pca

european journal of
postclassicalarchaeologies

volume 12/2022

SAP Società Archeologica s.r.l.

Mantova 2022

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"Post-Classical Archaeologies" is indexed in Scopus. It was approved on 2015-05-13 according to ERIH PLUS criteria for inclusion and indexed in Carhus+2018. Classified A by ANVUR (Agenzia Nazionale di Valutazione del sistema Universitario e della Ricerca).

DESIGN:
Paolo Vedovetto

PUBLISHER:
SAP Società Archeologica s.r.l.
Strada Fienili 39/a, 46020 Quingentole, Mantua, Italy
www.saplibri.it

Authorised by Mantua court no. 4/2011 of April 8, 2011

ISSN 2039-7895

pca

european journal of
postclassicalarchaeologies

volume 12/2022

CONTENTS PAGES

research

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Reflecting on artificial intelligence and archaeology: the ArchAIDE perspective

1. Introduction

Material culture is the primary source used by archaeologists for understanding the past (and the present). The importance given to things by the most recent theoretical approaches (Harris, Cipolla 2017; Gattiglia 2021) reflects the capacity of artefacts in helping archaeologists understand past societies, as well as the economy, identity, relationships with the environment, et cetera. The overwhelming production of pottery from neolithic to contemporaneity, joined with its post-depositional longevity, transformed this poor material into the most common class of artefact found by archaeologists. Allowing things to speak concerns the thorough recognition of these artefacts, which means an expensive and time-consuming activity pursued by pottery specialists. When a vast amount of data needs to be analysed and complicated, subjective, highly specialised, and time-consuming activities are required, Artificial Intelligence (AI) brings benefits. AI can manage challenging problems in archaeological data: incompleteness, noisiness, messiness, and non-linear relationships between the data. Consequently, AI has been applied to archaeological pottery. Automatic puzzle-solving for the reassembling of archaeological artefacts, based on 3D models using the information encapsulated in the thickness of the potsherd (Stamatopoulos, Anagnostopoulos 2016), 3D models of fragments and images (Derech *et al.* 2018), or on a comparison of vectors and surfaces, performed linearly (Filippas, Georgopoulos 2013) have been adopted. Reconstruction of potsherds and text has been achieved on a group of ostraka with demotic inscriptions, focusing on 2D reconstruction techniques using a specific multilayer architecture of Deep Neural Network (DNN) called Siamese Neural Network (Ostertag, Beurton-Aimar 2020), whereas automatic recognition of pottery has been developed by the ArchAIDE project (Anichini *et al.* 2021), and recently by Núñez Jareño *et al.* (2021).

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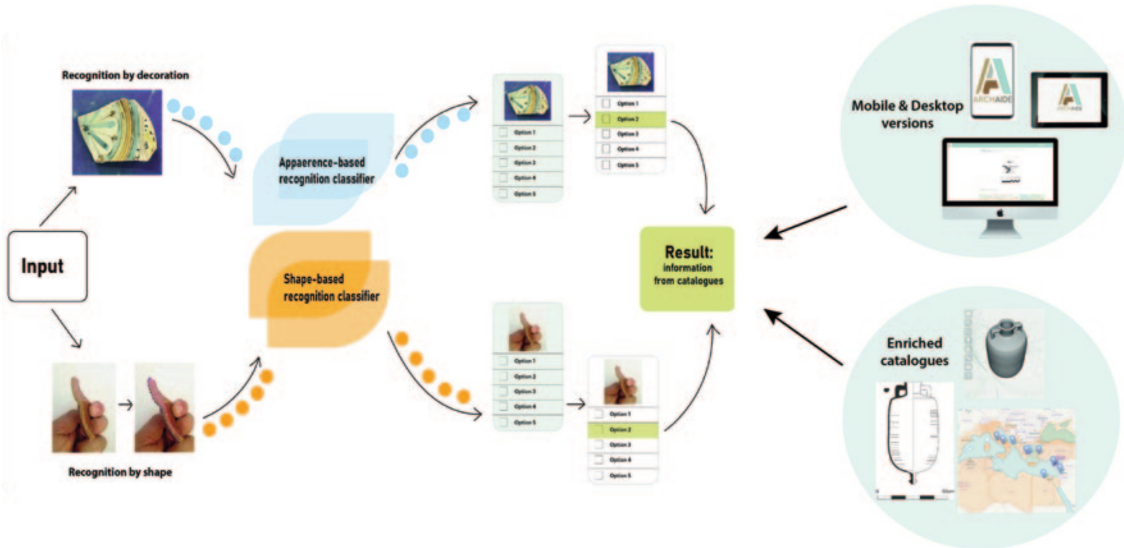

Fig. 1. The complete ArchAIDE environment: the two distinct processes for automatic recognition of archaeological pottery and the connection with the comparative collection and the desktop and mobile applications. The workflow works by taking one picture of a real-world potsherd to be sent to the AI classifier. The classifier answers five responses listed by the degree of accuracy. In shape-based recognition, a step is added: users must trace the potsherd profile and send it to the classifier.

This contribution stems from the reflections on the ArchAIDE project's sidelines, which posed many challenges related to Deep Learning techniques, data availability, ethics, epistemology, and hermeneutics. Three years after the end of the project, it is time for ArchAIDE to discuss its strengths and weaknesses and envisage how to improve its usability and sustainability.

2. ArchAIDE in a few keywords

The ArchAIDE project has been presented at many conferences and published in international journals (Anichini *et al.* 2020, 2021; Dellepiane *et al.* 2017; Itkin *et al.* 2019) to illustrate the project as a whole or specific, especially technological, aspects. Technically, ArchAIDE works (fig. 1) using two different Deep Neural Networks: one dedicated to image recognition (also called appearance-based recognition, for pottery decorations), the other to shape recognition (also called shape-based recognition, for pottery types). When speaking of ArchAIDE, two main points have to be considered: (i) ArchAIDE was developed as a proof-of-concept for demonstrating that the solutions adopted could work; (ii) ArchAIDE has been thought to be used in the field with easily available devices (smartphones, tablets and, to a lesser extent, laptops).

In other words, ArchAIDE must be considered a prototypal application, a technically fully operating system, realised intending to achieve the technical solutions for recognising potsherds primarily in the field through a single image taken with a mobile device and not in a controlled environment. The three-year project time span was insufficient to realise a system that could contain as much archaeological information as an archaeologically fully operating system.

3. Challenges and reflections

3.1. Archaeological challenges

Even if it was conceived with the ambition of realising a system capable of potentially recognising the types belonging to all classes of pottery, the ArchAIDE project aimed to release a technically working environment that could be implemented with more ceramic classes in the future[1] and whose source code could be openly reused. As a consequence, a selection of a few ceramic classes was made at the beginning of the project, chosen by the availability of well-structured catalogues, possibly open datasets (as in the case of Roman amphorae), real-world potsherds, and the possible attractiveness to the archaeologists. The intrinsic necessity of developing a deep neural network from scratch brought to choose a small number of standardised ceramic classes, such as Roman amphorae, Roman *terra sigillata*, and medieval and post-medieval Majolica produced in Montelupo Fiorentino (Italy) and from Barcelona and Valencia (Spain). The possibility of working with less standardised ceramic classes such as prehistoric/protohistoric pottery has been postponed to a later development starting from already robust technological solutions.

On the other hand, the initial idea of developing just one neural network capable of recognising both shape and decoration was rejected, given the technical complexity (Anichini *et al.* 2021). Likewise, the possibility of identifying the different pastes of potsherds was excluded because it was not achievable through an image in the spectrum of visible taken with a mobile device.

Despite the technical goals achieved by the project, the modest number of ceramic classes available inside the system has produced, as a consequence, limited use of ArchAIDE that can be seen in the few case studies in which it was

[1] After the end of the project, the Pisan Maiolica Arcaica collection was added, and research projects are ongoing to add adding new pottery classes such as 2nd and 1st millennium BCE pottery from Uşaklı Höyük (Turkey, http://usaklihoyuk.org/, accessed on February 22, 2022).

tested, circumscribed to the urban excavations in Palma, Andratx, Toledo and Laminium and the Roman villa in Cabañas de la Sagra in Spain. ArchAIDE was used with different mobile devices by archaeological companies in these circumstances and tested with cleaned fragments (mostly rims) in natural, artificial and even deficient light conditions. In general, the operability of mobile phones and tablets has been similarly evaluated when working in a warehouse, whereas the mobile phone was judged as more appropriate in an excavation environment because of its more effortless operability. The feedback highlighted the pros and cons. For decoration-based recognition, the pipeline has been evaluated as user-friendly and fast; any particular skill was requested. More importantly, the results were considered robust with all the devices used, and a higher score has often been associated with the correct output. Cons have been observed in the GrabCut algorithm, which can be misleading and produce lower output scores. In the case of shape-based recognition, pros were related to the robustness given by the fact that the use of different mobile devices did not influence the outputs. On the other hand, the feedback highlighted how the overall process is less automatic than the appearance-based recognition, and most of the responsibility for the final result belongs to the user. Relevant skills are needed for taking a picture in which the ruler is at the same level as the fracture to allow accurate scaling, choosing the potsherd's correct orientation and tracing the profile precisely. Consequently, if the classification is incorrect, it is impossible to know whether it is the user's or the system's fault. Finally, the professional archaeologists considered ArchAIDE more useful during the post-excavation study phase than during the excavation activity when the work priorities are different.

The evaluation of the shape-based and appearance-based identification gave an average mobile app top-5 accuracy of 83.8% for decoration recognition and 62.8% for shape recognition (Anichini *et al.* 2021). A good result and a good starting point, on which we are working to obtain better results by improving and migrating the neural network.

Giving five answers can be seen as a limitation of the system. Nevertheless, it addresses ethical questions. ArchAIDE does not aim to substitute the knowledge of archaeologists. On the contrary, it wants to safeguard the archaeologists' role in the decision-making process within the identification workflow (see 3.4); simultaneously, it simplifies and makes the process faster, reducing from many tens of types to just five. Besides, the system helps the seemingly tiresome task of checking the five outputs by directly linking the algorithm's results with the reference database, allowing a fast check of the outputs.

3.2. Data availability and copyright

Data availability represents a critical aspect of AI applications. AI requires large amounts of well-defined data to train algorithms. Unfortunately, collections

Fig. 2. Photo-campaign for collecting images for neural network training resulted in an unforeseen time-consuming activity. ArchAIDE meets archaeologists' needs creating a portable, user-friendly tool for mobile devices, able to be used everywhere, accelerating the collection phase during the work in the archaeological warehouses.

accessible in digital format, both for open reuse and as comparative data for AI applications, are extremely rare, and significant impediments to access, such as restrictive copyright, complicate the process. On the other hand, gathering *ex-novo* data could be very expensive and problematic. In the case of archaeology, enough training data for AI applications and standards for allowing data merging are often missing. This is due to often needing to train on objects spread across regions, countries, and individual physical archives and museums and to the research model typically employed. Unlike the hard sciences, which tend to produce research created by broad groups of researchers and large volumes of data, archaeology is driven by the work of individual researchers or small teams, making access to training data complicated and fragmented. The case of ArchAIDE seems paradigmatic from this point of view. It was necessary to conduct multiple photo campaigns to produce a complete dataset of images for all the ceramic classes under study, involving researchers beyond the consortium and more than 30 institutions across Europe (fig. 2). As for training the shape-based neural network, the extent of the work and the difficulties of finding enough already catalogued pottery types in archaeological warehouses forced the consortium to reduce the number of processed types by more than half. Overall, 3498 sherds were photographed for training the shape-based recognition model. For appearance-based recognition, it was possible to collect photos originally taken for different uses, such as graduate and PhD theses, archaeological excavations, etc., but it was also necessary to collect new images until the creation of a dataset containing 10036 items. These images are currently unavailable to researchers. In many European countries, legislation on cultural heritage is very restrictive and does not allow us to publish the photos of potsherds taken by ArchAIDE partners in national and regional collections. Our hope, as well as our efforts, go towards disseminating these comparative collections as open research data. Showing the usefulness of these data for developing AI applications might help convince cultural heritage national institutions and other researchers to move toward open data policies[2].

Digital comparative collections are an unsung but vital aspect of any archaeological AI application involving artefacts. Traditionally, these have taken the form of large, expensive paper catalogues, cumbersome to carry in the field and difficult to consult, making the identification process costly and time-consuming. While archaeologists are becoming more used to making their data available online, comparative collections are only rarely digitised and made open access. Participating in the H2020 open data pilot, ArchAIDE was committed to creating accessible outputs where the project held the copyright. Unfortunately, not all the collected data could be published as open data. The research exceptions allowed by the EU Directives do not mean the ArchAIDE project automatically holds the copyright to the newly digitised or remixed data[3]. Negotiation with copyright holders (publishers and distributors) for making these data available outside the project was pursued. ArchAIDE demonstrated that paper catalogues, once digitised, can be actively reused many years after the first publication. It was hoped to reach an agreement with publishers and other data providers for making their resources available in new ways, "with a tangible benefit (seeing their data in use within the app), thus furthering the long-term discourse around making research data open and accessible" (Anichini *et al.* 2020). Unfortunately, differences between research institutions and market-oriented companies have not allowed achieving this goal, demonstrating the difficulties of research institutions in the humanities domain in pursuing business solutions.

[2] Although all the data collected by users and stored in the ArchAIDE system are, by definition, private, the system offers the option to disseminate the data as open data. Sponsoring the open data philosophy, ArchAIDE suggests that the user share the data with the community, leaving each user to choose to do that or not (Anichini *et al.* 2020).

[3] Analysing the scientific research exceptions in the InfoSoc Directive and the Database Directive, published works and databases can be used, mentioning the source and the authors' name of the works for scientific purposes and to the extent justified by a non-commercial purpose (Anichini, Gattiglia 2021).

Instead, data owned by the project were made available as open data[4]. The ArchAIDE archive contains 2D vector drawings in SVG format and interactive 3D models created from the ADS Roman Amphorae digital resource. The multilingual vocabularies were published from the SPARQL endpoint and are also freely available for download and reuse in other Linked Open Data projects focused on archaeological pottery. Until May 2022, the ArchAIDE archive received 5262 visits, with 693 downloads and more 30,641 page views, demonstrating its usefulness and as an excellent standard of best-practice[5].

Therefore, even if it goes beyond the ArchAIDE aims, it seems imperative that archaeologists and AI specialists work together to identify and leverage the creation of digital comparative collections. It will also be essential to establish best practices and identify barriers to their creation, such as restrictive copyright.

3.3. Technical challenges

AI application in archaeology, and more in general in the Humanities, means dealing with specific technical challenges, especially when AI has to work in real-world scenarios. Let us consider human shape-based recognition. Archaeological pottery catalogues define each type by a 2D drawing of the profile of the complete vessel. Whereas the drawing describes the geometry of the profile of the entire vessel, a potsherd represents a relatively small part of the original, containing minimal information regarding the shape as a whole. Moreover, the fracture results from the pottery geometry and the random breakage process. Archaeologists can more or less recognise a type correctly due to training, which depends on the number of potsherds they have studied. Consequently, to build a neural network able to reproduce the expertise of an archaeologist needs to face significant challenges, including the lack of real-world data to train the algorithms, the large variability given by the partial view of an object obtained by a random breakage process, the fact that a large portion of the potsherds is almost entirely non-informative, the similarity among different ceramic types that cause ambiguity in the classification, and a noisy acquisition process.

In ArchAIDE, it was decided to use synthetic data to train the algorithm to overcome data paucity[6]. At first, the 3D model of the vessel was reconstructed by ro-

[4] https://archaeologydataservice.ac.uk/archives/view/archaide_2019/ [accessed 27 May 2022].

[5] https://archaeologydataservice.ac.uk/archives/view/archaide_2019/stats.cfm [accessed 7 June 2022].

[6] Recently, Núñez Jareño *et al.* (2021) proposed to use a transfer learning approach where the model is first trained on a synthetic dataset using smartphone photographs of near-complete Roman terra sigillata pottery vessels. The results obtained are pretty promising, with a higher level of accuracy than ArchAIDE. Nevertheless, the obtained accuracy depends on working with almost complete vessels, using a smaller dataset (9 instead of more than 90 types) and being measured within the training process instead of in the field. On the contrary, the method proposed by Núñez Jareño *et al.* does not rely on the user's input in taking the photographs, which seems explicitly better than the methodology used by ArchAIDE.

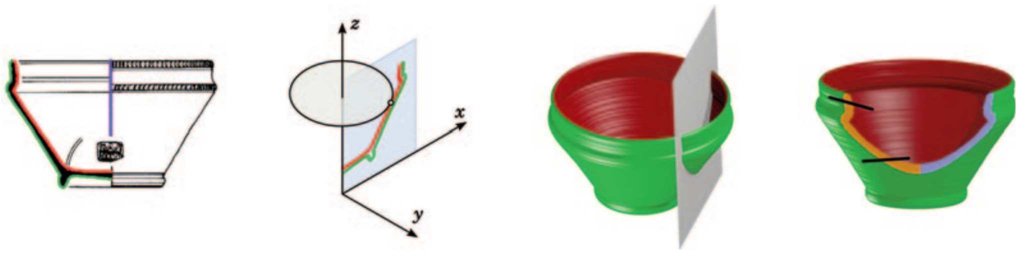

Fig. 3. The process for creating synthetic fractures. From left to right: (i) the extraction of inner and outer profiles from 2D drawing; (ii) The rotation process. A series of circles going around the vertical axis for each profile point generate a synthetic fracture from the profile; (iii) a random cutting plane cuts the 3D model. (iv) the synthetic fracture face. Two lines further cut the top and bottom of the fracture to create a potsherd with more realistic edges and size.

tating the profile extracted from the 2D drawing, and then it was virtually broken to derive synthetic sherds (Banterle *et al.* 2017). Being the making of a pottery vessel a non-industrial process, dimensional variability has been added to create more similarity with real-world vessels. This process resulted in computationally expensive 3D models. For circumventing the computation overhead of 3D reconstruction, a method for calculating only the surface of the synthetic fractures has been developed (Anichini *et al.* 2021). A series of circles going around the vertical axis for each profile point generate a synthetic fracture from the profile. Then the intersection of a random 3D plane with all the circles is computed, connecting the intersection points from the circles along the profile to generate the fracture face. The random plane is kept almost vertical to make the fracture shape more distinctive. After projecting the fracture back to 2D, its extent is reduced to match the dimensions of real potsherds, and the resulting polygon is cut using two almost-horizontal lines to add further realism to the synthetic fracture (fig. 3). All this process was based on empirical information given by archaeologists, not existing data about fragmentation and dimensional variability of the different pottery types. This represents another example of data paucity, or at least of the differences between data collected by archaeologists and the data needed by AI applications. Collecting data on thousands of potsherds for statistical analysis on fragmentation is a very time-consuming activity that archaeologists could use to understand formation processes and reuse for AI computation. Nevertheless, archaeology has recently addressed a Big Data and AI approach and has difficulties balancing between quantitative and qualitative analysis due to the cost of this process.

ArchAIDE has been conceived for use in real-world scenarios, i.e. by archaeologists in the field, and not in an aseptic lab environment, such as computing automatic recognition on satellite images. Let us consider when an archaeologist has to take a picture of the potsherd profile to send it to the classifier. A trained archaeologist has no difficulty approximating the vertical axis since the ceramic manufacturing process creates the potter's wheel lines and the orientation of the potsherd profile. Despite this ability to align the fracture correctly, this alignment is inexact since it is a manual process. Consequently, a slight random 3D rotation on each fracture was simulated before projecting it onto a 2D outline to add robustness.

Moreover, other concerns arise from the nature of the fieldwork. The correct recognition of a type depends not only on the shape but also on the dimension. This constrains taking a picture of the potsherd with a ruler used to infer scale information. Nevertheless, it is complicated to hold the ruler at the same distance as the fracture surface when holding the mobile device with one hand and the potsherd with the other hand. When combined with close-range photography, this seemingly slight distance from the camera has been shown to lead to scale computations that cause potsherds to appear up to 50% larger than their actual size. Consequently, a random scale factor was added to achieve robustness (Anichini *et al.* 2021).

Developing the image recognition neural network for decoration was easier (Anichini *et al.* 2021), but real-world challenges also occurred. Data augmentation was necessary to create a robust training dataset, but using the app in the field means working with varying backgrounds and lighting conditions. While varying lighting conditions could be simulated during training (by augmenting the image), removing the background and ruler from the image (as these can be understood by the algorithms and correlated to specific types, thus generating a bias) was more challenging.

Automatic extraction of the background and ruler in the training set using an interactive extraction algorithm (GrabCut) allowed to retrain the model with the background removed automatically and lighting augmentation and produced more robust results significantly in the face of varying photography conditions.

ArchAIDE neural networks were developed using TensorFlow 1.0 released in 2015, an open-source software library for artificial intelligence developed by Google. A second version, TensorFlow 2.0, was released in September 2019, immediately after the end of the project. As soon as the MAPPA lab, in collaboration with the SME Miningful Studio s.r.l.[7], started working on managing the networks for future implementation, it appeared clear that the migration from TensorFlow1.0 to 2.0 was not easy, and large sections of the code should be re-written. The choice has been to migrate the code to PyTorch, a deep learning framework developed by Facebook and released as open source in 2017. PyTorch appears more tightly integrated with Python, a wide-diffusion programming language. Maintaining a neural network is of paramount importance for the sustainability of

[7] http://www.miningfulstudio.eu/.

research projects that, differently from AI projects developed by worldwide digital companies, have to face budget limits and long-term usability. Consequently, even the technical choice of the digital framework is not a secondary aspect of AI application in archaeology.

3.4. Ethics

Transparency represents the ethical side of the challenges that AI poses to archaeology. Transparency is necessary for understanding biases in the data and the functioning of the algorithms. If the archaeologists cannot trust and verify that the AI algorithm has made a correct identification, the result cannot be used in research. ArchAIDE has worked and still works, in this direction. AI is often seen through the clichéd metaphor of the black box[8]. A black box generates outcomes, but knowledge of how they arrive remains hidden. It is seen as a mysterious, inscrutable, powerful entity connected to a "data-driven algorithmic culture" (Striphas 2015, p. 396). The other side of the black box is the transparency metaphor of the glass box. A glass box reveals what was hidden by the black box (Guidotti *et al.* 2018). One aspect of black-boxing is coupled with the opacity of proprietary software (Burrell 2016). An easy response is using open source software and making the code available. This is the choice followed by ArchAIDE. The source code and neural network models are publicly available as open source in the MAPPA Lab GitHub repository[9], and the same will be for the PyTorch version and the new classifiers, to allow reuse and future development by other researchers and permit reading and understanding of the neural network functioning. However, understanding the code requires technical skills. Moreover, deep learning techniques are especially problematic because algorithms "based on training data do not naturally accord with human semantic explanations" (Burrell 2016).

Transparency would also mean replicating the process, explicating the different variables and threshold values (Davis 2020) and sharing the training and testing dataset as open data. Unfortunately, all the data used by ArchAIDE has not yet been shared openly because of what was discussed in 3.2. Other methods for accessing digital black boxes have been suggested, among others, by Huggett (2017), Christin (2020), and Bucher (2016). In particular, the necessity of providing intelligible explanations of AI functioning is supported by Explainable Artificial Intelligence (XAI) (Barredo Arrieta *et al.* 2020) pursuing technological solutions. All these solutions are challenging and far from straightforward. The complexity of deep learning and neural networks with thousands of layers

[8] Not only AI applications but also many devices used in archaeology can be considered black boxes: digital cameras, hyperspectral cameras, terrestrial and airborne laser scanners, magnetometers, XRF technology, etc. (Huggett 2017).

[9] https://github.com/mappaLab (accessed on 28 February 2022).

and parameters makes these algorithms highly opaque. For example, the ArchAIDE neural network for appearance-based recognition uses a ResNet-50 network (He *et al.* 2016) composed of a sequence of blocks whose maps are multidimensional and contain a varying number of channels, and the network for shape-based recognition based on PointNet is even more complex (Anichini *et al.* 2021). The limitations of these approaches do not contradict the necessity of providing intelligible explanations, even if archaeological research is currently more focused on developing AI tools than on spending effort on incorporating methodologies to explain their outcomes (Huggett 2021). To avoid the black box risk, where little or no human intervention is envisaged beyond the allocation of their inputs, and subsequent incorporation of their outputs in analyses, the ArchAIDE system offers five results to the user at the end of the recognition process. Giving the last word to archaeologists at the end of the recognition process is a choice planned with professional archaeologists during the multiplier event and workshop organised by ArchAIDE to avoid the black box effect.

3.5. Epistemology and hermeneutics

Using ArchAIDE App through a mobile device, apart from a feeling of magic, gives a sensation of disruptiveness. The smartphone is mediating between the user and the potsherd. Archaeologists no longer need to take the potsherd in their hand, see and touch its surfaces and observe the paste for performing hermeneutics. The archaeologists only have to take a picture through the smartphone, while technology performs cognition instead of them.

Attention to epistemology, hermeneutics, technological agency, and competitive cognitive artefacts, which give rise to concerns about digital practices and autonomy lying beyond human control, have to be paid. Such devices have not yet become part of the everyday archaeological practice but, as in the case of ArchAIDE, are developed for day-to-day archaeological practice in the field, especially for professional archaeologists (fig. 4). Consequently, it is of paramount importance to address the challenges posed by autonomous digital tools possessing technological agency before they are more widely employed within archaeology (Huggett 2021).

If technology gives voice to things (Ihde 2009, p. 63), it also supports information to talk in the digital world. In a Big Data approach (Gattiglia 2015), the focus moves on technology's role in producing an interpretation, in other words, on the mediating role of algorithms in perceiving the world. Such digital material hermeneutics[10] emphasises the necessity to comprehend digital technology's role in mediating archaeological practice. In today's archaeology, a new platform

[10] Material hermeneutics is a hermeneutics which "gives things voices where there had been silence and brings to sight that which was invisible" (Ihde 2005).

Fig. 4. The ArchAIDE system was presented in numerous international events dedicated to professional and academic archaeologists. The aim is to support the work in the field with a free and easy-to-use tool that can be used both during excavation and post-excavation activities. ArchAIDE registered users can save a variety of information about pottery (e.g. classification information obtained from the automatic classification tools) and access information about their sites/assemblages/sherds stored in the device's local memory and, if the device is online, on the ArchAIDE server. The app registers the information locally when offline but will be saved to the server when online.

or application – as in the case of ArchAIDE[11] – determines new informational structures and may even lead to changes in the content itself. From the digitisation/datafication perspective (Gattiglia 2015)[12], datafication represents a changing and unstable representation and can be seen as a *performance* (Manovich 2013). In the performance, algorithms (in particular Deep Learning) deliver information and define how it is presented to the users. The performances vary, given when and who uses the app. For example, the same potsherd of Majolica of Montelupo photographed with different devices or light conditions or viewpoint, etc., and sent to ArchAIDE classifier always has the 83% probability of being in the top five responses, but with a different level of confidence given by the algorithms. In other words, it could be on the top, middle, or bottom of the list, varying the conditions. This means that information cannot be reread because it changes every time it is displayed. Nonetheless, performance and, therefore, datafication can perform hermeneutic tasks. The algorithms perform hermeneutics by extracting meaning from data, and the virtual cognitive process is embodied in computational media (Hayles 2017). This process can be considered cognition, which, unlike thinking, is achieved by humans and non-humans, including technology.

Moreover, algorithms "have a strong evolutionary potential than any other technology, and they have this potential because of their cognitive capabilities, which [...] enable them to simulate any other system" (Hayles 2017, p. 33). In

11 https://archaide-desktop.inera.it/home [last accessed 28 February 2022].

12 Digitisation is the migration of something in digital support; datafication is the transformation of an object or a phenomenon into tabular data that can be analysed through algorithms (Anichini, Gattiglia 2018).

other words, AI technology actively mediates the world and possesses technological intentionality; therefore, hermeneutic relations[13] in AI reflect the algorithms' technological intentionality. The algorithm achieves the interpretation and directs the user what to read. Consequently, AI algorithms have autonomy and intentionality; they require cognition and create a trace in the world. This non-anthropocentric shift embodies the more and more crucial role of AI algorithms. In the AI age, archaeology's challenge is to recognise technology as an agent (Huggett 2021) on whom we depend for extracting meaning and, at the same time, as something that partially reflects our hermeneutics (Wellner 2020).

A more disruptive element in AI is related to building the neural network. The data set needed to train an AI algorithm represents an example of composite intentionality. The creation of the training set is partly due to human choice and partly to technology intentionality. It does not only contain biases but it also contains agency. Both Ihde and Verbeek (2005) understand agency in terms of the technology's ability to mediate. In AI, we can imply a composite agency, a human agency that is given by human intentionality in building the neural network, and a technological agency given by digital technology intentionality. Disruption happens when we use AI; the algorithm performs hermeneutics, but it is rather hybrid intentionality (Verbeek 2008), in which humans and technology merge through their agency, creating a symbiotic agency (Demetis, Lee 2018, p. 944). When ArchAIDE gives its five answers, who is answering is a hybrid agent. The application leaves the archaeologists the opportunity to choose if the algorithm suggests the correct answer. Are we sure the ArchAIDE app really allows archaeologists to perform hermeneutics? Or is it only a shade of?

Digital technology used in archaeology allows experiencing phenomena that otherwise would not be perceptible by the body, but they become experienced because they are technologically mediated. Furthermore, digital technology has intentionality that is not directed at representing a phenomenon; instead, it constructs reality. To sum up, archaeology is mediated by instruments that are never neutral, and our knowledge of material evidence depends on the technology used. With AI algorithms, a sense of disruptiveness is added. When technologies support information to talk, everything changes. We cannot understand how the algorithms work, and we feel as being in front of a black box, but rather because algorithms perform hermeneutics instead of humans. When the ArchAIDE algorithm recognises pottery, algorithms perform cognitive processing. Their autonomous digital technological intentionality creates information, performs hermeneutics instead of us and finally directs archaeologists what to read. ArchAIDE offers five answers and leaves archaeologists the last control, but are we

[13] In hermeneutic relations, technologies deliver representations of reality, which need interpretation. A thermometer, for example, displays a value that requires to be read and interpreted for knowing the temperature (Ihde 1990, p. 89).

sure archaeologists can really understand how those answers were derived? Here, the critical question becomes whether the algorithmic mediation, digital hermeneutics and cognitive outputs are capable of explanation. At present, they are not or, if they are, the explanations are either uninterpretable or greatly simplified. Even if transparency seems achieved by publishing the source code on GitHub, the high specialist skill level needed for their understanding produces a form of opacity given by technical illiteracy (Hugget 2021). On the other hand, using human semantic explanations is equally problematic because it does not naturally accord with neural networks (Burrell 2016, p. 10). All this delivers ethical questions about the difficulties (or impossibilities) of verifying what cannot be fully understood. Finally, when we infer knowledge based on algorithms, we should be aware that the intentionality of the algorithms mediates between us and the world. In the AI age, the understanding of the past is non-anthropocentric. Digital technology is an agent on whom we depend to extract meaning and, at the same time, partially reflects our hermeneutics because in training a neural network, we use our knowledge, and in some way, we transfer our agency to algorithms.

4. Discussion and future steps

The three-year period after the project's end, also experienced by the covid-19 pandemic, has shown how appalling challenges are related to long-term sustainability – a question strictly associated with the research funding strategy. EU and national programmes support the research through a project-based process. Long-term sustainability is mainly transferred to the market or the possibility of obtaining new funding for further development projects. Market-oriented long-term sustainability is difficult to be pursued in the cultural heritage domain. As in the case of ArchAIDE, In-App purchase or app selling solutions are challenging due to the copyright restriction we discussed in 3.2 and the necessity of achieving an as complete as possible reference database of pottery classes. If the first issue involves legal aspects of a complex solution, the second one means conspicuous funding before being ready for the market. Furthermore, the absence of a business attitude of research institutions in the cultural heritage domain makes the transition to the market almost impossible. At least in the case of ArchAIDE, where neither research nor industrial partners accepted the challenge of moving to the market.

After the end of the project, ArchAIDE is maintained by the MAPPA Lab of the University of Pisa with the help of two SMEs: INERA S.r.l., which was involved in the project and continues to manage the web application, and Minigful studio S.r.l., which is maintaining the NNs. Moving from a 2.5 million euro funding to ordinary university funding caused an inevitable restriction in the operability and development of the system, and the going offline of the web application as well as the associated NNs have been unfortunately reported. This economic downgrade has an obvious implication for the number and quality of the components of the research team. The project-based strategy allows the construction of strong international (or national) research teams, which cannot be maintained after the project period, weakening the long-term sustainability of research products, especially in a fast-developing research field.

This awareness brought a medium-range strategy devoted to improving the system's overall reliability and a step-by-step research and innovation policy.

Reliability will be reached through better system maintenance, avoiding offlining the system and strengthening the NNs through their migration to PyTorch. Research and innovation will concern with adding new ceramic classes and new technological development. In the first case, MAPPA Lab[14] populated the reference database with a new class, Pisan Maiolica Arcaica, which is already online, whereas the training of the related decoration-based classifier is envisaged in the following months as soon as the NN migration is completed. The archaeological team led by Anacleto D'Agostino (University of Pisa) is implementing 2nd and 1st millennium BC pottery classes from the site of Uşaklı Höyük (Turkey) into the reference database to create an open web catalogue and train the shape-based network with a less standardised pottery class, which will also represent a new technical challenge. A collaboration has also begun with the University of Camerino, DAI (Deutsches Archäologisches Institut) and MIC (Italian Ministry of Culture) to populate the reference database with Roman common ware. These activities are time-consuming and expensive in terms of a person/month effort, even if fastened by the semiautomatic tools for the database population developed by CNR during the project. These aspects go in parallel with the political struggle to promote the dissemination of all the comparative collections as open research data in the ArchAIDE archive. An action, those for open data, that the MAPPA lab has carried out since 2012. All these challenges can be addressed by bringing together a wide variety of stakeholders from the technology and archaeology domains: a difficult task in a fragmented environment often characterised by the paucity of digital resources (see data availability) and funding, a framework even worsened by the project-based funding model. In this direction goes the recent involvement of MAPPA Lab in the doctoral project "Design and development on an open source platform of a terrestrial rover with autonomous and remote driving for geophysical and archaeological surveys" developed by Quirino Saraceni and promoted by the National Doctorate in Artificial Intelligence, dedicated to using a robotic arm able to distinguish in separate groups the different ceramic classes through AI. The project provides for the development of the ArchAIDE appearance-based NN to recognise pottery at a more general level (classes, at least technological classes, instead of types) and group them on a table with the robotic arm.

[14] The work was made thanks to the collaboration of Marcella Giorgio, a specialist in this ceramic class.

No less critical is the theoretical discourse for awareness in the use of AI application in archaeology and understanding of the agency role of AI in archaeology, investigating, for example, how inscribing agency into the algorithms may lead to algorithmic bias (O'Neil 2016), which reflects human bias, which recently the MAPPA Lab started for a human-centred AI[15].

Acknowledgments

This contribution was conceived after the development of the EU Horizon 2020 ArchAIDE project (GA No. 693548). We thank all the members of the ArchAIDE team (http://www.archaide.eu/teams). In relation to this paper, special thanks go to Nevio Dubbini for maintaining the neural networks and to Holly Wright for her continuous support. This contribution was conceived by Francesca Anichini (FA) e Gabriele Gattiglia (GG) together. FA wrote section 1, 2, and 3.2; GG section 3.1, 3.3, 3.4 and 3.5. Section 4 has been written by FA and GG together.

Abstract

The ArchAIDE project realised an AI-based application to recognise archaeological pottery, developing two deep learning algorithms to propose identifications based on images captured on-site while retaining key decision points necessary to create trusted results. One method relies on the shape of a potsherd; the other on decorative features. Developing the project meant facing challenges related to real-world archaeological data, deep learning techniques, ethics, epistemology, and hermeneutics. The project is still alive and moving towards long-term sustainability, which involves new challenges.
Keywords: Artificial Intelligence, pottery, data, ehics, hermeneutics.

Il progetto ArchAIDE ha realizzato un'applicazione basata sull'intelligenza artificiale per il riconoscimento della ceramica archeologica, sviluppando due algoritmi di Deep Learning per proporre le identificazioni sulla base di immagini acquisite sul campo, pur mantenendo punti decisionali chiave necessari alla creazione di risultati credibili. Un metodo si basa sulla forma dei frammenti ceramici, mentre il secondo sulle caratteristiche decorative. Lo sviluppo del progetto ha imposto il confronto con problematiche relative ai dati archeologici, alle tecniche di Deep Learning, a questioni etiche, epistemologiche, ermeneutiche. Il progetto è ancora attivo, ma è ora rivolto alla ricerca di una sostenibilità a lungo termine, problema che comporta nuove sfide da affrontare.
Parole chiave: *Intelligenza Artificiale, ceramica, dati, etica, ermeneutica.*

[15] As an example, see the presentation held at CAA 2021 virtual conference "Critical Digital Archaeology. A postphenomenological approach to AI applications in Archaeology" by Gabriele Gattiglia: https://2021.caaconference.org/wp-content/uploads/sites/28/2021/06/CAA2021_Detailed-Programme_16June.pdf. [last accessed: 27 May 2022].

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