Garaizar, Oriol López-Bultó, Eneko Iriarte, Carlos Pérez-Garrido, Raquel Piqué, Arantza Aranburu, Mara José Iriarte-Chiapusso, Illuminada Ortega-Cordellat, Laurence Bourguignon, Diego Garate, and Iñaki Libano. A Middle Palaeolithic wooden digging stick from Aranbaltza III, Spain. *PLOS ONE*, 13(3):1–15, 03 2018.

[9] Insight3D. Open-Source Image Based 3D Modeling Software. Online: http://insight3d.sourceforge.net/. [Accessed 24-April-2018].

[10] Miran Erič, David Stopar, Franc Solina, and Katja Kavkler. Reconceptualization of the contemporary maritime museum. do we really need the original waterlogged wooden artefacts and objects? *Skyllis*, 2018. Submitted.

[11] Andrej Gaspari and Miran Erič, editors. *Potopljena preteklost–Arheologija vodnih okolij in raziskovanje podvodne kulturne dediščine v Sloveniji, Zbornik ob 128-letnici Dežmanovih raziskav Ljubljanice na Vrhniki (1884-2012)*. Didacta, Radovljica, 2012.

[12] S F El-Hakim, J A Beraldin, M Picard, and G Godin. Detailed 3D reconstruction of large-scale heritage sites with integrated techniques. *IEEE Computer Graphics and Applications*, 24(3):21–29, May 2004.

[13] J A Benavides López, G Aranda Jiménez, M Sánchez Romero, E Alarcón García, S Fernández Martín, A Lozano Medina, and J A Esquivel Guerrero. 3D modelling in archaeology: The application of Structure from Motion methods to the study of the megalithic necropolis of Panoria (Granada, Spain). *Journal of Archaeological Science: Reports*, 10:495–506, 2016.

[14] Paul J. Besl and Neil D. McKay. A method for registration of 3-D shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 14(2):239–256, Feb 1992.

[15] Chung-Hung Hsieh and Jiann-Der Lee. Markerless augmented reality via stereo video see-through head-mounted display device. *Mathematical Problems in Engineering*, 2015:1–13, 2015. Article ID 329415.

[16] Miran Erič, Rok Kovačič, Gregor Berginc, Mitja Pugelj, Žiga Stopinšek, and Franc Solina. The impact of the latest 3D technologies on the documentation of underwater heritage sites. In *Proceedings of the 2013 Digital Heritage International Congress, Marseille, France*, pages 281–288. IEEE, 2013.

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