Archaeological Technological Developments in the Use of Computing and Statistical Analysis

Khabzaoui Abdelkarim [1], Cherifi Mourad [2]

[1] University of Souk Ahras (Algeria), a.khabzaoui@univ-soukahras.dz
[2] University of Medea (Algeria), cherifi.mourad@univ-medea.dz

Received:04./09/2025 *Accepted: 20./12/2025* *Published:26./01/2026*

Abstract:
This paper examines the transformative impact of advanced digital technologies and computational methods on archaeological research. It specifically addresses the question: In what ways have tools such as 3D imaging, Geographic Information Systems (GIS), remote sensing, and artificial intelligence (AI) revolutionized archaeological discovery and analysis? The review underscores enhancements in site detection, non-invasive exploration, and the generation of data-driven insights into ancient environments. Additionally, it explores the challenges associated with digital integration, with a focus on cultural heritage preservation, accessibility through interactive platforms, and privacy concerns in the management of archaeological data.

Keywords: Virtual excavations, Digital mapping, Data analysis and statistics, Big data analysis, Artificial intelligence.

INTRODUCTION:

In the last decade, archaeology has undergone a radical transformation owing to the integration of advanced digital technologies at all stages of research and analysis. With the increasing reliance on computing, geographic information systems (GIS), and artificial intelligence (AI), archaeological methods have become more precise and capable of processing complex data and exploring sites noninvasively. Despite significant progress in statistical processing tools, 3D modeling, and remote sensing, challenges related to digital data preservation, privacy, and fair access to knowledge remain unresolved.

This article aims to analyze the impact of digital technologies on the development of archaeological research methods by providing a critical review of the statistical tools and computational methodologies currently adopted, and highlighting their applications in investigation, discovery, and interpretation. It also discusses the interaction between archaeological theory and technical practices, focusing on the ethical and practical issues arising from the increasing dependence on digital solutions. This article is a scientific review that highlights current trends and contributions resulting from collaboration between archaeologists and technology experts and offers an analytical perspective on the future of digital research in this field.

Theoretical framework:

This study is based on a theoretical framework that integrates conventional archaeological work with modern digital practices, emphasizing data management, 3D modeling, GIS applications, and big data analysis using AI and machine learning. This article discusses the benefits of these tools in enhancing artifact classification and predicting discovery sites, while also addressing technological ethics issues such as data ownership and the accurate representation of cultural heritage. In addition, it examines the digital divide among research institutions and stresses the importance of capacity building and the dissemination of technical knowledge in archaeological communities.

.1.Digital Technologies and Computing in Archaeology

1.1.3D imaging and modelling of archaeological sites and artefacts

3D imaging and modelling technology has significantly improved archaeological research and renovation efforts by enabling the creation of specified virtual representations of websites and artifacts. These advanced techniques, together with photogrammetry, laser scanning, and light scanning, permit archaeologists to capture particular measurements and textures, resulting in accurate three-D models. These virtual replicas offer researchers remarkable access to spatial and visible statistics, facilitating remote studies, analyses, and collaborations. (García-Molina et al., 2021)

The democratization of this generation expands past studies, offering innovative solutions for cultural background maintenance and public engagement. By growing special virtual replicas, researchers can take a look at and examine gadgets without risking damage to the unique artefacts. This noninvasive approach is particularly valuable for fragile or deteriorating gadgets, including textiles. Furthermore, three-D fashions allow the digital reconstruction of historic structures and landscapes, offering new insights into civilizations and allowing for immersive academic reviews. These virtual representations can be effortlessly shared and accessed globally, democratizing access to cultural history and fostering international collaboration in archaeological studies and conservation efforts.

The packages of three-D imaging and modeling in archaeology are diverse and large. These technologies permit the documentation of fragile or inaccessible websites, facilitate the reconstruction of broken or partly excavated systems, and are useful resources for the conservation and healing of artifacts. Additionally, 3-D fashions can be used for public engagement and schooling, permitting museums and academic establishments to create interactive exhibits and virtual excursions. As generation keeps to boost, the mixing of 3-D imaging and modeling with other virtual equipment, together with digital and augmented fact, guarantees to in addition enhance our information and appreciation of archaeological heritage web sites.(Khater, 2025)

1.2.Virtual excavation using augmented-reality techniques.

Virtual excavations and the use of augmented reality (AR) strategies represent a huge advancement in archaeological studies and education. This revolutionary approach combines virtual technology with traditional archaeological strategies, allowing researchers and students to discover historic websites without causing physical disturbances. AR overlays virtual data onto the actual environment, creating an immersive experience that complements the understanding of archaeological contexts and their spatial relationships. The software of AR in digital excavations provides several advantages. This permits the renovation of delicate artifacts and sites while offering sensible simulations of excavation procedures. Researchers can manage digital layers of soil and examine digital representations of artifacts in situ, gaining insights into stratigraphic relationships and placement formation techniques that have been previously inaccessible. Additionally, AR technology helps with collaborative work among geographically dispersed teams, allowing experts to present their findings and interpretations in real time. This approach additionally serves as a powerful academic tool, making archaeological ideas extra on hand to students and the general public, thereby fostering greater engagement with the cultural background.(Ramos Sánchez et al., 2022)

1.3.Geographic Information Systems (GIS) for digital mapping and site analysis.

Geographic Information Systems (GIS) have visualized digital mapping and placement analysis by providing effective gear for gathering, analyzing, and visualizing spatial facts. GIS integrates diverse forms of geographic records, along with topography, land use, population demographics, and environmental elements, into a single platform. This integration allows for complex spatial analyses and the creation of unique interactive maps that can be easily updated and visualized for specific programs.

In site analysis, GIS plays a crucial role in decision-making methods for urban planning, environmental control, and infrastructure improvement. This allows planners and analysts to overlay multiple layers of information, including zoning policies, soil types, and flood risk zones, to discover the

most desirable locations for new developments or check the ability effect of proposed tasks. GIS also allows the creation of 3D models and simulations, permitting stakeholders to visualize and examine specific scenarios before implementation. Furthermore, the incorporation of real-time data from sensors and satellite imagery complements the accuracy and timeliness of website checks, making GIS an essential tool for current spatial planning and analyses.(Santos et al., 2024)

1.4.Practical applications of computing in field recording, laboratory analysis , and restoration.

Computing technology has visualization subject recording practices in various clinical disciplines. Researchers now hire superior digital devices and software programs to seize, shop, and examine data with unprecedented accuracy and efficiency. These tools range from handheld GPS gadgets for unique region tracking to state-of-the-art sensors that measure environmental parameters in real time. In ecology and wildlife research, computerized digital camera traps and acoustic recorders allow long-term monitoring of species behavior and population dynamics, producing full-size record sets for evaluation. (Ahumada et al., 2019)

In laboratory settings, computing has converted analytical tactics, allowing for faster and more complicated information processing. High-performance computing clusters allow the evaluation of massive-scale genomic facts and climate models, in addition to complex simulations. Machine learning algorithms are increasingly being implemented to perceive patterns and extract insights from numerous datasets, accelerating discoveries in the fields of drug and material sciences. Additionally, digital and augmented reality technologies beautify the visualization of complicated statistics, facilitating better knowledge and collaboration among researchers. In recuperation initiatives, computing aids create unique virtual models of damaged artifacts or ecosystems, guide specific reconstruction efforts, and allow for the virtual checking out of different recuperation processes before implementation. (Lercari et al., 2017)

2.The Use of Data Analysis and Statistics in Archaeology

2.1.Big data analysis related to archaeological sites.

Big information evaluation in archaeology includes processing and interpreting full-size quantities of records amassed from archaeological websites. This technique combines conventional archaeological methods with superior computational techniques to find styles, relationships, and insights that might not be apparent through traditional analyses. Archaeologists have evolved various data resources, including satellite imagery, LiDAR scans, geophysical surveys, and evolution ancient statistics, to create comprehensive datasets for evaluation.

The application of large data strategies in archaeology has revolutionized the sphere, allowing researchers to examine large-scale spatial and temporal patterns across a couple of websites and areas in approaches that had previously not been possible. Machine learning algorithms and synthetic intelligence are increasingly being used to identify potential archaeological functions, predict web site locations, and reconstruct past landscapes. These strategies not only enhance the performance of archaeological research but also provide new perspectives on ancient societies, their interactions with the environment, and long-term cultural changes. As technology keeps to strengthen, big facts analysis is expected to play an increasingly more essential function in archaeological studies, supplying revolutionary methods to explore and understand human history via employing synthetic intelligence to research archaeological photographs and texts .(Kintigh & Ammerman, 1982)

2.2.Statistical analysis of settlement patterns and geographic distribution of archaeological finds.

The textual content describes a method used in archaeology to examine how human beings lived in the past. It involves:

1. Examining where ancient settlements have been placed
2. Analyzing how archaeological objects are spread across an area
three. Using statistical methods to recognize styles on these records

This approach, known as spatial evaluation in archaeology, provides a powerful framework for expertising historic human settlements and their interactions with the modern-day surroundings of the contemporary. By inspecting the distribution of archaeological web sites throughout landscapes, researchers can infer patterns of land use, aid exploitation, and social

specialization. Analyzing agreement patterns can reveal preferences for unique topographical features, proximity to water resources, or protective positions, dropping light on the choice-making strategies of ancient societies. (Peacock, 1998)

Spatial evaluation encompasses various strategies and methodologies that permit archaeologists to research the spatial relationships among archaeological sites, artifacts, and environmental competencies. These strategies frequently include the use of Geographic Information Systems (GIS) and remote sensing technologies, which permit researchers to examine large-scale spatial statistics and create different maps of archaeological landscapes.

Furthermore, spatial evaluation allows archaeologists to discover the relationships among unique settlements and identify functionality networks of trade, verbal exchange, and cultural exchange. By reading the distances amongst sites and their relative positions in the landscape, researchers can hypothesize the nature of interactions among agencies and the waft of goods, thoughts, and those at some stage in ancient landscapes.(Casana, 2021)

By mapping adjustments in site distribution and density over time, researchers can tune population dynamics, shifts in land-use techniques, and the expansion or contraction of cultural corporations. The temporal size of spatial analysis is essential for understanding the long-term improvement of human societies and their version of converting environmental situations. It can reveal patterns of migration, specialization of new territories, and abandonment of previously occupied regions.

This approach also allows the identification of hierarchical settlement systems, together with the presence of vital places and specialized manufacturing websites within archaeological documents. By studying the dimensions, complexity, and spatial arrangement of settlements, archaeologists can infer social and political structures, including the emergence of city centers and the organization of regional politics. (Ye & Niyogi, 2022)

Spatial analysis can also be carried out at more than one scale, from the distribution of artifacts within an unmarried site to the arrangement of sites

across entire regions and continents. This multi-scalar technique allows researchers to investigate both neighborhood and nearby patterns of human behavior and cultural development.

Combined with different archaeological records, artifact assemblages, and environmental information, spatial evaluation affords a complete approach to reconstructing past landscapes and human-surrounding interactions. This allows researchers to combine diverse traces of proof, including fabric culture, paleo environmental facts, and historic records, to create more nuanced and holistic interpretations of historic societies. (Wilkinson, 2003)

Spatial evaluation in archaeology has significant implications for background management and conservation. By determining patterns in web page distribution and predicting the probability of archaeological remains in unexplored regions, this approach can inform techniques for website protection and manual future excavation efforts in the area.

In conclusion, spatial evaluation has turned out to be a fundamental device in modern archaeology, supplying insights into the complex relationships among human societies and their environments at some point in history. As generation advances and new analytical techniques are developed, the potential for spatial evaluation to show formerly unknown elements of historical cultures continues to grow, promising exciting discoveries and a deeper understanding of our shared human past. (Chase et al., 2012)

3.Modern Technologies for Detection and Excavation

3.1.Remote sensing was performed using satellite and LiDAR imagery.

Remote sensing refers to the gathering of records of gadgets or regions from a distance, normally using satellites and planes. In this context:

1. Satellites: These are devices orbiting the Earth that can take photos or gather facts on the earth's floor.
2. LiDAR (Light Detection and Ranging): This era uses laser moderate to degree distances and creates precise three-dimensional maps of the Earth's floor.

These superior tools allow scientists and researchers to conduct studies of large terrestrial and marine areas, providing extremely good insights into

environmental dynamics. By utilizing satellite tv for pc tv for computer imagery, a long way flung sensing generation, and geographic statistics structures (GIS), researchers could have a have a look at and take a look at big-scale phenomena that were previously tough to reveal. This functionality allows for the detection of subtle modifications in ecosystems, land use styles, and oceanic conditions over prolonged periods, facilitating the monitoring of long-term trends and the identification of potential environmental threats. (D'Urban Jackson et al., 2020)

The capacity to create correct maps and terrain models has revolutionized numerous fields, including geology, ecology, and urban planning. These designated representations of the Earth's surface enable researchers to better understand topographical capabilities, assess natural dangers, and plan conservation efforts. Additionally, the combination of these gears with other information assets allows for comprehensive analyses of herbal assets, aiding sustainable control practices and informed decision-making. In urban contexts, these technologies guide the study of urban growth patterns, infrastructure development, and the impact of urbanization on surrounding ecosystems, thereby contributing to more sustainable urban planning strategies. (Shamai & Jafarpour Ghalehteimouri, 2024)

This technology is valuable because it provides a way to collect data about places that might be difficult or dangerous to reach on the ground, and it can cover vast areas quickly and efficiently.

3.2.drones (UAVs) and aerial photography.

Drones, also called Unmanned Aerial Vehicles, are flying devices that can be managed remotely. In the context of online pictures on websites, drones are used to capture pictures from the top of the site. Aerial images offer a completely unique angle of places, permitting visitors to view entire websites from a bird's-eye view.

The use of drones for aerial imaging has several benefits.

1. Access to difficult-to-attain regions
2. Ability to capture massive areas quick
3. Cost-powerful as compared to traditional aerial pictures strategies
4. Flexibility in flight paths and altitudes

5. High-first-class photos and movies Drones equipped with cameras may be used in diverse fields, including:
1. Archaeology: Surveying and mapping historic web sites
2. Construction: Monitoring progress and location planning
three. Real property: Showcasing houses and land
4. Environmental studies: Assessing landscapes and ecosystems
five. Event insurance: Capturing big gatherings from above
Overall, drones have revolutionized aerial imaging, making it more available, green, and versatile for a number of programs.

3.3.Magnetic surveys and ground-penetrating radar were used to detect subsurface structures.

Magnetic surveying and ground-penetrating radar are two techniques used to identify hidden structures beneath the Earth's surface.

3.3.1. Magnetic surveying:

- Detects versions inside the Earth's magnetic subject
- Useful for locating metal items or magnetic minerals underground
- Involves the usage of touchy instruments to degree magnetic field electricity

Ground-penetrating radar (GPR) is a non-invasive geophysical technique that employs excessive-frequency radio waves to analyze subsurface functions. This generation transmits electromagnetic pulses into the floor and analyzes the pondered alerts to create precise images of underground structures. GPR can locate a wide variety of subsurface objects and anomalies, including non-steel materials, cavities, soil layers, and buried artifacts. The depth of penetration and backbone of the GPR photographs depend on factors such as soil composition, moisture content, and frequency of the radar waves used. (Gish et al., 2002)

One of the crucial advantages of GPR is its versatility and potential to provide real-time data without worrying about the ground. This makes it beneficial for archaeological investigations, geological surveys, and infrastructure assessments. GPR may be used to locate buried utilities, map bedrock topography, identify subsurface voids, and discover hidden graves and historic systems. This technology has been applied in several fields, including civil engineering, environmental studies, and forensic investigations. However, interpreting GPR facts calls for expertise because

different factors may have an impact on sign reflections and create functionality artifacts inside the resulting pictures.

Both techniques are non-invasive and help researchers understand what lies beneath the ground without digging.

4.Geochemical Survey and Scientific Analysis

1.1.Analysis of soil samples and archaeological geochemistry.

Textual content refers to the examination of soil samples and the use of chemical analysis strategies in archaeology. This includes:

Collecting soil samples from archaeological sites is important for understanding beyond human sports and the environment. Archaeologists carefully extract soil from various layers and contexts inside a site, ensuring the correct documentation of the pattern region, intensity, and related artifacts. These samples provide valuable data on stratigraphy, depositional records, and human impacts on the landscape.

Once collected, the soil samples were subjected to chemical analyses to determine their composition. This method involves diverse strategies, including spectroscopy, chromatography, and elemental evaluation. Scientists look for specific chemical markers consisting of natural compounds, hint factors, and isotopes. These chemical signatures can monitor facts approximately beyond diets, agricultural practices, waste disposal methods, and industrial activities. By evaluating the chemical profiles of different soil samples across the website with manipulated samples from undisturbed regions, researchers can identify patterns and anomalies that suggest that humans have impacted soil composition over the years. When combined with other archaeological proof, this statistics allows reconstruct a more complete photo of beyond human activities and their interactions with the environment.(Fernández et al., 2002)

This approach to archaeological investigation, referred to as geochemical assessment, offers a more comprehensive expertise of historic net sites by examining the chemical signatures preserved in soil samples. By analyzing these chemical traces, archaeologists can obtain precious statistics on past human activities, diets, and environmental conditions that might not be obvious using traditional excavation strategies. This approach can display

screen patterns of careers, perceive regions of unique sports that incorporate food training or metalworking, and offer insights into historical alternate networks and useful resource utilization.

The use of portable X-ray fluorescence (pXRF) gadgets and exceptional atomic and nuclear techniques has revolutionized archaeology and fabric analyses. These gear permit researchers to perform non-adverse in situ analyses of artifacts, systems, and soil samples at archaeological sites or museum collections. By detecting the basic composition of substances, these strategies can assist in determining the origin of uncooked substances, reconstruct ancient technology, and help in the authentication and conservation of cultural historical artifacts. The portability and rapid evaluation capabilities of these gadgets have substantially improved the scope and efficiency of archaeological research, allowing scientists to acquire large datasets in the place and make informed alternatives regarding excavation techniques and artifact renovation.(Forster et al., 2011)

5.Challenges and Opportunities of Integrating Computing in Archaeology

5.1.Preserving cultural heritage through digital analyses .

Digital analysis has emerged as a powerful tool for maintaining cultural heritage, imparting progressive methods for documenting, analyzing, and safeguarding artifacts, ancient websites, and intangible cultural practices. Advanced technology, including 3D scanning, photogrammetry, and spectral imaging, allows researchers to create specific digital replicas of objects and systems, enabling their examination and conservation without risking harm to the originals. These digital representations can be shared globally, democratizing access to cultural backgrounds and facilitating collaborative cross-border studies.

Furthermore, synthetic intelligence and device learning algorithms were used to analyze large datasets of cultural records, uncovering patterns and connections that might otherwise remain hidden. This method provides new insights into ancient practices, inventive techniques, and social traits. Digital upkeep also plays an important function in shielding cultural historical past from threats such as climate exchange, battle, and natural disasters by using creating permanent virtual records that can survive even if physical artifacts

are misplaced or broken. As technology continues to improve, the sphere of virtual heritage maintenance is probable to amplify, imparting an increasing number of sophisticated tools for understanding and protective our shared cultural legacies.(Siliutina et al., 2024)

5.2.Providing access to archaeological sites and educational experiences through digital and interactive media.

Providing access to archaeological websites and academic reviews via virtual and interactive media considerably complements public engagement and knowledge. Through technologies such as virtual reality (VR), augmented truth (AR), and 3D reconstructions, users can discover ancient websites remotely and gain immersive insights into ancient civilizations without bodily travel. This equipment allows for the precise visualization of artifacts, reconstruction of ruins, and simulation of beyond environments, making archaeology more accessible to college students, researchers, and the general public. Digital platforms also provide multilingual content and adaptive mastering interfaces, broadening inclusivity and catering to numerous audiences and wishes.

Moreover, interactive media foster energetic mastery by allowing users to dynamically interact with archaeological content. Gamified reviews, interactive timelines, and virtual excavations stimulate interest and critical questioning, mainly among younger audiences. These virtual initiatives now not only keep fragile heritage websites by lowering physical foot visitors but also function as treasured instructional resources for establishments with restrained access to the sector. By integrating storytelling, multimedia, and consumer-driven exploration, virtual and interactive media play critical roles in democratizing archaeological information and selling global cultural background attention.(Langat, 2024)

5.3.Issues of privacy and accuracy in digital and virtual data.

The big series of virtual and virtual records of the usage of various technologies have become pervasive in contemporary society. Personal devices, online systems, IoT gadgets, smart metropolis structures, and biometric surveillance contribute to an ever-growing pool of information about humans and their behavior. This deluge presents full-size annoying conditions in terms of control, protection, and moral use. Privacy issues are

paramount because of the threat of record breaches, unauthorized access, and commercialization of private facts maintains to grow. The international nature of statistics flows further complicates these issues, as unique worldwide locations function below varying statistics protection necessities, developing a complex prison and regulatory landscape.

The accuracy and interpretation of digital and virtual data present additional stressful situations. While gadget studying and AI structures provide powerful analytical abilities, they can also perpetuate and increase existing biases in educational records. This can result in unfair outcomes in important regions, in conjunction with hiring practices, lending alternatives, and criminal justice court cases. Moreover, the rapidly evolving digital surroundings mean that statistics can quickly become obsolete or irrelevant, making it difficult to maintain their accuracy and relevance. Addressing the ones multifaceted annoying situations requires a comprehensive method that combines technological solutions, robust regulatory frameworks, and ongoing moral concerns to ensure that the gathering and use of digital and virtual data serve the overall public hobby while safeguarding man or woman rights and their privacy.(Giliberto & Labadi, 2021)

Conclusion:

The integration of digital technologies and advanced computational methods has revolutionized archaeological research, practice, and education. Tools such as 3D imaging, virtual excavation, GIS, remote sensing, and big data analytics now enable precise documentation, noninvasive exploration, and robust data analysis, fundamentally expanding the scale and depth of archaeological investigations. These innovations have democratized access to heritage, supported public engagement through interactive platforms, and facilitated collaborative research across borders and disciplines. However, these advances also present new challenges, particularly concerning ethical stewardship, privacy, and the equitable distribution of resources and training. As archaeology continues to embrace technological evolution, scholars and practitioners must balance innovation with the preservation of cultural heritage and the protection of sensitive data, ensuring responsible, inclusive, and sustainable progress in uncovering and understanding the human past.

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