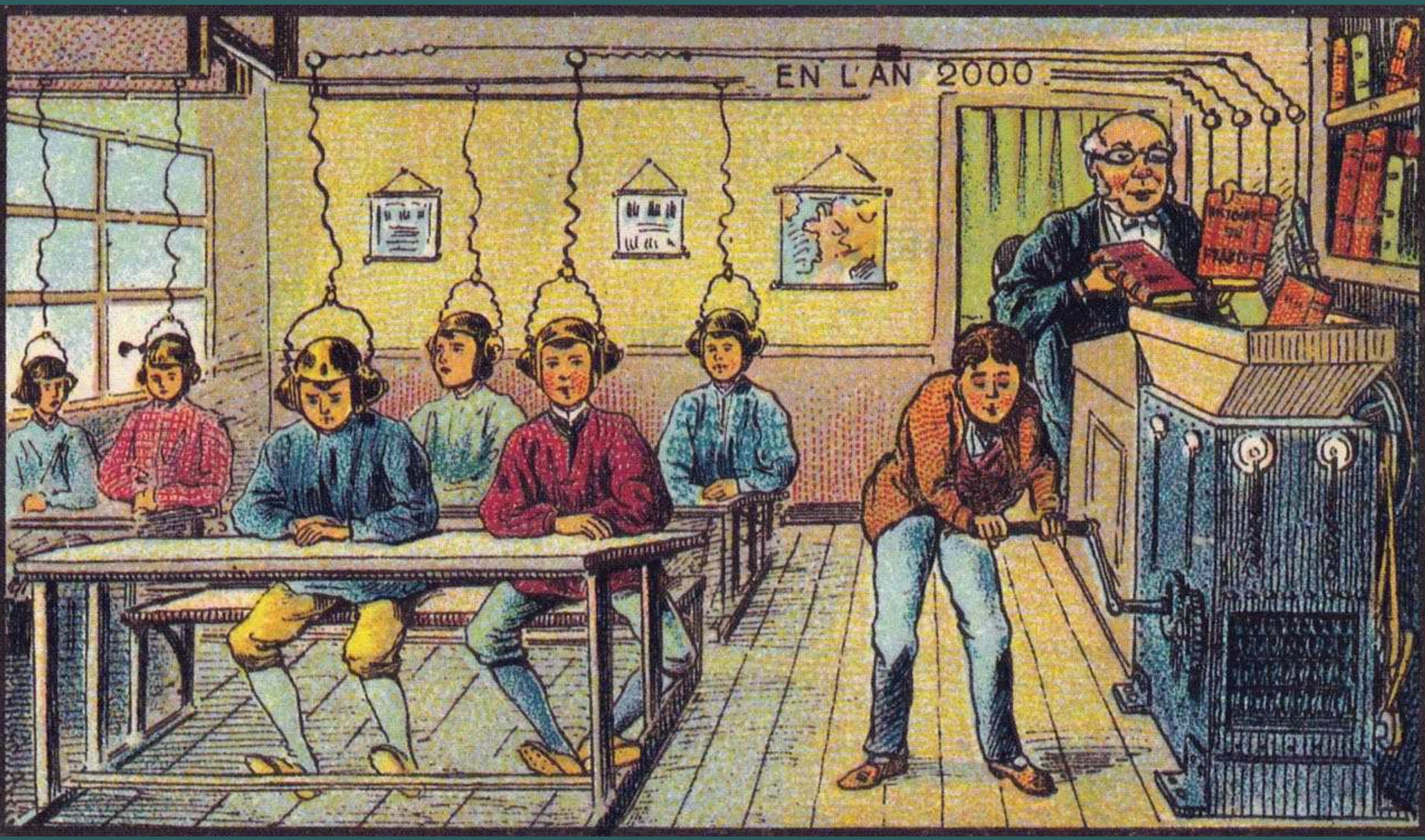
Critical Archaeology in the Digital Age



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Contents

Impactful Technologies

Rethinking Data

The Past of Digital Futures

CHAPTER 7

Scientific Dissemination of Archaeological Interpretation of Airborne LiDAR-derived Data

Benjamin Štular

Introduction

NASA archaeologist Thomas Sever is responsible for the first attempt at using airborne LiDAR data in archaeology in 1984–85 (Sheets and Sever 1988). However, at the time not even NASA had the computer power to make use of the data. As the technology matured, airborne LiDAR drew the wider attention of archaeologists in the 2000s (for example, Barnes 2003, Holden et al. 2002, Motkin 2001, van Zijverden and Laan 2004) and by the end of that decade it was established as a 'new' tool in the archaeological remote-sensing toolbox (for an overview see Opitz and Cowley 2013, Štular 2011). At the end of the second decade of the new millennium the potential for the method continues to grow, limited only by the availability of affordable computing and free or inexpensive datasets with nation- or state-wide coverage. Especially in heavily forested areas, there is up to a tenfold increase in the quantity of archaeological data for projects employing archaeological interpretation of airborne-LiDAR-derived high-resolution digital elevation models (colloquially referred to as LiDAR DEMs). Successful examples include entire cityscapes in a tropical forest (Evans 2016), more than one hundred thousand potential archaeological sites in a single German state, Baden-Württemberg (Hesse 2016), or thousands of prehistoric features recorded—and over one hundred thousand estimated—in the Slovenian landscape of Knežak (Laharnar et al. 2019).

However, after several years of preliminary reports in scientific journals on 'revolutionary' discoveries, the truly profound paradigm-changing impact of airborne LiDAR data on archaeology is still absent. For a while, it seemed that it was just a matter of time for the projects to be published in full. However, after conversing with many of the leading European specialists, a common theme emerged: the sheer quantity of the data prevents timely publication in the format that would adhere to the current standards for scientific publication in archaeology. In the meantime, the resources that the teams working on airborne LiDAR have already invested in data-processing and mapping require scientific (that is, professional) recognition, thus precluding the release of 'raw data.' The outcome of these circumstances is often the hoarding of data in the hope that the funding for the final publication is just around the corner. Corners don't turn, years pass. Such a predicament is not unique to airborne LiDAR, but is a recurring theme in several fields of digital archaeology. Solutions, therefore, must not and cannot emerge in isolation but rather in the context of digital archaeology as a whole, to which this volume is dedicated.

Airborne LiDAR in Archaeology

Airborne laser scanning (ALS), commonly referred to as airborne LiDAR, is a remote-sensing technique widely used for recording the landscape surface for different applications, archaeological prospection among them. The process of data acquisition is well established (for example, Doneus et al. 2008, Kobler et al. 2007, Wehr and Lohr 1999). The laser scanner—usually mounted on an airplane, a helicopter, or recently a UAV—emits optical laser light in pulses in different directions across the flight path toward the earth's surface. The time it takes for a pulse to return to the sensor is a measure of the distance between the laser head and the ground. The laser measurements are georeferenced with accurate differential global positioning systems and inertial measurement units that record the angle orientation of the sensor to the ground. This equipment allows for measurements of surface elevations with an accuracy in the centimeter range. The sheer quantity of laser pulses—up to 500,000 per second—enables sensors to 'penetrate' vegetation canopies, allowing the underlying terrain elevation to be accurately modeled (for example, Dong and Chen 2018:19–26, Petrie and Toth 2008). As a rule of the thumb, it can be said that if a person standing in the forest looking at the sky can see even the tiniest bits of the sky, then airborne LiDAR will be able to scan the ground.

The result of such scanning is a huge amount of 3D measurements. These measurements are first processed into a 3D point cloud, from which various products are produced, suited to many different purposes. In archaeology, the most important product is a representation of the surface topography in digital format called a digital elevation model (DEM). The processing of data specific for archaeology is a four-stage process, from raw data acquisition and processing, point cloud processing, and derivation of the products to the archaeological interpretation and dissemination and archiving (Lozić and Štular 2021; Figure 7.1.).

Ideally all four stages would be implemented with archaeology in mind. The most important requirement in data processing for archaeology is the noise-to-detail ratio. In archaeology, high detail–high noise is preferred to lower detail–low noise. In archaeological practice, however, data processing (Figure 7.1., stages 1 and 2) is often blackboxed (Doneus and Briese 2011:59, Doneus et al. 2020:93, Lozić and Štular 2021:1, see also Latour 1999:183–85). Custom 3D point cloud processing is becoming more and more common, thanks in large part to the software LAStools. The importance of DEM interpolation is still underestimated and typically only the most rudimentary algorithms are employed. In contrast, most archaeological studies implement custom DEM visualization(s), which is a result of intensive methodological development in the past decade (see for example, Figure 7.2.). With this in mind, it is clear that in current archaeological practice of airborne LiDAR-derived data processing, the importance of custom data processing is still too often disregarded, and the importance of the operator's decision-making is underappreciated (Doneus et al. 2020:93, Doneus and Briese 2011:59, Doneus and Kühtreiber 2013:33–34, Lozić and Štular 2021:1–2, Opitz and Cowley 2013:6, Štular and Lozić 2020:2).

The results of the processing described above may be manipulated to create enhanced visualizations of airborne LiDAR-derived high-resolution DEMs (for example, raster grid cell size 0.5 m). These are interpreted by archaeologists with "a combination of perception and comprehension" (Parcak 2009). A successful archaeological interpretation of this data relies on a user-determined, knowledge-based interpretation that includes complex pattern recognition and the ability of the interpreter to recognize, identify, and classify complex landforms based on experience and previous archaeological knowledge (Challis et al. 2008, Crutchley 2009, see also Parcak 2009). The process, therefore, is based on a substantial body of knowledge on the one hand and on objective decision-making on the other hand. If this process, by which an interpretation is developed, is documented, it is by definition a process of scientific knowledge creation.

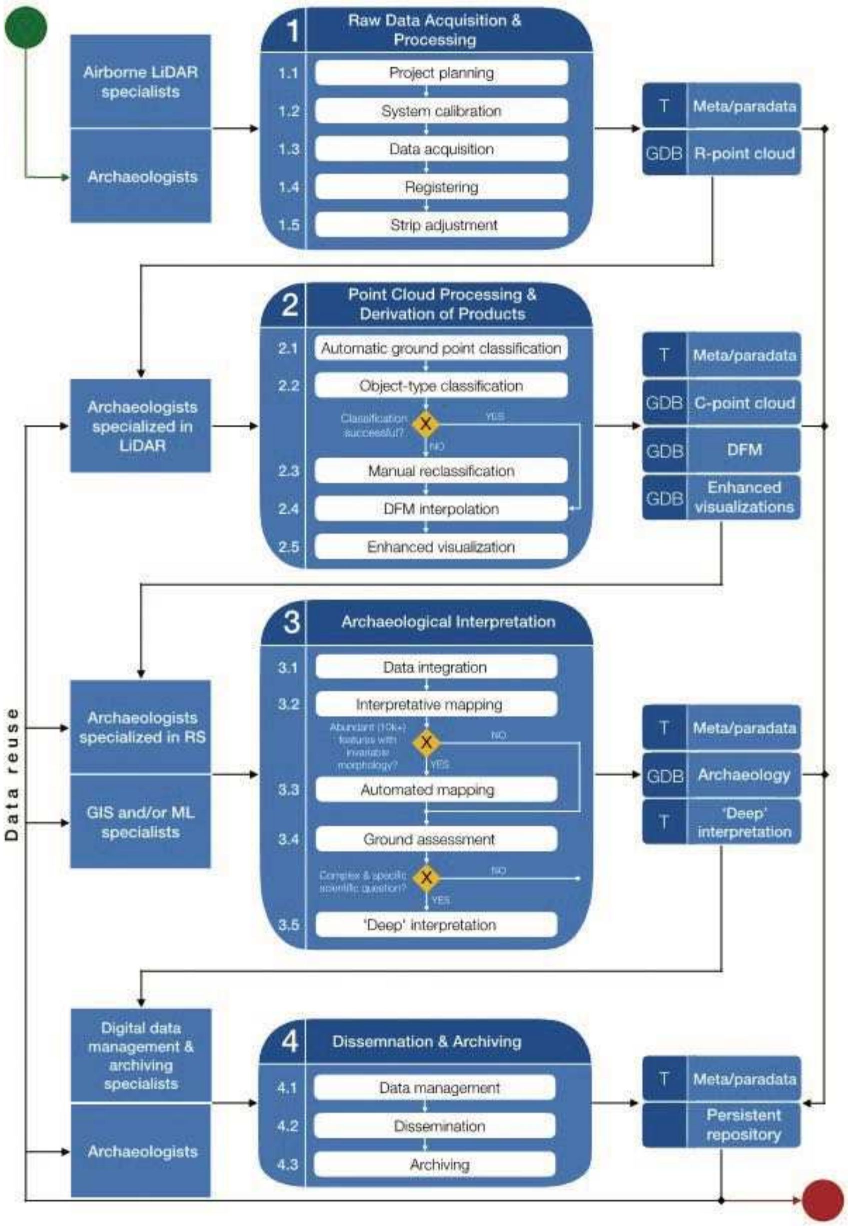

Figure 7.1. Context data-flow diagram (DFD1) of archaeology-specific airborne LiDAR data processing. Symbols for external entity, process, data flow, and data store are based on Gane and Sarson's (1979) notations, but with additional notations for data store types: GDB—geodatabase, T—(textual) descriptive data store. *After Lozić and Štular 2021, Figure 1.*

The archaeological interpretation of airborne LiDAR-derived data, most often in the form of enhanced visualizations, has proven to be very successful in the detection of various archaeological features, ranging across houses, ramparts, trenches, ditches, fossil fields and terraces, past land division, abandoned quarries and mining areas, burial mounds, ancient roads, and other elements of archaeological landscape and sites. It has been successfully applied for archaeological prospection in flat and undulating agricultural regions (for example, Challis et al. 2008 with earlier references, Buteux and Chapman 2009, Corns and Shaw 2009, Crutchley 2009) as well as forested slopes on hilly or mountainous terrain (Devereux et al. 2005, Doneus et al. 2008, Sittler 2004, Štular 2011) and even in tropical jungles (for example, Beach et al. 2019, Chase et al. 2010, 2011, Evans 2016).

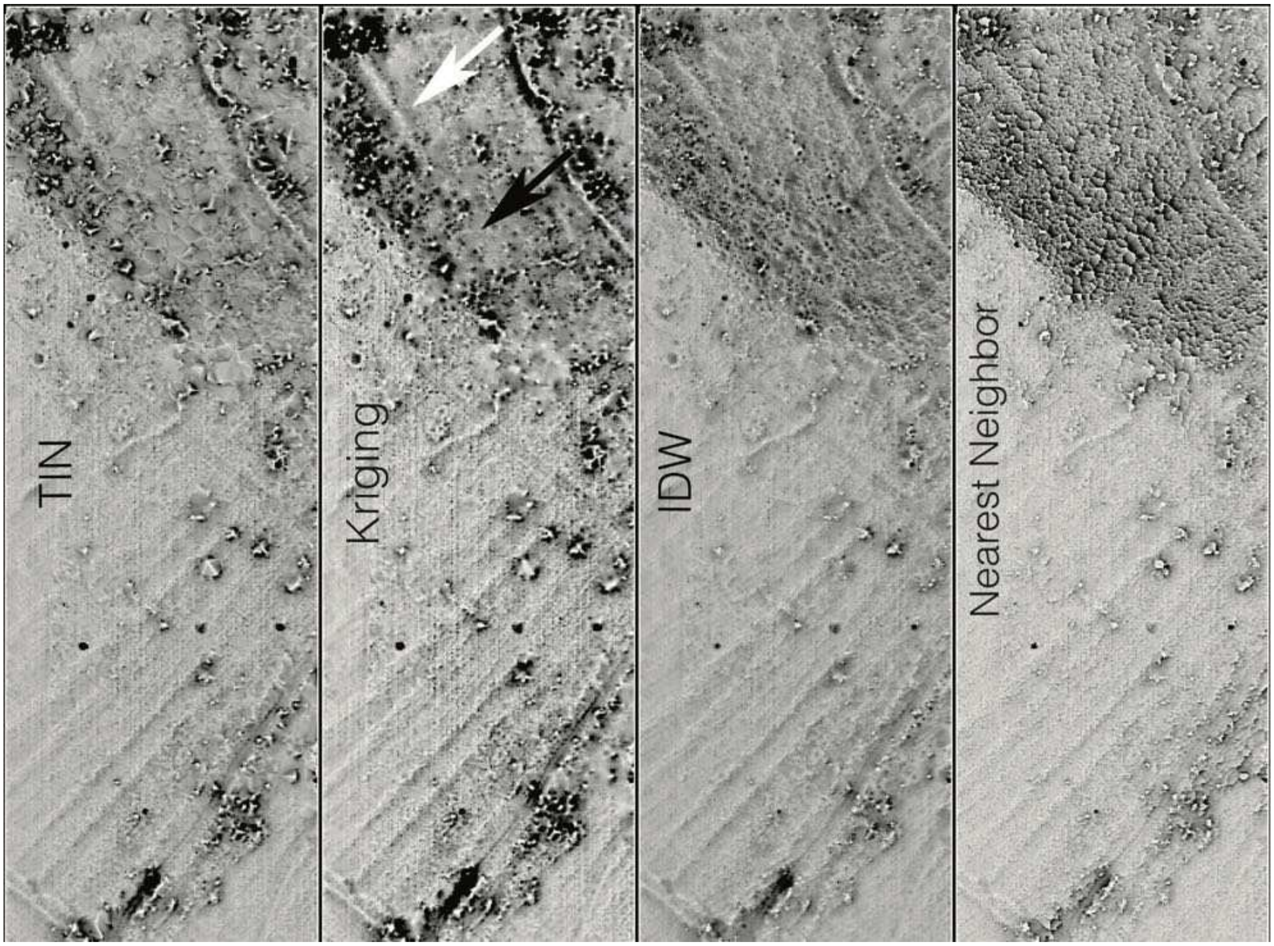

Figure 7.2. Nadleški hrib Roman military camp (Slovenia), an extract showing the eastern ditch. Four different interpolation algorithms (from left: triangulated irregular network, kriging, inversed distance weighting, and nearest neighbor) of the same airborne LiDAR-derived data are shown. The white arrow points to the section of the ditch visible on all visualizations, the black arrow points to the section detectable only with the kriging interpolation. *Image by B. Štular and E. Lozić.*

In many contexts, airborne LiDAR is the most prolific method in archaeological prospection. The ability of the airborne LiDAR to map the ground surface beneath most types of vegetation canopy is particularly relevant. No other remote-sensing method in archaeology is able to consistently produce excellent results in such environments. It can be said without reservation that in forested areas, airborne LiDAR has eclipsed past incremental improvements in remote sensing in archaeology. Typically, in such environments, this method increases the number of known archaeological features between five- and tenfold. Such an increase in quantity and quality of data sheds entirely new light on our understanding of conflict landscapes, archaeology of movement, settlement archaeology, and even paradigmatic changes to broad topics such as prehistoric settlement in the circum-Adriatic region. It is also forcing archaeologists into completely new research directions (such as infrastructural landscape).

At the same time, it is important to caution against overly high expectations (see Crutchley 2009), as the potential for data is unevenly distributed, both across the discipline and across different landscape contexts. For example, the benefits for archaeology of cave sites or industrial archaeology are limited, and urban areas have significantly lower potential than forests.

Knowledge Production Process

The above description demonstrates that the processing of airborne LiDAR-derived data in archaeology has reached a stage of methodological maturity. However, a profound paradigm-changing impact is still missing. One of the key reasons for this is the lack of ubiquitous scientific dissemination of archaeological interpretations of airborne LiDAR-derived data. It is only such publications that will enable extensive engagement from the larger archaeological community and it is only such extensive engagement that will spur the profound impact on archaeology. The reason for this may seem superficial at first. In most airborne LiDAR research projects, huge amounts of archaeological interpretations are produced, mostly in the form of geodatabases. However, huge amounts of archaeological interpretations are almost never published (no such example is known to the author at the time of writing). One possible solution would be sharing of the data, in the geodatabase format for example. But currently, this solution is not sustainable due to the lack of professional recognition, the additional labor required to prepare the data, and the lack of suitable repositories (see Selhofer and Geser 2015).

Anecdotally, the number one obstacle for such publication is the lack of time and resources to prepare a 'full publication' in the format that adheres to current standards for scientific publication in archaeology. These standards mandate physical dating evidence and ground assessment, in addition to the archaeological interpretation of detected features. The former is by far the most time-consuming part of the process, especially for a typical laboratory-based team of airborne LiDAR specialists with finite resources. As an example, we can look to the case of Knežak, Slovenia. Archaeological interpretation of the airborne LiDAR-derived data took about two months, and yet field assessment has been ongoing for three years. In that time, less than 10 percent of the features have been investigated on the ground, and even there, ground assessment provided little or no new information (Figure 7.3.). The estimated cost of trial trenching and Carbon-14 dating of 10 percent of all features discovered is approximately two million euros, twenty times the cost of the original mapping.

To make this more tangible, we can look to a Europe-wide simulation. 43 percent of EU countries are forested (Cook 2018, see also Fuchs et al. 2012; Figure 7.4.), and by 2020 airborne LiDAR data will be accessible for most of the area. If we use the most conservative estimate for the increase of known archaeological features in forested areas (five-fold), there is potential for a 215 percent increase in known archaeological features on the EU scale. Ground assessment of such an immense quantity of newly detected features would take generations of archaeologists to investigate.

This, however, is not a superficial logistical problem but one that it is deeply rooted in archaeological practice. Landscape archaeology, and perhaps archaeology in general, is a field-based discipline, as summed up in a candid description by Johnson:

> In landscape archaeology, a central arena of everyday practice is 'the field.' The encounter with primary data in the field remains central in the hearts and minds of archaeologists. 'Direct field experience' is routinely cited as a primary determinant of evidence. A routine device in the praise of archaeologists is to praise the length and arduous nature of their time in the field. (Johnson 2012:518)

In other words, airborne LiDAR-derived archaeological data obtains the status of archaeological information only upon assessment in the field. That this act is colloquially known as 'ground-truthing' is telling.

That is not to deny the pivotal position of 'the field' in the knowledge production process. Firstly, there is the indispensable data gathering; artifacts and dating samples must be obtained and interviews with locals must be conducted. Furthermore, there is an undeniable positive effect in a set of bodily practices and sensibility gained during the field work (for example, Johnson 2012:518–21). Therefore, 'the field' is and will remain a vital part of archaeological practice. What I argue is that the laboratory-based archaeological interpretation of airborne LiDAR-derived data is a knowledge production process in its own right, just as much as the bodily experience of fieldwork or interpretation of an artifact. Hence, its dissemination must be awarded the status of scientific text (for example, scientific article, scientific monograph). Similar trends can be observed in other disciplines that strive toward the acceptance of executable scientific publications (Strijkers et al. 2011) and

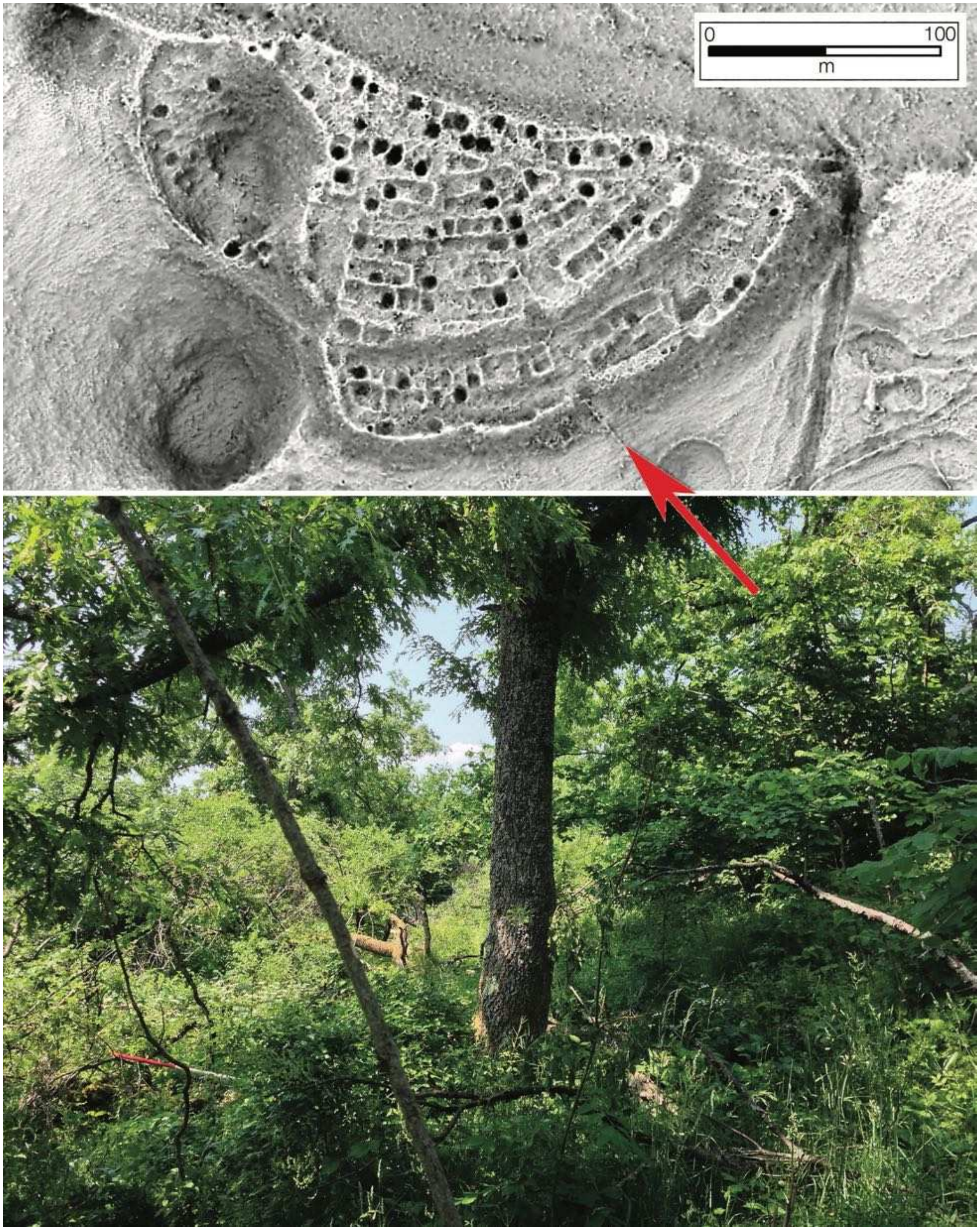

Figure 7.3. Knežak (Slovenia) hillfort. Compare the information value of the photograph taken in the field (view from southeast toward the hillfort entrance) with that of the visualization (image fusion based on SVF and openness) of the airborne LiDAR-derived high-resolution (0.5 m) DEM. *Image by B. Štular and E. Lozić.*

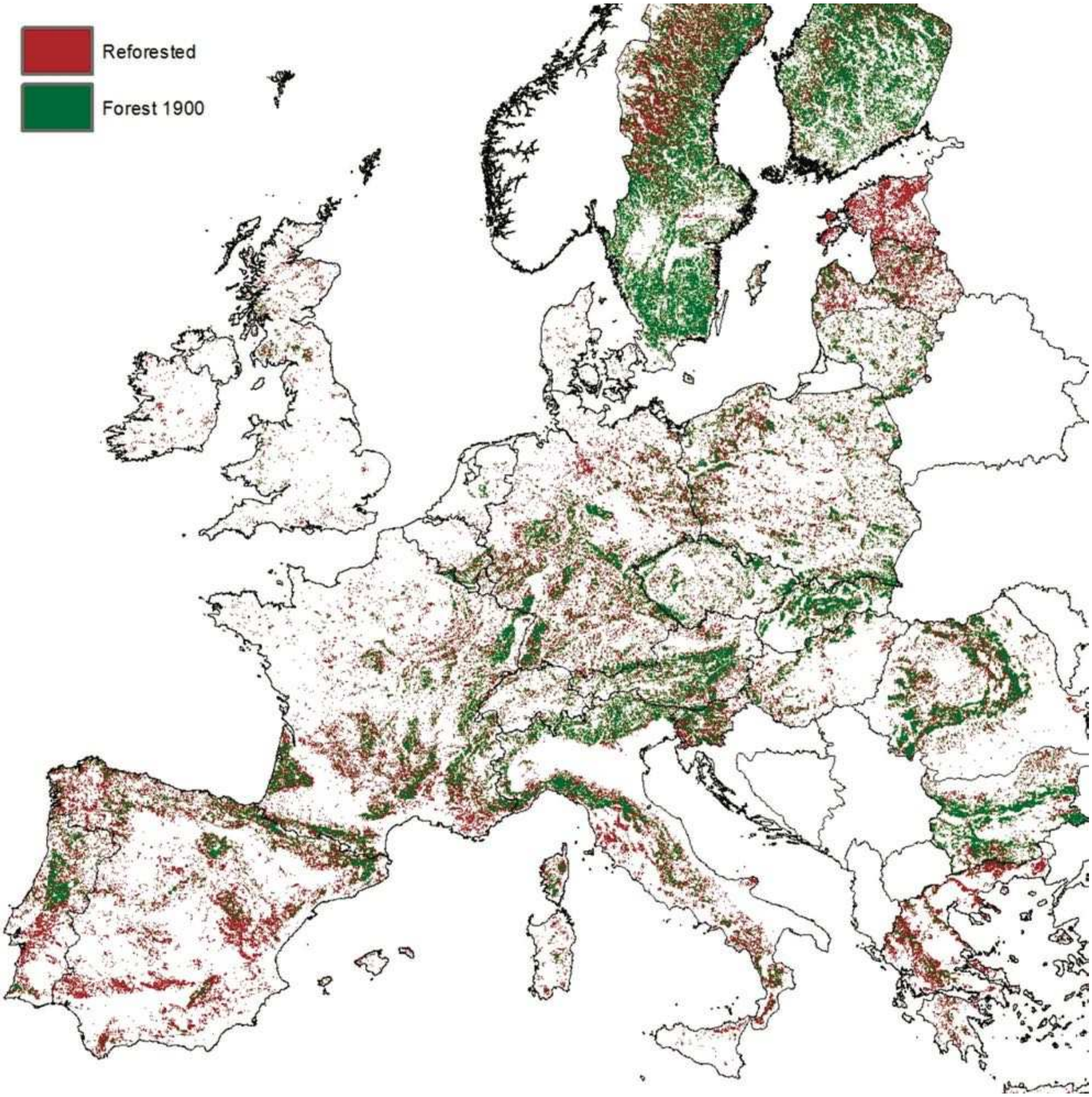

Figure 7.4. Forests in EU countries—green: 1900; red: reforested after 1900. *Sources: Fuchs et al 2013, Fuchs et al. 2014. Image by B. Štular.*

data papers (Li et al. 2019). Once this is accepted by the archaeological community, one major obstacle for large-scale dissemination will be removed. As a consequence, the field assessment process will be distributed among the interested archaeological community; each feature mapped can be inspected at any time in the future as funds, need, or scientific interest arises.

Scientific Dissemination Platform

The above demonstrates that to use the enormous potential of airborne LiDAR, archaeology must evolve as a science and devise coping mechanisms. The key is to accept laboratory-based archaeological interpretation of airborne LiDAR-derived data, as well as other 'digital work,' as a scientific process. To this aim, the practitioners must make big strides to make this process as transparent and as repeatable as possible. The dissemination platform proposed here is a backbone for this mechanism.

A clear distinction must be made between what is proposed here and the undertakings for scientific recognition to publish high-quality research data with appropriate documentation and alignment to accepted standards (for example, Kansa and Kansa 2014, Pfeiffenberger and Carlson 2011). In the case of airborne LiDAR-derived data in archaeology, a DEM that is custom-processed for archaeology is suitable for data publication. The key focus here is on archaeological interpretation, which is a model example of scientific interpretation. However, granting this type of archaeological interpretation a status of scientific interpretation in itself is not sufficient, since current scientific publication platforms are not well suited to this aim. This is often the case with digital-born data, as elaborated by several papers in this volume.

A brief overview of archaeological publication platforms where airborne LiDAR is a common topic is warranted. Inspecting a few of the most commonly used—*Journal of Archaeological Science, Remote Sensing, Antiquity, Archaeological Prospection*—reveals that a) most are still also published in print, but b) most are predominantly disseminated as digital files in pdf format; c) some offer attachments (such as GIS files), but d) attachments are rarely accessed by readers (as can be conjectured by the lack of citations), and e) the publication process is either lengthy (for example, more than one year) or rushed (like one week to implement reviewers' remarks).

An overview of the contents is also revealing. Firstly, unless paradata and/or metadata are the subject of the article these are rarely published in any detail. This absence is sometimes taken to the absurd, when for instance a visualization of airborne LiDAR-derived DEM is referred to simply as a "LiDAR image." This, however, is often at least in part the result of editorial policy and/or peer-review process that deem these data unnecessary. Secondly, there are no accepted standards for graphical representations of the archaeological features that are crucial to this subject matter. For example, when the features in question are only hinted at by arrows or similar icons, the reader is put at a considerable disadvantage; they lack the context for the process of interpretation and the aids used by the author(s), such as different visualizations, different scales of observation, or supporting cartographic and/or remote-sensed data. Thirdly, visualizations of DEM are currently the best documented segment of the entire process, yet different visualizations of the same (set of) feature(s) is rarely present.

Therefore, I would like to suggest that a new dissemination model is needed to 1) adhere to the accepted standards of scientific publication, and 2) overcome the current shortcomings. The primary interface of the dissemination platform must conform to existing expectations in order to be recognized by the target scientific community. This includes text and elementary figures published in pdf format that can be printed by those who want it in paper form. However, this format on its own is not sufficient for dissemination of this particular type of information. For example, the size of a printed map of a typical medium-sized case study of 10 by 10 kilometers at an appropriate scale of 1:2000 is 5 by 5 meters, and a sheet with metadata for ten thousand features is approximately forty pages long. The new format must enable a seamless fusion of reading experience with that of browsing maps in a digital, GIS-like environment. In addition, the envisaged dissemination model must be designed to mitigate other identified shortcomings by achieving the objectives outlined below.

The first objective is to enable the process of archaeological interpretation to be as transparent and as repeatable as possible. This can be resolved by a rigorous control over and publication of a) paradata, which describe the modeling process and data sources, b) standardized per-feature metada for archaeological interpretation (such as visibility, visualization used, interpretation/chronology description, interpretation/chronology confidence level), and c) standardized mapping conventions for archaeological features.

The second objective is to enable the rapid process of metadata and paradata publication. One of the key reasons why metadata and paradata are so rarely published in their entirety is that it is a tedious and lengthy process. However, this can be significantly alleviated by embedding the following services in the dissemination platform: a) a standardized online form for metadata and paradata entry (provided but not mandatory), b) metadata standards for archaeological interpretation (such as template GIS files) that will, if properly implemented throughout the process of archaeological interpretation, significantly shorten the effort invested in per-feature metadata description, c) collection of metadata for commonly used data sources (for example, if the same acquisition parameters have been used for an entire country/state, metadata must only be published once), and d) certain metadata parameters can be created automatically from the data attachments (for example, raster resolution).

The third objective is to provide assistance in the review process. In the current practice of scientific publication, there is a pressure on rapid publication. However, speeding up the established process is more often than not based on pressuring the voluntary reviewers and authors into rushing respective tasks. This can lead to diminished thoroughness of both parties. To this end, partial automatization of the review process for selected qualitative (for example, metadata and paradata entered via the online form) and quantitative (for example, presence/absence of per-feature metadata) parameters would be available as an aid to both authors and reviewers. This is to say, validity checks (presence/absence of technical content) can be automatized so that the reviewer can focus on the scientific content.

The fourth objective is to reach the target audience. As mentioned, the publication format must enable seamless fusion of the pdf-reading experience with that of browsing maps in a digital GIS-like environment, enabling the following: a) seamless back-and-forth transition between basic (text reading) and advanced (GIS-like environment) functionality, b) basic search capabilities, foremost in connection with the text of article (for example, particular features mentioned in the text must be seamlessly identifiable), c) inspection of various DEM visualizations in 2.5D and 3D, d) dissemination, including (but not limited to) at least the four most commonly used visualizations (relief shading, sky view factor, openness, color-casting; see Kokalj and Hesse 2017), and e) per-feature metadata.

The technical platform to achieve these objectives could be based on an open-source service for 'visual media' files, such as ARIADNE visual media services (Ponchio et al. 2016, Štular et al. 2016). This service already provides easy publication of complex visual media assets on the web powered by open-source software 3DHOP (Potenziani et al. 2015) and Relight. This, or similar, service could be built upon with custom solutions suited for airborne LiDAR, such as large 2D images, 3D models, and hyperlinks to data. This solution should be integrated with an open source journal management and publishing platform, such as Open Journal Systems. For example, a pilot within the ongoing ARIADNEplus project will be built on the d4science (www.d4science.org) Virtual Research Environment.

Conclusion

"As all archaeologists now use digital tools in some, if not most, aspects of their work, we have the responsibility to critically interact with these tools and their potential impact on the way we do archaeology." These are the words with which Kevin Garstki invited participants to the conference from which this proceeding stems. Airborne LiDAR-derived data are no exception but rather a prime example of this. The use of these data in archaeology has produced an unprecedented amount of new data in the last few years, but the knowledge production process is mostly poorly documented, often blackboxed, and the data remain unpublished. Therefore, the benefits for archaeology as a discipline remain limited. The obstacles were long perceived to be logistical in nature and the solution seemed to be just around the corner. However, corners didn't turn and years passed. It would seem that it will take nothing less than a shift in landscape archaeology from being a predominantly 'ground-based' science to become an at least partially 'data-led' science. This will enable large-scale dissemination of archaeological information that in some environments will be on an unprecedented scale. In turn, this will trigger engagement from a larger archaeological community and the potential for paradigm-shifting archaeological discoveries on a regional scale will be unlocked.

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Critical Archaeology in the Digital Age

Every part of archaeological practice is intimately tied to digital technologies, but how deeply do we really understand the ways these technologies impact the theoretical trends in archaeology, how these trends affect the adoption of these technologies, or how the use of technology alters our interactions with the human past?

This volume suggests a critical approach to archaeology in a digital world; to understand how digital tools are used, how they work, and how they affect practice. The chapters in this volume demonstrate how this critical, reflexive approach to archaeology in the digital age can be accomplished, touching on topics that include 3D data, predictive and procedural modelling, digital publishing, digital archiving, public and community engagement, ethics, and global sustainability.

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Above: View of the façade of the Temple of Vespasian and Titus in Rome from the west rostra.
Image rendered from the Rome Reborn model, copyright 2019 Flyover Zone Productions.
Front: A card produced in France in either 1901 or 1910 with art by Jean-Marc Côté/Villemard
depicting a French schoolroom of the year 2000. Public domain image from Wikimedia Commons.

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