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2.4. An ASV (Autonomous Surface Vehicle) for Archaeology: The Pladypos at Caesarea Maritima, Israel

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MOBILIZING *the* PAST *for a* DIGITAL FUTURE

The Potential of
Digital Archaeology



Edited by
Erin Walcek Averett
Jody Michael Gordon
Derek B. Counts

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FOR A
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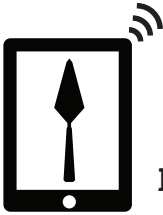
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Preface & Acknowledgments

This volume stems from the workshop, “Mobilizing the Past for a Digital Future: the Future of Digital Archaeology,” funded by a National Endowment for the Humanities Digital Humanities Start-Up grant (#HD-51851-14), which took place 27-28 February 2015 at Wentworth Institute of Technology in Boston (<http://uwm.edu/mobilizing-the-past/>). The workshop, organized by this volume’s editors, was largely spurred by our own attempts with developing a digital archaeological workflow using mobile tablet computers on the Athienou Archaeological Project (<http://aap.toumazou.org>; Gordon *et al.*, Ch. 1.4) and our concern for what the future of a mobile and digital archaeology might be. Our initial experiments were exciting, challenging, and rewarding; yet, we were also frustrated by the lack of intra-disciplinary discourse between projects utilizing digital approaches to facilitate archaeological data recording and processing.

Based on our experiences, we decided to initiate a dialogue that could inform our own work and be of use to other projects struggling with similar challenges. Hence, the “Mobilizing the Past” workshop concept was born and a range of digital archaeologists, working in private and academic settings in both Old World and New World archaeology, were invited to participate. In addition, a livestream of the workshop allowed the active participation on Twitter from over 21 countries, including 31 US states (@MobileArc15, #MobileArc).¹

¹ For commentary produced by the social media followers for this event, see: <https://twitter.com/electricarchaeo/status/571866193667047424>, <http://shawngraham.github.io/exercise/mobilearcday1wordcloud.html>, <https://twitter.com/electricarchaeo/status/571867092091338752>, <http://www.diachronicdesign.com/blog/2015/02/28/15-mobilizing-the-past-for-the-digital-future-conference-day-1-roundup/>.

Although the workshop was initially aimed at processes of archaeological data recording in the field, it soon became clear that these practices were entangled with larger digital archaeological systems and even socio-economic and ethical concerns. Thus, the final workshop's discursive purview expanded beyond the use of mobile devices in the field to embrace a range of issues currently affecting digital archaeology, which we define as the use of computerized, and especially internet-compatible and portable, tools and systems aimed at facilitating the documentation and interpretation of material culture as well as its publication and dissemination. In total, the workshop included 21 presentations organized into five sessions (see program, <http://mobilizingthepast.mukurtu.net/digital-heritage/mobilizing-past-conference-program>), including a keynote lecture by John Wallrodt on the state of the field, "Why paperless?: Digital Technology and Archaeology," and a plenary lecture by Bernard Frischer, "The Ara Pacis and Montecitorio Obelisk of Augustus: A Simpirical Investigation," which explored how digital data can be transformed into virtual archaeological landscapes.

The session themes were specifically devised to explore how archaeological data was digitally collected, processed, and analyzed as it moved from the trench to the lab to the digital repository. The first session, "App/Database Development and Use for Mobile Computing in Archaeology," included papers primarily focused on software for field recording and spatial visualization. The second session, "Mobile Computing in the Field," assembled a range of presenters whose projects had actively utilized mobile computing devices (such as Apple iPads) for archaeological data recording and was concerned with shedding light on their utility within a range of fieldwork situations. The third session, "Systems for Archaeological Data Management," offered presentations on several types of archaeological workflows that marshal born-digital data from the field to publication, including fully bespoke paperless systems, do-it-yourself ("DIY") paperless systems, and hybrid digital-paper systems. The fourth and final session, "Pedagogy, Data Curation, and Reflection," mainly dealt with teaching digital methodologies and the use of digital repositories and linked open data to enhance field research. This session's final paper, William Caraher's "Toward a Slow Archaeology," however, noted digital archaeology's successes in terms of

time and money saved and the collection of more data, but also called for a more measured consideration of the significant changes that these technologies are having on how archaeologists engage with and interpret archaeological materials.

The workshop's overarching goal was to bring together leading practitioners of digital archaeology in order to discuss the use, creation, and implementation of mobile and digital, or so-called "paperless," archaeological data recording systems. Originally, we hoped to come up with a range of best practices for mobile computing in the field – a manual of sorts – that could be used by newer projects interested in experimenting with digital methods, or even by established projects hoping to revise their digital workflows in order to increase their efficiency or, alternatively, reflect on their utility and ethical implications. Yet, what the workshop ultimately proved is that there are many ways to "do" digital archaeology, and that archaeology as a discipline is engaged in a process of discovering what digital archaeology should (and, perhaps, should not) be as we progress towards a future where all archaeologists, whether they like it or not, must engage with what Steven Ellis has called the "digital filter."

So, (un)fortunately, this volume is not a "how-to" manual. In the end, there seems to be no uniform way to "mobilize the past." Instead, this volume reprises the workshop's presentations—now revised and enriched based on the meeting's debates as well as the editorial and peer review processes—in order to provide archaeologists with an extremely rich, diverse, and reflexive overview of the process of defining what digital archaeology is and what it can and should perhaps be. It also provides two erudite response papers that together form a didactic manifesto aimed at outlining a possible future for digital archaeology that is critical, diverse, data-rich, efficient, open, and most importantly, ethical. If this volume, which we offer both expeditiously and freely, helps make this ethos a reality, we foresee a bright future for mobilizing the past.

* * *

No multifaceted academic endeavor like *Mobilizing the Past* can be realized without the support of a range of institutions and individ-

uals who believe in the organizers' plans and goals. Thus, we would like to thank the following institutions and individuals for their logistical, financial, and academic support in making both the workshop and this volume a reality. First and foremost, we extend our gratitude toward The National Endowment for the Humanities (NEH) for providing us with a Digital Humanities Start-Up Grant (#HD-51851-14), and especially to Jennifer Serventi and Perry Collins for their invaluable assistance through the application process and beyond. Without the financial support from this grant the workshop and this publication would not have been possible. We would also like to thank Susan Alcock (Special Counsel for Institutional Outreach and Engagement, University of Michigan) for supporting our grant application and workshop.

The workshop was graciously hosted by Wentworth Institute of Technology (Boston, MA). For help with hosting we would like to thank in particular Zorica Pantić (President), Russell Pinizzotto (Provost), Charlene Roy (Director of Business Services), Patrick Hafford (Dean, College of Arts and Sciences), Ronald Bernier (Chair, Humanities and Social Sciences), Charles Wiseman (Chair, Computer Science and Networking), Tristan Cary (Manager of User Services, Media Services), and Claudio Santiago (Utility Coordinator, Physical Plant).

Invaluable financial and logistical support was also generously provided by the Department of Fine and Performing Arts and Sponsored Programs Administration at Creighton University (Omaha, NE). In particular, we are grateful to Fred Hanna (Chair, Fine and Performing Arts) and J. Buresh (Program Manager, Fine and Performing Arts), and to Beth Herr (Director, Sponsored Programs Administration) and Barbara Bittner (Senior Communications Management, Sponsored Programs Administration) for assistance managing the NEH grant and more. Additional support was provided by The University of Wisconsin-Milwaukee; in particular, David Clark (Associate Dean, College of Letters and Science), and Kate Negri (Academic Department Assistant, Department of Art History). Further support was provided by Davidson College and, most importantly, we express our gratitude to Michael K. Toumazou (Director, Athienou Archaeological Project) for believing in and supporting our

research and for allowing us to integrate mobile devices and digital workflows in the field.

The workshop itself benefitted from the help of Kathryn Grossman (Massachusetts Institute of Technology) and Tate Paulette (Brown University) for on-site registration and much more. Special thanks goes to Daniel Coslett (University of Washington) for graphic design work for both the workshop materials and this volume. We would also like to thank Scott Moore (Indiana University of Pennsylvania) for managing our workshop social media presence and his support throughout this project from workshop to publication.

This publication was a pleasure to edit, thanks in no small part to Bill Caraher (Director and Publisher, The Digital Press at the University of North Dakota), who provided us with an outstanding collaborative publishing experience. We would also like to thank Jennifer Sacher (Managing Editor, INSTAP Academic Press) for her conscientious copyediting and Brandon Olson for his careful reading of the final proofs. Moreover, we sincerely appreciate the efforts of this volume's anonymous reviewers, who provided detailed, thought-provoking, and timely feedback on the papers; their insights greatly improved this publication. We are also grateful to Michael Ashley and his team at the Center for Digital Archaeology for their help setting up the accompanying Mobilizing the Past Mukurtu site and Kristin M. Woodward of the University of Wisconsin-Milwaukee Libraries for assistance with publishing and archiving this project through UWM Digital Commons. In addition, we are grateful to the volume's two respondents, Morag Kersel (DePaul University) and Adam Rabinowitz (University of Texas at Austin), who generated erudite responses to the chapters in the volume. Last but not least, we owe our gratitude to all of the presenters who attended the workshop in Boston, our audience from the Boston area, and our colleagues on Twitter (and most notably, Shawn Graham of Carlton University for his word clouds) who keenly "tuned in" via the workshop's livestream. Finally, we extend our warmest thanks to the contributors of this volume for their excellent and timely chapters. This volume, of course, would not have been possible without such excellent papers.

As this list of collaborators demonstrates, the discipline of archaeology and its digital future remains a vital area of interest for people who value the past's ability to inform the present, and who

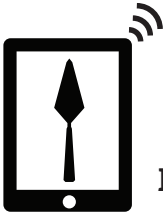
recognize our ethical responsibility to consider technology's role in contemporary society. For our part, we hope that the experiences and issues presented in this volume help to shape new intra-disciplinary and critical ways of mobilizing the past so that human knowledge can continue to develop ethically at the intersection of archaeology and technology.

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Derek B. Counts (Department of Art History, University of Wisconsin-Milwaukee)

October 1, 2016



How To Use This Book

The Digital Press at the University of North Dakota is a collaborative press and *Mobilizing the Past for a Digital Future* is an open, collaborative project. The synergistic nature of this project manifests itself in the two links that appear in a box at the end of every chapter.

The first link directs the reader to a site dedicated to the book, which is powered and hosted by the Center for Digital Archaeology's (CoDA) Mukurtu.net. The Mukurtu application was designed to help indigenous communities share and manage their cultural heritage, but we have adapted it to share the digital heritage produced at the "Mobilizing the Past" workshop and during the course of making this book. Michael Ashley, the Director of Technology at CoDA, participated in the "Mobilizing the Past" workshop and facilitated our collaboration. The Mukurtu.net site (<https://mobilizingthepast.mukurtu.net>) has space dedicated to every chapter that includes a PDF of the chapter, a video of the paper presented at the workshop, and any supplemental material supplied by the authors. The QR code in the box directs readers to the same space and is designed to streamline the digital integration of the paper book.

The second link in the box provides open access to the individual chapter archived within University of Wisconsin-Milwaukee's installation of Digital Commons, where the entire volume can also be downloaded. Kristin M. Woodward (UWM Libraries) facilitated the creation of these pages and ensured that the book and individual chapters included proper metadata.

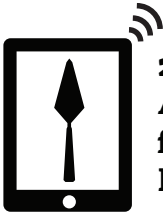
Our hope is that these collaborations, in addition to the open license under which this book is published, expose the book to a wider audience and provide a platform that ensures the continued availability of the digital complements and supplements to the text. Partnerships with CoDA and the University of Wisconsin-Milwaukee reflect the collaborative spirit of The Digital Press, this project, and digital archaeology in general.

Abbreviations

AAI	Alexandria Archive Institute
AAP	Athienou Archaeological Project
ABS	acrylonitrile butadiene styrene (plastic)
ADS	Archaeological Data Service
Alt-Acs	Alternative Academics
API	application programming interface
ARA	archaeological resource assessment
ARC	Australian Research Council
ARIS	adaptive resolution imaging sonar
ASV	autonomous surface vehicle
BLM	Bureau of Land Management
BLOB	Binary Large Object
BOR	Bureau of Reclamation
BYOD	bring your own device
CAD	computer-aided design
CDL	California Digital Library
CHDK	Canon Hack Development Kit
cm	centimeter/s
CMOS	complementary metal-oxide semiconductor
CoDA	Center for Digital Archaeology
COLLADA	COLLABorative Design Activity
CRM	cultural resource management
CSS	Cascading Style Sheet
CSV	comma separated values
DBMS	desktop database management system
DEM	digital elevation model
DINAA	Digital Index of North American Archaeology
DIY	do-it-yourself
DoD	Department of Defense
DVL	doppler velocity log
EAV	entity-attribute-value
EDM	electronic distance measurement
EU	excavation unit/s
FAIMS	Federated Archaeological Information Management System
fMRI	functional magnetic resonance imaging
GIS	geographical information system
GCP	ground control point
GNSS	global navigation satellite system
GPR	ground-penetrating radar

GUI	graphic user interface
ha	hectare/s
hr	hour/s
Hz	Hertz
HDSM	high-density survey and measurement
ICE	Image Composite Editor (Microsoft)
iOS	iPhone operating system
INS	inertial motion sensor
IPinCH	Intellectual Property in Cultural Heritage
IT	information technology
KAP	Kaymakçı Archaeological Project
KARS	Keos Archaeological Regional Survey
km	kilometer/s
LABUST	Laboratory for Underwater Systems and Technologies (University of Zagreb)
LAN	local area network
LIEF	Linkage Infrastructure Equipment and Facilities
LOD	linked open data
LTE	Long-Term Evolution
m	meter/s
masl	meters above sea level
MEMSAP	Malawi Earlier-Middle Stone Age Project
MOA	memoranda of agreement
MOOC	Massive Online Open Course
NGWSP	Navajo-Gallup Water Supply Project
NeCTAR	National eResearch Collaboration Tools and Resources
NEH	National Endowment for the Humanities
NHPA	National Historic Preservation Act
NPS	National Park Service
NRHP	National Register of Historic Places
NSF	National Science Foundation
OCR	optical character reader
OS	operating system
PA	programmatic agreement
PAP	pole aerial photography
PARP:PS	Pompeii Archaeological Research Project: Porta Stabia
PATA	Proyecto Arqueológico Tuti Antiguo
PBMP	Pompeii Bibliography and Mapping Project
PDA	personal digital assistant

PIARA	Proyecto de Investigación Arqueológico Regional Ancash
PKAP	Pyla-Koutsopetra Archaeological Project
Pladypos	PLAtform for DYnamic POSitioning
PLoS	Public Library of Science
PQP	Pompeii Quadriporticus Project
PZAC	Proyecto Arqueológico Zaña Colonial
QA	quality assurance
QC	quality control
QR	quick response
REVEAL	Reconstruction and Exploratory Visualization: Engineering meets ArchaeoLogy
ROS	robot operating system
ROV	remotely operated vehicle
RRN	Reciprocal Research Network
RSS	Rich Site Summary
RTK	real-time kinetic global navigation satellite system
SfM	structure from motion
SHPO	State Historic Preservation Office
SKAP	Say Kah Archaeological Project
SLAM	simultaneous localization and mapping
SMU	square meter unit/s
SU	stratigraphic unit/s
SVP	Sangro Valley Project
TCP	traditional cultural properties
tDAR	the Digital Archaeological Record
UAV	unmanned aerial vehicle
UNASAM	National University of Ancash, Santiago Antúnez de Mayolo
UQ	University of Queensland
USACE	U.S. Army Corp of Engineers
USBL	ultra-short baseline
USFS	U.S. Forest Service
USV	unmanned surface vehicle
UTM	universal transverse mercator
XML	Extensible Markup Language



2.4. An ASV (Autonomous Surface Vehicle) for Archaeology: The Pladypos at Caesarea Maritima, Israel

*Bridget Buxton, Jacob Sharvit, Dror Planer, Nikola Mišković,
and John Hale*

This chapter seeks to inform the archaeological community about a robotic autonomous surface vehicle (ASV) currently being developed for shallow-water applications in marine sciences and archaeology (Mišković *et al.* 2011, Mišković *et al.* 2013; Vasilijević *et al.* 2015). The ASV Pladypos (a PLATform for DYnamic POSitioning; FIG. 1) was developed at the University of Zagreb Faculty of Electrical Engineering and Computing, in the Laboratory for Underwater Systems and Technologies (LABUST). Its main characteristic, from which it obtained its name, is dynamic positioning at sea. The Pladypos uses GPS to keep a steady position at a requested location or along transects while actively compensating for external disturbances such as wind, waves, and currents (FIG. 2). The Pladypos can deploy with a variety of cameras and sensors to survey submerged ancient harbors and coastal settlements, or any underwater landscape where current digital recording strategies do not scale well beyond the size of individual shipwreck sites.

The Pladypos was originally developed to answer research needs identified by underwater archaeologists and other marine scientists, and collaboration between the engineers and archaeologists on real field missions was planned from the outset as a means to increase interdisciplinary understanding and identify areas for improvement. Here we present some preliminary results and describe the experience of an interdisciplinary team using the Pladypos to create a georeferenced bathymetric map and integrated photomosaic of the submerged ruins at Caesarea Maritima in Israel (FIG. 3).

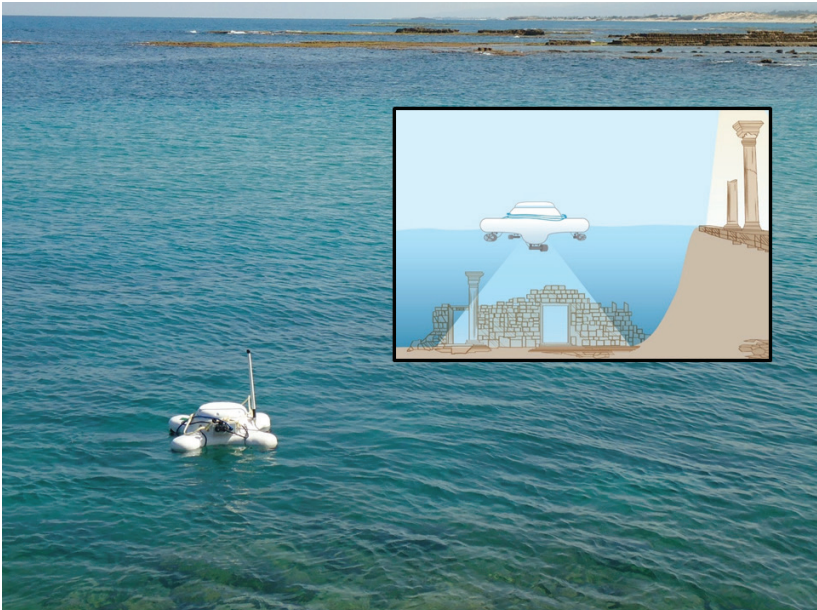


Figure 1: The Pladypos ASV at Caesarea Maritima, Israel, in 2014.



Figure 2: The Pladypos following a preprogrammed survey pattern in the intermediate Herodian harbor at Caesarea in 2014; the vehicle's ability to stay on course is not significantly affected by the 0.5 m swell.

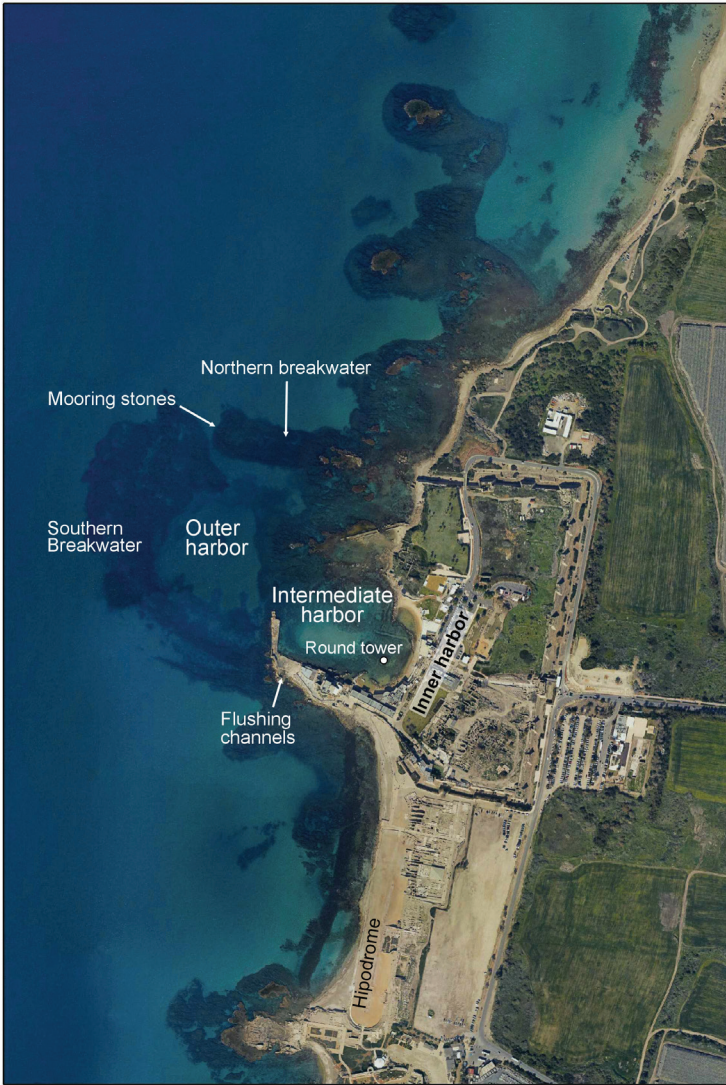


Figure 3: Aerial view of Caesarea Maritima.
Image courtesy of the Israel Antiquities Authority.

In 2014, a three-day expedition focused on the task of mapping the submerged breakwaters and interior of King Herod's ancient harbor of Sebastos in Caesarea Maritima (henceforth, we refer to the entire underwater site as "Caesarea"). In 2015, the Pladypos spent two full days in the ancient harbor recording the area of a new shipwreck discovery. It will return in 2016 to complete its task of mapping approximately 3 km² of Caesarea's underwater archaeological area. The Pladypos can potentially map 10 km² at maximum resolution in an eight-hour work day, and larger areas can be done in the same time span at lower resolution. The three-year duration of our project reflects the fact that our research goals and funding are primarily for technical development and experimental field trials rather than to answer any specific archaeological research questions. The field trials tested the Pladypos' capabilities in a variety of scenarios and sea conditions for shallow-water mapping, and an unexpected opportunity to utilize the robot on an Israel Antiquities Authority (IAA) shipwreck excavation at Caesarea in 2015 further demonstrated the robot's versatility.

The Pladypos began the first experimental merged acoustic and photographic imaging of Caesarea's sunken port structures in May 2014. One archaeological goal of this ongoing mission is to create the first fully georeferenced underwater site map of King Herod's famous harbor with a level of accuracy and detail normally only seen in underwater archaeology in the excavations of single ancient shipwrecks. Achieving centimeter levels of accuracy in recording the architectural features of large Mediterranean terrestrial sites has been the standard for more than a century, so this was the goal we set for the Pladypos in mapping Herod's harbor.

Our longer-term expectation is that by collaborating on real research missions, the archaeologists and engineers will be able to improve the Pladypos' utility for underwater archaeology, with a view to developing the system into an affordable, commercially viable off-the-shelf technology. Based on the Pladypos' performance to date, we eagerly anticipate a not-too-distant future in which highly portable and versatile autonomous robotic vehicles like the Pladypos are fully integrated into the underwater archaeologist's toolkit, and the recording of large and complex underwater inshore sites does not fall short of the established standards in terrestrial archaeology.

DIGITAL ARCHAEOLOGY UNDERWATER

Digital site-recording strategies in underwater archaeology have developed along a different trajectory from parallel advances in terrestrial archaeology. An appreciation of the Pladypos' strengths and limitations requires that we begin with an overview of the current state of underwater site mapping, and understand some of the unique challenges of vehicle localization and accurate site recording in marine environments.

While underwater excavation techniques using dredges and airlifts have changed little in the last 50 years, at least on sites lying within the range of scuba divers, advances in digital photogrammetry for site recording and acoustic sensors for landscape survey have revolutionized the discipline. Many underwater archaeologists in the field today began excavating at a time when digital photo-modeling was not yet considered trustworthy enough to forego slate and tape measure. Early computer-aided design (CAD) programs came into widespread use in the late 20th century, generating digital reconstructions as an alternative to 2D site maps, but not initially removing the need for tape measures and manual triangulation. Today, massive quantities of spatial data can now be stored and visualized in digital formats, making the printed page increasingly obsolete as a medium for storing and disseminating excavation and survey results. Arguably, only a lingering resistance to digital publication continues to prevent the full potential of the new media from being realized.

Photogrammetry, photo-modeling, simultaneous localization and mapping (SLAM), structured light imaging, multibeam and various other acoustic sensing technologies have all been utilized on Mediterranean underwater sites in the last decade (Brandon *et al.* 2004; Brandon 2008; Demesticha 2011; Buxton 2012; Skarlatos *et al.* 2012; Drap *et al.* 2013; Scaradozzi *et al.* 2013). It is increasingly common, though not universal, to find underwater archaeologists well versed in the use of CAD and GIS (geographic information systems), and who are able to conduct their own underwater surveys with off-the-shelf oceanographic sensors and imaging software. The digital revolution has had a dramatic impact on underwater recording strategies, enabling archaeologists to think far more ambitiously about seafloor survey. What Mediterranean underwater archaeology currently lacks is any kind of single, widely adopted digital recording standard and

toolkit for high-resolution imaging of large sites—that is, those larger than a typical ancient shipwreck, but smaller than a landscape survey area where sidescan sonar alone might provide adequate coverage. For shallow sites on the scale of harbors and submerged settlements, there are as yet no standard tools and conventions equivalent to the total stations and FileMaker databases now in widespread use in terrestrial classical archaeology.

There are many reasons for the divergence between terrestrial and underwater archaeological site recording technologies and strategies. Because of the unique exigencies of the underwater environment, underwater archaeology is the only major academic specialization within archaeology that is defined by an environmental variable rather than a cultural division or category of evidence. This rift is exacerbated by the technological divide between the oceanographic sciences and their terrestrial counterparts, extending even into different protocols for basic data collection. For example, on an oceanographic expedition, the most important organizational baseline for incoming data is often units of time, whereas recording in archaeology is organized by spatial units (though time is increasingly seen as a relevant variable for archaeological recording when site formation processes are considered; Demesticha 2011).

The incompatibility of standard scientific recording technologies and conventions on land and sea is not problematic for most scientists, whose research questions typically exist only in one sphere or the other. For archaeologists, on the other hand, the research questions do not necessarily change whether we are investigating the terrestrial or submerged sections of an ancient settlement, but the resources needed to answer those questions differ in each case. The archaeological investigation of large, shallow coastal sites presents unique challenges that require customized solutions adapted from oceanographic technology.

Unlike on land sites where the tradition of Wheeler squares and the locus system have created linear frameworks for organizing spatial data, the basic measure of detail, if not accuracy, in digital underwater site mapping is the point cloud. A point cloud is the number of data points recorded within a given three-dimensional space defined by x , y , and z coordinates, which represents the external surface of an area being recorded. Underwater, a point cloud is typically created using acoustic sensors, which may simultaneously be collecting data to aid a



Figure 4: Caesarea shore operations base in 2014 (top) and 2015 (bottom).



Figure 5: The Pladypos surveying the intermediate Herodian harbor in 2015.



Figure 6: Launching the Pladypos from Sdot Yam beach, south of Caesarea, in 2014.

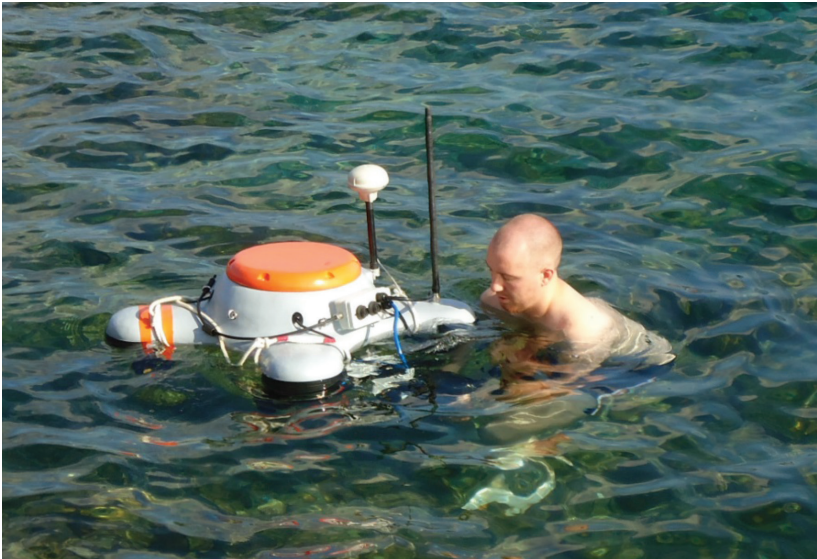


Figure 7: LABUST engineer Nikola Stilinović with the Pladypos in the intermediate harbor, Caesarea (2015).

robotic vehicle's localization. Although the term 3D is often used casually to describe the product of this type of recording, when the point cloud is produced solely from bathymetric data (the relative depth of each point), it is more accurate; as a result, it is gradually becoming conventional to describe the resulting digital models as 2.5D.

The technology required to integrate point clouds and photo-mosaics to produce archaeologically useful diagrams and publication-quality georeferenced 2.5D maps of underwater sites is exclusive to underwater environments. Because archaeologists typically lack the training or resources to own and operate oceanographic remote-sensing technology or to process the data themselves, producing state-of-the-art underwater site maps can be a costly undertaking. Oceanographic mapping tools are often developed with the budgets and requirements of industry and deep water environments in mind. The shallow coastal regions where archaeological material is concentrated demand different, low-cost solutions.

In these coastal underwater archaeological scenarios, marine robots are not faced with the technical difficulty or high cost of operations found in deep water exploration, but they arguably face a far greater challenge in that they are entering direct competition with highly efficient human divers who are often "free" volunteers. These human advantages start to disappear, however, as the area to be mapped gets larger or deeper and the datasets and high-definition image libraries become so massive as to be unmanageable outside a purely digital recording system. The advantage of deploying robotic drones whenever the mapping task gets too big is also illustrated in Steven Wernke and colleagues' chapter in this volume (Ch. 2.3). The ancient port of Caesarea and its surrounding coastal and submerged features is the perfect example of a site that is simply too big to be recorded to centimeter accuracy by human divers working alone, even with the aid of powerful imaging tools (Brandon *et al.* 2004; Brandon 2008). At the same time, shallow water and good visibility make Caesarea an ideal site to record the seafloor from a surface vehicle.

THE PLADYPOS: TECHNICAL SPECIFICATIONS

The ASV Pladypos surface vehicle was designed for inshore underwater mapping and visualization as one of its primary scientific functions. The Pladypos utilizes a differential GPS to adhere to



Figure 8a: Google Earth image of Caesarea's intermediate harbor with superimposed survey transects (2014).

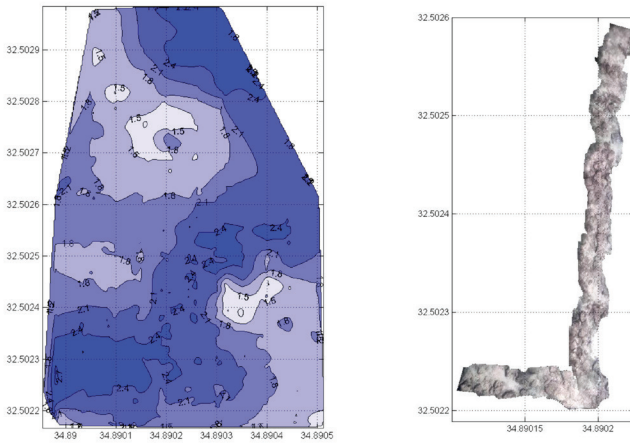


Figure 8b: Sample draft photomosaic produced from the survey area delineated in FIG. 8a.



Figure 8c: Bathymetric data collected from the survey area delineated in FIG. 8a.

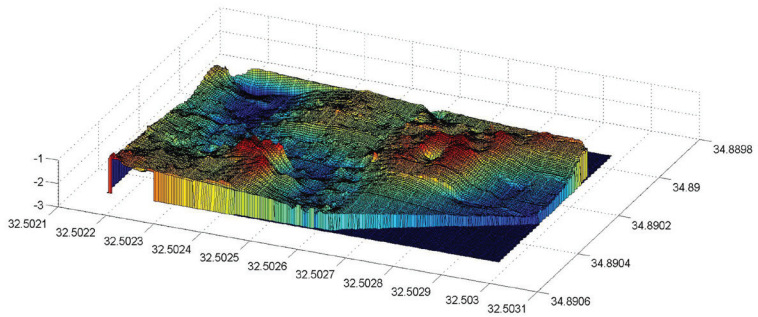


Figure 8d: 2.5D visualization of ancient tower foundations from the survey area delineated in FIG. 8a.

systematic survey patterns with far greater precision than is possible for a human swimmer or even a submersible robotic vehicle (satellite navigation and localization using GPS is not possible underwater). By staying on the surface, the Pladypos can maintain a wireless link for instant communication between the robotic vehicle and the operator on shore (FIGS. 4, 5), unlike the slow acoustic communication channel required to link with an autonomous underwater vehicle.

Also appropriately called an unmanned surface vehicle (USV), the Pladypos can operate either autonomously, following a pre-programmed mission such as a typical “mowing the lawn” survey pattern, or maneuvering under the remote control of a human operator with a laptop (FIGS. 4a, b). The vehicle can switch between the pre-programmed task and direct control on command, and the mission can even be changed once the vehicle is deployed and working on the water. This degree of flexibility and responsiveness is a necessity for an ASV built to operate in dynamic coastal environments where there is more likely to be marine traffic and other hazards.

The Pladypos maneuvers using four thrusters arranged in an X configuration, vaguely though not deliberately resembling its namesake aquatic mammal, and it can move easily in any horizontal direction. The symmetrical design makes efficient use of an onboard battery power source. A simple lead-acid battery may be used, which also provides more options for air-shipping the vehicle. Once it arrives at its destination, another advantage of the Pladypos when compared to many remotely operated vehicles (ROVs) or AUVs is its portability. The Pladypos measures 0.35 m high, 0.707 m wide and long, and it weighs approximately 25 kg without payload. This lightweight design allows the Pladypos to be manually launched and recovered by two people from a beach or jetty, with no need for a winch or a support boat (FIG. 6). In good sea conditions the Pladypos’ operations were limited only by battery time and the schedules of the humans waiting on shore.

The basic tool set of the Pladypos includes a number of data-gathering sensors such as mono cameras, stereo cameras, and, in 2015, a high-resolution ARIS multibeam sonar (adaptive resolution imaging sonar) was added to provide higher-resolution point clouds than those produced by the DVL (Doppler velocity log) used in 2014. The Pladypos has a ROS-based architecture (robot operating system; <http://www.ros.org>) for control, communication, telemetry, and acoustic and optical

data logging. The navigation sensors provide a level of localization accuracy within tens of centimeters and consist of 9-axis INS (inertial motion sensor), high-precision GPS, and DVL. The 4-beam DVL (LinkQuest 600) is capable of 5 Hz depth sampling in shallow water, and it generates a point cloud at the rate of 20 points per second. At a cruising speed of 1 knot, the DVL produces a non-homogeneous point cloud density of 40 points per square meter. The DVL is used to measure speed over ground but also to provide depth measurements. For documenting an underwater archaeological landscape extending over several square kilometers, this represents extremely detailed coverage, though improving the point cloud resolution and the efficiency of post-processing software continues to be a goal for the future development of the system.

The control computer (isolated from environmental disturbances inside the Pladypos hull) is in charge of performing control and guidance tasks (dynamic positioning, path following, diver following) and all the data processing. Apart from the compass, GPS, DVL batteries, and CPUs, the Pladypos is equipped with a mono camera for seafloor mapping, an ultra-short baseline (USBL) system used to determine the position of a scuba diver relative to the robot (the anticipated role of scuba divers in Pladypos operations is discussed further below). The USBL is used simultaneously for localization and two-way data transmission via an acoustic link with the scuba diver; a second modem is mounted on a scuba diver when the vehicle is operating as a surface dive buddy. Support for Pladypos operations from the shore station, which may also be set up on a small boat, includes the controller's laptop and laptops for monitoring the vehicle's sensors, along with WiFi antennae and a wireless modem used to transmit data between the Pladypos and the base of operations (FIG. 7).

During the initial sea trials in Israel in 2014, the Pladypos was equipped to collect two types of data: a georeferenced point cloud of the seabed and sunken archaeological features using the DVL, and visual imaging using the Bosch FLEXIDOME IP starlight 7000 VR mono camera, in a custom-made waterproof housing. A GoPro Hero3 camera in a waterproof housing was also taped onto the vehicle to gather additional high-definition color video. The georeferenced point cloud was acquired by following pre-programmed transects across the survey area with a certain amount of overlap to facilitate the fusion of the data.



Figure 9: Pladypos photomosaic of ruins from Caesarea's intermediate harbor created with Microsoft ICE freeware (2014).

One of the first requirements of a robotic survey vehicle designed for shallow coastal and underwater archaeology is that it can be ready to launch on a new mission ideally within hours, and it can respond swiftly to changing weather or chance discoveries. Assuming the presence of a trained operator, Pladypos missions can be plotted out relatively quickly using Google Earth (FIGS. 8a, b). Since the Pladypos can be operated either manually (teleoperation mode) or autonomously, the ability to adapt missions that are already in progress when circumstances demand is a very convenient feature. Directing the vehicle manually is as simple as manipulating a joystick or pointing to a GPS destination on Google Earth, and does not require specialist training.

After the issue of cost, which we will return to, the key to integrating the Pladypos into a digital recording system for underwater archaeology that will have widespread appeal is the efficiency and user-friendliness of the software, especially the user interface. In 2014, the Pladypos relied on a custom set of scripts produced by LABUST for the georeferenced bathymetry presentation. Scripts written in MatLab were used to unpack the logged data, to fuse navigation and depth measurements, and to generate 2.5D bathymetry images. For the photomosaic, Microsoft Image Composite Editor (ICE) software was used to stitch together the images, while LABUST MatLab script was used to fuse navigation data with large-scale images (FIG. 9). This data was processed off-line to create a microbathymetry map, and a 2.5D digital model of the survey area was also extracted and created from the same data set. The optical data was then merged with the telemetry data to build a photorealistic model of the seafloor along the survey transects. The main limitation on the amount of data gathered along each transect was the width of the visual field on the downward-facing camera, which naturally varied with the depth of the water.

The most technical part of the operation followed the completion of fieldwork, when the LABUST team set to work stitching together the optical data with Microsoft ICE for the final georeferenced photomosaics. The completed images were then aligned with the telemetry data in subsequent processing. In fact, LABUST has developed software to fuse optical and telemetry data for both image stitching and georeferencing. On the final large-scale, high-resolution site map produced from this process, information such as the absolute

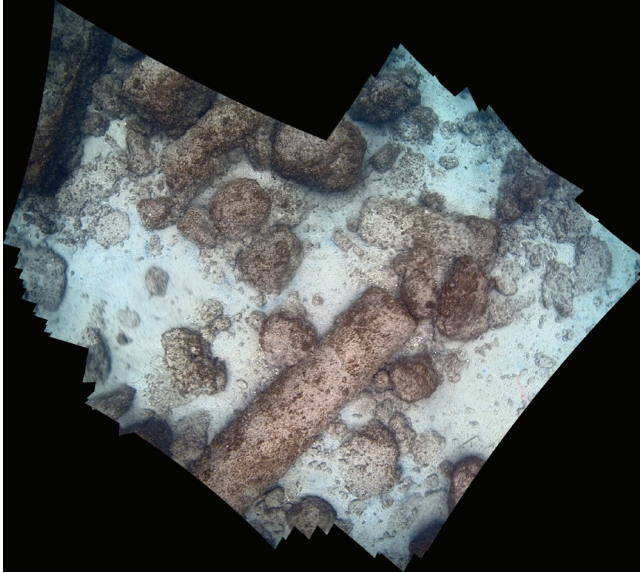


Figure 10a: Pladypos photomosaic of architectural debris in Herod's intermediate harbor, Caesarea (2015).

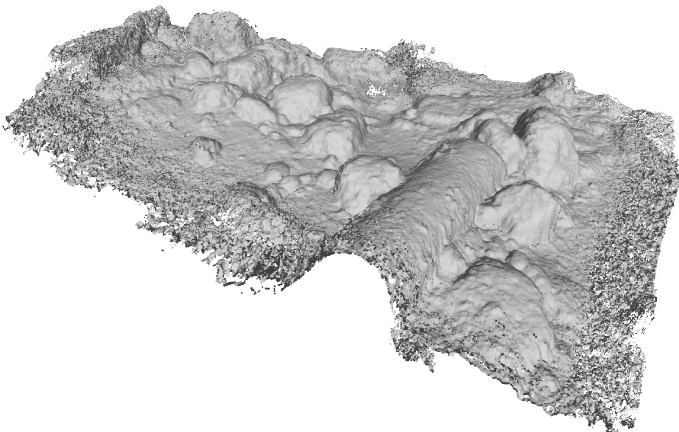


Figure 10b: Point cloud of the architectural debris from FIG 10a.

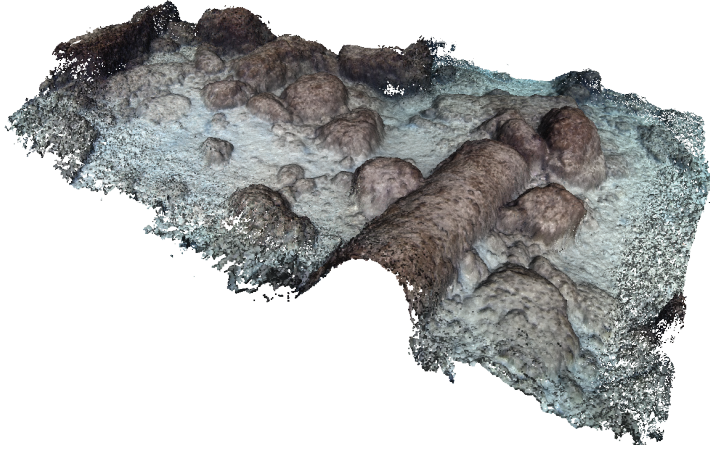


Figure 10c: Map of architectural debris in Figure 10a from merged video and georeferenced bathymetric data.

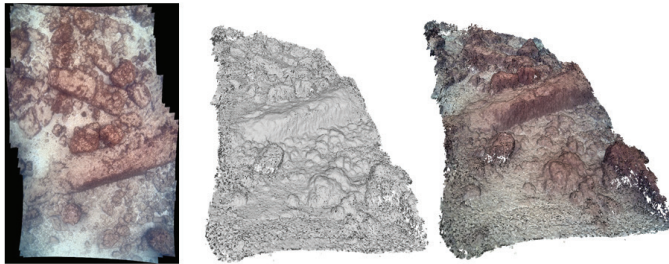


Figure 11: Another example of merged Pladypos photomosaic and point cloud images of submerged architectural debris from Caesarea (2015).

positions of underwater objects and features and their dimensions can be determined within a range of centimeters. In this way, the Pladypos achieves a centimeter-level of precision in small area maps, but it can reproduce this performance on a scale of many square kilometers given time and appropriate conditions.

The choice of Google Earth for the GIS overlay was simple given its universality and ease of use, and also because Google Earth does not treat the land-sea interface as a barrier (FIG. 8c). On dynamic coastal archaeological sites where the visible remains are often changing, being able to visualize the relationship between submerged and semi-submerged coastal features is very important. Observing change over time around the interface of the land and underwater landscapes can help local authorities to monitor erosion and other long-term changes that threaten coastal archaeological sites.

The evolving site map that archaeologists work from in the field is necessarily rougher than the site map produced for a final publication, and the Pladypos preserves this convention by producing “rough and ready” SLAM-generated photomosaics while collecting the data that will eventually be transformed during post-processing into a high-resolution 2.5D map (FIG 8d). Preliminary mosaics were produced on-site at land stations set up on Caesarea’s modern breakwater, providing real-time information to the archaeologists. At present, there is scope for improvement in the speed of the high-level post-processing, which required many hours of work by the engineers in the weeks following the conclusion of the fieldwork (see FIGS. 10a, b, and c, and FIG. 11 for examples of the generated results). It is not unusual to wait for weeks or months to obtain processed bathymetric data and photomosaics on oceanographic expeditions, but as a future goal, it is obviously preferable for the required processing from raw data to publication-ready 2.5D maps to be automatic, or nearly so.

CAESAREA MARITIMA

An important goal of the collaboration between the archaeologists and Pladypos engineers was to give the latter a greater understanding of the kinds of research the robot was intended to support. The IAA’s important ongoing archaeological work at Caesarea provided this opportunity, giving the engineers first-hand experience of a typical

coastal fieldwork environment, and an appreciation of how the archaeologists hoped to use the Pladypos' data.

The first-century A.D. Jewish writer Josephus described King Herod's gigantic artificial harbor at the Judean city of Caesarea Maritima as "a triumph over nature" (*Bellum Judaicum* 1.410–412). The name Caesarea came from the family name of Rome's first ruling dynasty, the Caesars. The actual harbor was technically called Sebastos, after the Greek rendering of Augustus, the first of Rome's emperors and an important political patron of King Herod (d. 4 B.C.). The maritime gateway to King Herod's new city was the largest completely artificial harbor in the Mediterranean world, with breakwaters encompassing over 20 hectares (FIG. 3). Upon its completion in the last decade of the first-century B.C., Caesarea Maritima's port provided one of the Levantine coast's only deep water anchorages (Raban *et al.* 2009).

One of the reasons that archaeologists are eager to have more accurate maps of the ruins of Caesarea's Roman harbor is because it was the most ambitious port construction of its day (Hohlfelder 2007). Caesarea's engineers used hydraulic cement in the creation of the breakwaters, employing a special mortar composed of lime and pozzolana, a volcanic ash imported from central Italy. The scale of the project was beyond even Herod's abundant resources, reflecting the power and wishes of the new imperial government in Rome. The new port helped Caesarea to prosper, and the city soon grew to be five times the size of Jerusalem; it remained one of the most important towns on the Levantine coast until the Muslim conquest. During this time, Caesarea appears to have been damaged by several major earthquakes and tsunamis, though the impact of these ancient disasters on the Herodian port structures is still being investigated (Reinhardt *et al.* 2006). The damage caused by natural disasters has to be set against evidence of the port's decline through simple lack of maintenance and flaws in the original construction (Hohlfelder 2007). Exactly what caused the outer breakwaters of one of the ancient world's most magnificent ancient harbors to fall into disrepair even before the end of the first century A.D. is one of the questions that a comprehensive underwater map of the entire port area could help us to answer.

Unlike the archaeologists of the previous century, we can now integrate a vast amount of georeferenced bathymetric and photographic data into a GIS, meaning we are no longer forced to choose between coverage and accuracy in the underwater recording of exceptionally



Figure 12: Before (top) and after (bottom) the storm season at Caesarea Maritima.

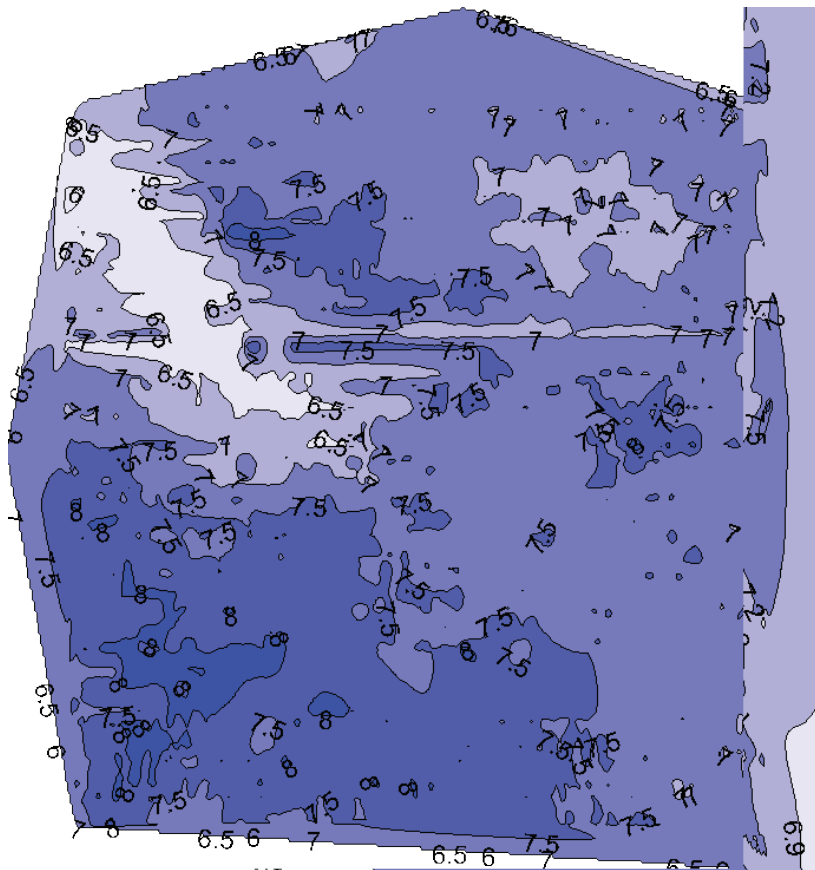


Figure 13: Bathymetric data collected at the site of a medieval shipwreck containing Fatimid coins, near Herod's southern outer breakwater, Caesarea (2015).

large sites. Until recently, however, there has not been an appropriate vehicle for conducting such a large-scale systematic underwater survey at Caesarea that offered a cost-effective improvement over simply integrating local results into a regional plan derived from aerial photographs.

We are certainly not the first team to seek a solution to the problem of how to map the ancient harbor in its entirety. Experiments with earlier digital mapping systems based on PhotoModeler were hampered by variable visibility and the heavily eroded, irregular surfaces of the sunken ruins at Caesarea (Brandon 2008). Underwater site mapping techniques based purely on visual data and photogrammetry, such as that used at the Mazotos shipwreck site off of the southern coast of Cyprus, also require the placement of calibration targets, such as plastic disks or distinctively marked ceramic tiles (Demesticha 2011; Santagati *et al.* 2013). Even on small sites, these targets get moved around in dynamic sea conditions, and the technique is simply not practical for large port structures. Once again, Caesarea is a good example of a well-known and historically important underwater site that has been extensively excavated and studied but never comprehensively mapped because of these challenges.

Today, Caesarea's sunken ruins are the centerpiece of a national park, and the innermost of the three Herodian harbor basins is covered by lawns and restaurants. The scattered remains of the intermediate and outer harbors present an ever-changing puzzle for archaeologists as the open sea regularly uncovers new features and moves or reburies others (FIGS. 12a, b). Israel's winter storms in 2010 were powerful enough to tear down Caesarea's modern reinforced-concrete breakwaters, and at this point the need for a new conservation assessment of the ancient harbor became clear. Figures 12a and 12b show how environmental changes over the past few years have transformed the appearance of the underwater ruins, in some areas revealing new features that were missed in earlier archaeological studies. Completing the first georeferenced digital imaging of the entire underwater site of Caesarea will not only help us to integrate the results of previous excavations into a unified up-to-date GIS, but it will also aid the IAA in future planning and conservation efforts.

THE 2014 MISSION

In 2014, the ASV Pladypos was deployed at Caesarea in a collaboration between the Israel Antiquities Authority and researchers from the University of Zagreb, the University of Rhode Island, and the University of Louisville. Over a period of three days, the Pladypos was manually launched from the shore and travelled under its own battery power to a series of small survey areas, where it mapped the seabed using a combination of downward cameras and a DVL to create a merged georeferenced photomosaic and digital point cloud. The 2014 surveys took place both within and beyond the modern breakwaters in the Herodian harbor, and the foundations of a Roman pier were also mapped at nearby Sdot Yam to the south. When sea conditions allowed, the Pladypos operated out in the open sea, where the water depth and acceptable seafloor visibility extends to approximately 10 m depth in normal conditions. When the sea became too rough, the Pladypos surveyed the ruined foundations of Roman towers in the intermediate basin protected by the modern seawall, an area that ranges in depth from 1–3 m (FIGS. 8a, b, c, d).

Like many of Caesarea's submerged structures, these semi-buried tower foundations are not immediately obvious or comprehensible to a swimmer on the surface. The sand and rubble, however, transform into recognizable architecture when reconstructed as a 2.5D digital image (FIG. 8d). The Pladypos generated a georeferenced microbathymetric map of this area using LABUST's customized MatLab-based software. The data that the Pladypos produces is less like a traditional site-map and more like a scale digital reconstruction of an archaeological landscape. The results are suitable for GIS presentation, for example using Google Earth as shown in Figure 8c. Unlike a traditional paper map, moreover, the Pladypos reconstruction has the same "zoom" functions as the Google Earth GIS framework in which it is imbedded.

The exercise of surveying the tower foundations in the sheltered intermediate harbor, which took little more than an hour, provided a preview of what we could expect from a high-resolution 2.5D map of the entire port. Herod's outer harbor is more exposed and deeper (up to 10 m in places), with a depth range of 3–8 m in most of the area surveyed in 2014. This exposed area out in the open sea posed a greater challenge for the small Pladypos to stay on target while

buffeted by wind, waves, and a moderate 1–1.5 knot longshore current. Despite these conditions and Caesarea’s infamous surge, the Pladypos held position and continued to collect good data. Three missions were performed along a 250 m stretch of the submerged southern breakwater, and the results were merged to create a 2.5D reconstruction and a microbathymetry map. When the open sea became too rough, work in the intermediate harbor continued (FIG. 5).

THE 2015 MISSION

An important lesson of the 2014 Caesarea expedition was that having the archaeologists and robotics scientists working collaboratively in the field resulted in a far greater mutual understanding than if the archaeologists had simply viewed the engineers as technicians providing a service, or the engineers viewed the archaeological mission purely as a field trial. In this volume, the Federated Archaeological Information Management System (FAIMS) team likewise found that ongoing dialogue between the software developers and archaeologists was extremely helpful (see Sobotkova *et al.*, Ch. 3.2). Concepts such as mapping and measuring can have surprisingly different meanings across different disciplines, and it was valuable for all involved to have their assumptions highlighted and questioned. An ambitious “to-do” list to enhance the Pladypos’ performance and utility from an archaeological perspective was another important result of the 2014 season. One conclusion was that more precise measurement of the depth below the Pladypos would significantly enhance the quality of the photomosaics. For that reason the LABUST group integrated the high-resolution ARIS multibeam sonar onto the vehicle when it returned to Caesarea in 2015.

The Caesarea mapping project resumed in July 2015, though the vagaries of international shipping meant that the Pladypos itself was delayed for a week in Madrid and was only available for two full days of fieldwork on its second visit. During this brief time, however, the Pladypos surveyed or re-surveyed an estimated 60–70% of the intermediate Herodian harbor and over 25% of the outer harbor. The ARIS multibeam system generated a high-resolution 3D point cloud of the seabed, in addition to the image mosaic produced by the survey (some results are illustrated in FIGS. 10a-c, 11, and 13). In 2015, the Pladypos’ mapping mission took on an unexpected urgency, as Caesarea became

the scene of an Israel Antiquities Authority rescue excavation of a recently exposed medieval shipwreck site.

In February 2015, winter storms exposed a scatter of gold coins lying among the rocks in King Herod's outer harbor, where they were discovered by local scuba divers. IAA underwater archaeologists Jacob Sharvit and Dror Planer led the subsequent recovery operation, and over 2,500 coins were retrieved from the surface of the seafloor during the following days. The coins dated from the 10th to 11th centuries A.D. and were minted by the Fatimid Caliphs of Egypt (the Fatimids were an Ishmaili Shia dynasty that ruled the Levantine coast during the early Medieval period). IAA numismatist Robert Kool identified the name of Abu 'Ali Mansur al-Hakim bi-Amr-Allah (A.D. 996–1021) on many of the coins. Al Hakim was the sixth Caliph to rule the Fatimid Empire, and he is a controversial figure revered in the traditions of Israel's Druze community. The presence of medieval anchors near the hoard suggested the coins came from a shipwreck that probably occurred in the period of the 1020s to 1030s.

The likelihood of further storms and wave action destroying the archaeological context of the discovery posed the greatest immediate threat to the site. The accessibility of the shallow site in an area frequented by scuba divers was also a concern. The IAA immediately provided resources for a rescue excavation. The site presented unusual challenges, however, as it had no obvious center or limits, and it consisted primarily of scattered rubble and sand. Such amorphous and complex shapes provide few "hard edges" as spatial reference points and are notoriously difficult to map.

In Israel and other regions of the world where the preservation of a rich inshore archaeological heritage is complicated by a highly dynamic coastal environment, the scenario described above is not unusual. During Israel's winter storms, historic shipwrecks and submerged structures can appear in the coastal surf zone and then be reburied or destroyed within the space of a few days. An unknown number of sub-seafloor sites must experience this fate every winter without archaeologists ever being aware of their existence. Even in the case of the Caesarea Fatimid coin hoard discovery, which, fortuitously, was immediately reported and investigated by archaeologists, the limitations of current technology for underwater site recording and rescue excavations were highlighted. The discovery nevertheless provided an unexpected opportunity for the Pladypos to demonstrate

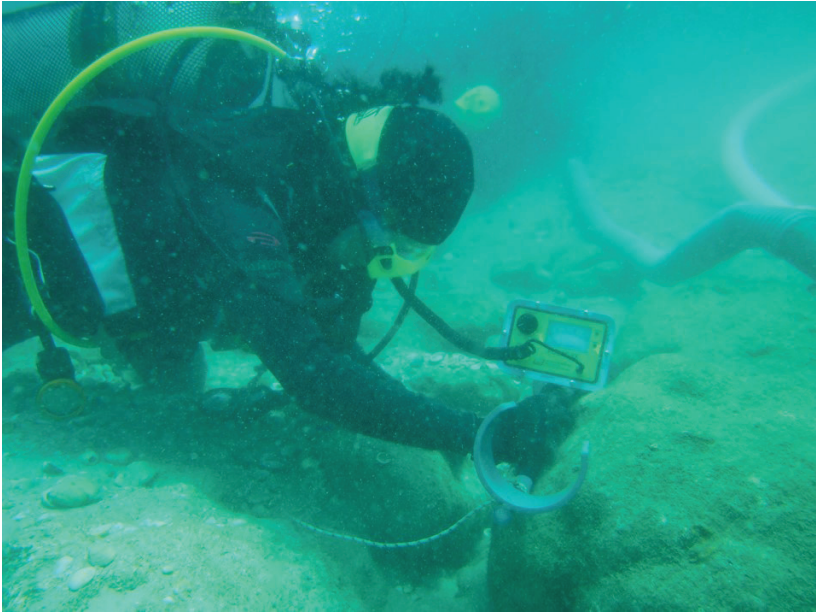


Figure 14: After the top layer of rocks was removed from the Fatimid shipwreck site in July 2015, a second pocket of gold coins was located using a JW Fisher Pulse 8x metal detector.



Figure 15: Medieval coins recovered from the Caesarea Fatimid gold hoard site, July 2015.



Figure 16: The Pladypos provides real-time diver localization to a GIS on an underwater tablet and relays the diver's typed messages to shore operations (underwater archaeologist Krunoslav Zubčić testing the system on a submerged Roman villa site at Colentum in Croatia).

its ability to create a large high-resolution seafloor map in a rescue excavation scenario (FIG. 13).

After the initial recovery effort removed the most easily accessible coins, the excavation of the Fatimid shipwreck site did not begin until July 2015 (FIG. 14). This delay was deliberate and planned to coincide with the return of the LABUST University of Zagreb engineering team (FIG. 4b). The Pladypos now focused on mapping the area of the coin hoard discovery. The clear, relatively shallow water enabled the Pladypos to obtain approximately half a million high-resolution photographs of the site and the surrounding seafloor in a matter of hours. These fully georeferenced images preserve important information that may not be immediately obvious to human divers searching the rock-strewn seafloor. Confident that no critical information would be lost, the archaeologists were now able to remove rocks along a transect in the area of the discovery, revealing a second substantial pocket of gold dinars in the sand underneath and bringing the total hoard to over 3,000 coins (FIG. 15). It was during this work that a 10 cm-long iron spike was discovered with gold coins concreted to it, providing the strongest evidence yet that the hoard came from a shipwreck. A preliminary photomosaic of the area produced in the field was also available for immediate use by the archaeologists as the work of excavation proceeded.

The Caesarea Fatimid coin hoard discovery provided the perfect illustration of the utility of a robot that can produce a high-resolution georeferenced 2.5D site map of an area larger than a football field in a matter of hours, enabling a rescue excavation to proceed without fear of losing critical data in the rush to recover fragile evidence. However, the experience also highlighted the importance of having the Pladypos on-site and ready to deploy at a moment's notice, not standing by in an engineering lab on another continent. The Pladypos also has a long way to go before it can be an affordable, "ownable" piece of technology that is ready to deploy off the back of a pickup truck without needing a team of four LABUST engineers to operate it. We conclude with some considerations and plans for the future of the Pladypos, with a view to developing a commercially-viable product that end users can own and operate without specialist training.

CONCLUSIONS AND FUTURE DIRECTIONS

The recent development of DVL and multibeam systems compact enough for deployment on small USV/ASV platforms such as the Pladypos creates important new opportunities for the recording and monitoring of large shallow-water coastal archaeological landscapes. Using these capabilities of the Pladypos, we are able to meet and even surpass the high standards of accuracy in manual site mapping established by scuba divers in the late 20th century—and this achievement can now be replicated on a much larger scale in a very short time. The rescue excavation of the Caesarea Fatimid coin hoard site in July 2015 demonstrated that the Pladypos could be just as useful for the intensive recording demands of a small-scale rescue excavation as it has been for high-resolution landscape survey at Caesarea, and in other experiments conducted on shallow archaeological sites at Colentum in Croatia (FIG. 16) and Lake Valgjärv in Estonia.

To be as effective and useful as a human diver for the management and excavation of coastal archaeological sites, the Pladypos needs to be able to arrive on the site and be ready to go to work with the same speed as the archaeologists. In 2015, the Pladypos was able to start work overseen from a makeshift operations center within hours of arriving on-site, and it completed its recording tasks efficiently. A minimum of two people were needed to operate the vehicle: one to monitor the robot itself, and the other to monitor and begin processing the incoming data.

It follows that the most obvious area of improvement for future iterations of the Pladypos is not in technical capability, or even the general compatibility of its data products with archaeological conventions, but in “ownability.” A function of durability, ease-of-use, and cost, ownability will determine which robotic vehicles and their dependent digital recording systems will ultimately become an everyday part of an underwater archaeologist’s toolkit, and which will merely hold a place in the evolutionary process. The first affordable and user-friendly off-the-shelf robotic technology to pass this threshold and come into widespread use within the realm of scientific diving will reshape archaeological methodology underwater in the same way that the evolution of iOS-based paperless systems is currently transforming terrestrial archaeology. From the archaeologist’s perspective, the Pladypos will not achieve “ownability” until the entire system

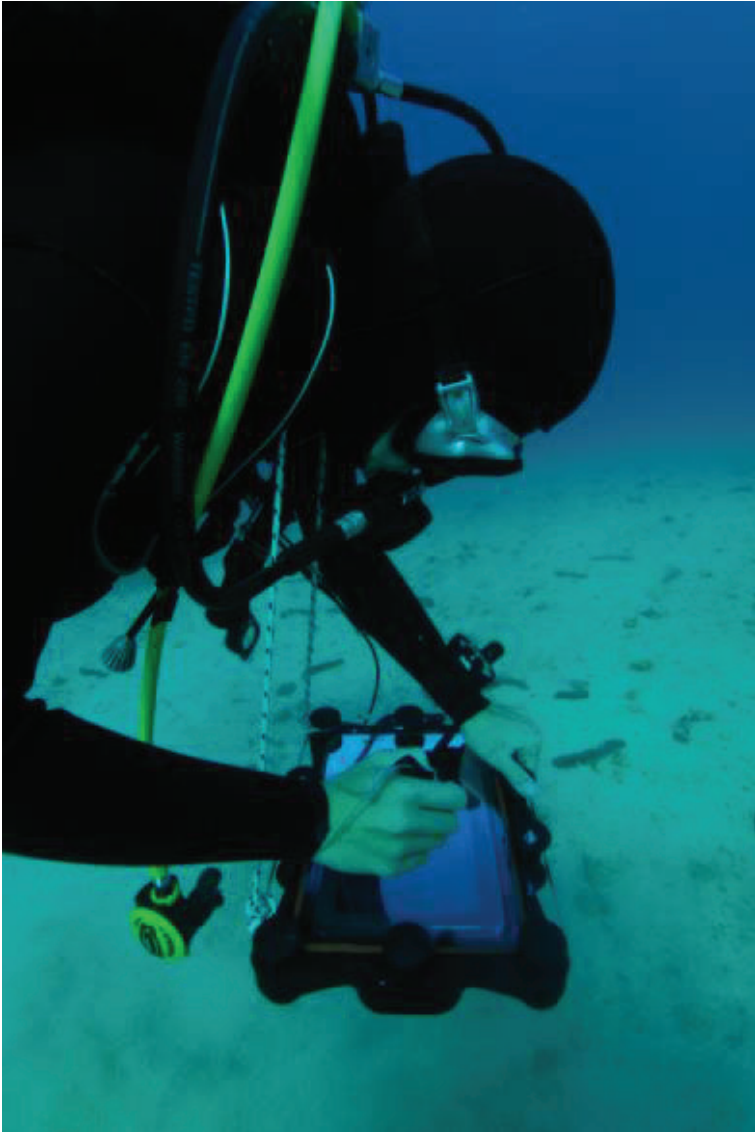


Figure 17: Diver using the underwater tablets (image supplied courtesy of LABUST).

can be purchased for under \$20,000, and the graphic user interface (GUI) is intelligible to even the most non-technical user. In addition, the data products (geo-referenced data, videos, still images, and the DVL/sonar point cloud) must be able to be integrated into a GIS by a non-expert user with readily available commercial software, or, ideally, freeware. At this stage, it is difficult to predict when this might happen: we are still in the first phase of establishing proof-of-concept with the Pladypos itself.

To this point we have been discussing operations in very shallow water, which may be defined as the depth at which the seafloor is still visible from the surface for the purpose of creating photomosaics. However, the utility of the Pladypos does not end there, and future missions will develop and demonstrate the vehicle's applications in deeper water. While in some respects the Pladypos' sphere of operations puts the vehicle into competition with human divers, it is more appropriate to say that the vehicle is designed to complement human capabilities. When deployed as a surface dive buddy, the Pladypos integrates human functionality to accomplish tasks in deeper water that would be expensive, difficult, or even impossible for the current generation of underwater robotic vehicles.

As mentioned earlier, the Pladypos is equipped with an integrated ultra-short baseline (USBL) localization system, which it can use to hover above and track a scuba diver with a tank-mounted transponder and battery pack. An acoustic modem maintains a low bandwidth link with the surface, allowing the two-way transfer of email messages, photos, and GIS data between the diver and the land base via an ordinary Android tablet in a waterproof housing designed by LABUST (FIG. 17). Currently the 2014 Samsung Galaxy Note 10.1 is the tablet best adapted for use with the waterproof housing, but its main drawback is that the FileMaker-based applications popular in terrestrial archaeology are not available for Android devices at the time of writing. The popularity of iPads in terrestrial archaeology illustrated by other projects discussed in this volume, and the appearance of a new commercially available underwater casing for iPads, the iDive (<http://idivehousing.com/>), provide compelling incentives to make the next iteration of the Pladypos compatible with iOS-based technologies.

Using the Pladypos' current system, a diver can access most of the tablet's applications using a modified touch-screen pen (FIG. 17). While the archaeologist gathers data and images from the seafloor

using the tablet, the Pladypos collects multibeam data from the surface and relays information to the diver about his or her location on the map, including transect lines and GPS coordinates. In this way, the robot does not lose the ability to produce georeferenced photo-mosaics at greater depth or in poor visibility: it simply delegates the visual part of the task to a human diver with a tablet computer—or, in another project currently under development, a second autonomous robotic vehicle.

The Pladypos is also intended to enhance diver safety. It can serve as a mobile surface marker for the diver's position (very useful when manually checking sonar targets in offshore live-boating situations), but in future it will also be able to monitor the diver's physical state, duplicating the role of a dive buddy as well as a scientific assistant.

In addition to conducting archaeological research and completing the mission at Caesarea, the over-arching goal of the Pladypos project in Israel is to develop through interdisciplinary collaboration the first universal standard ASV customized to support digital underwater archaeology, and to make it as versatile, robust, and affordable as possible. The brief 2014 and 2015 missions helped the engineering team to identify and address technical issues, and to experience first-hand a real archaeological project environment. The mission itself helped to build mutual understanding of the needs of specialists in two very different fields, as well as improving their ability to communicate productively and work together toward common goals. Importantly, the engineering team were able to leverage their resources and grants for technological development to keep the cost to the archaeologists of the 2014 and 2015 Pladypos deployments under U.S. \$10,000 per week.

We view the ongoing Caesarea expeditions as early steps along a path to the full integration of robotic vehicles into all aspects of the underwater archaeologist's work, making underwater research faster, safer, better—and ultimately much more cost-effective. Such a major transformation will require further improvements in the technology, and the culture and methodologies of underwater archaeologists will also need to adapt to the new, fully digital environment. Collaborative field trials, such as the ones described here, help to achieve both goals.

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<https://mobilizingthepast.mukurtu.net/collection/24-asv-autonomous-surface-vehicle-archaeology-pladypos-caesarea-maritima-israel>

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