— PhD position (M/F) —

Archaeological Mapping in Southeast Asia from Airborne LiDAR data with Machine Learning

**Laboratories** EFEO & IMAGINE (LIGM, ENPC)
**Location** EFEO, 22 Avenue du Président Wilson, 75116, Paris, France
**Supervisors** Loic Landrieu, PhD HDR; Damian Evans, PhD; Vladyslav Sydorov, PhD
**Starting date** September 2023 (or earlier)
**Contract** Full time, 36 months
**Remuneration** 2171,00 euros gross monthly
**Keywords** Machine learning, computer vision, segmentation, archaeology, geospatial, LiDAR

**Context**

Recent advances in remote sensing technology, such as airborne LiDAR scanning, have greatly facilitated the surveying and identification of archaeological sites. This technology has made it possible to detect traces of ancient societies in heavily forested areas that would have otherwise remained invisible to satellite imagery. LiDAR instruments mounted underneath an aerial platform emit approximately a million pulses per second, which can penetrate through the foliage and generate extensive 3D point clouds of the forest floor. These point clouds can be processed to remove the foliage cover and provide a precise and detailed map of the underlying terrain. Archaeologists can then use this information to analyze and categorize anthropogenic structures and plan potential explorations on site.

We have collected, curated, and manually annotated archaeological geospatial data in Southeast Asia spanning thousands of square kilometers: 80 billion 3D points, 25,000 high resolutions images, and over 100,000 individual man-made structures verified by archaeologists. We focus on the northwestern region of Cambodia, which was the heartland of the former Khmer Empire between the 9th and 15th centuries and is known for its expansive temple complexes. For over a century, art historians and architects have studied the medieval Angkor monuments in the area. However, recent LiDAR acquisitions [1, 2] have revealed a vast archaeological landscape reaching as far as Laos, far beyond the major temples, and which was previously concealed by the jungle. In the past decade, archaeologists have identified and hand-annotated tens of thousands of cultural sites such as ponds, temples, and occupation mounds in the region. This work was carried out by the Khmer Archaeological LiDAR Consortium (KALC) and the Cambodian Archaeological LiDAR Initiative (CALI), covering an area of 370 km$^2$ and 1900 km$^2$ respectively.

In early 2023, we have obtained an additional LiDAR coverage of 4000 km$^2$ in Laos as part of the ADF-funded CHAMPA project and the ERC-funded Archaeoscape project, which also
funds this PhD position. This new LiDAR acquisition uncovered the remnants of an ancient civilization similar to the one we had previously identified in Cambodia. We plan to automatically recover archaeological features from this new data by leveraging the large quantity of preexisting annotations. The scale and quality of this labelled dataset makes this problem well-suited for deep learning approaches.

The availability of aerial imagery datasets [3, 4] and their closeness to computer vision data has made machine learning techniques increasingly attractive for the automated archaeological analysis from optical sensors [5]. Promising results have also been obtained with LiDAR data for segmentation [6] and detection [7] tasks, although they mostly rely on 2.5D representations such as digital terrain model (DTM) and hillshades, instead of pointcloud data [8]. However, machine learning for archeological feature detection with 3D data has been hampered by the reliance on small, proprietary datasets [6, 9]. Archaeology-oriented LiDAR datasets are expensive to acquire and difficult to share, with legal and ethical barriers to dissemination [10].

Our collected annotated data offer an exceptional opportunity to contribute to the field by providing in open-access a vast cleaned dataset of 3D LiDAR data and aerial imagery. Drawing on the combined expertise of the archaeology and machine learning researchers involved in the project, we aim to establish a tailored methodology that will be beneficial to archaeologists performing similar survey tasks. Moreover, we aim to contribute to the computer vision research community by highlighting the unique challenges of our problem and its exciting applications.
Figure 2: During acquisition we photograph the landscape (a), and save the full waveform information of LiDAR reflections, recording the distribution of the returned light energy. We post-process it into a point cloud, with associated $x, y, z$ coordinates and intensity metadata (b). We then classify and isolate the ground returns (c). We rasterize into a 2.5d representation, interpolating $z$ values onto a regular grid (d). Sometimes a hillshaded raster is produced by imitating an illumination source (e). Finally, the features are annotated by the archaeologists and verified in the field (f).

**Objective**

We are looking for a candidate who is motivated and creative. They will be able to choose the project direction and shape it according to their talents and background, based on our mutual research interests. Their focus will be on the intersection between archaeology and computer vision, contributing to both communities. Here are some possible directions:

- One of the objectives of the Archaeoscape program is to develop specialized techniques working directly on the LiDAR data instead of the derivative image products — an under-explored direction in archaeology field. Moving closer to the original acquired data would allow us to retrieve the information lost during the transformations. For example, when forming the DTM (Figure 2d) interpolation error is introduced, moreover we lose access to meta-information such as return intensity, that can serve as an indication of the mirroring angle and material. Additionally, we have access to the full waveform which contains even richer information.

- In the studied area the distribution of the objects is very heterogeneous. In the vicinity of the temple complexes the sites are tightly packed and highly intertwined, at the same time there are low-density urban settlements which cover the vast areas in-between, and we are especially interested in locating and categorizing them. There is also the issue of defining appropriate metrics, as the common object segmentation metrics are either adapted for objects distributed either sparsely (instance segmentation), or densely (panoptic segmentation [11]).
• The above problem is exacerbated by large inter- and intraclass variations in feature size. The archaeological sites that we seek are classified by their functional purposes and discerning between them requires taking the spatial context into account, including reasoning at multiple scales. Additionally, the orientation of the features can be important — clusters of spatially autocorrelated sites can be identified and serve as an indicator to their purpose.

• A concurrent work is pursued in the team on the structural similarities between Khmer and Mayan culture, based on the LiDAR data from Mesoamerica. This raises the possibility of studying the transfer-learning approaches, adapting our models to the datasets acquired in the historical areas of Mayan or other Southeast Asian cultures.

• There are established collaborations with the ecologists and botany specialists who work in the field in the region. With LiDAR data we can reconstruct highly-detailed models of the trees and vegetation, which can be used to perform environmental studies [12] and to study the environmental impact of the ancient cultures, including ecological legacies of ancient occupation patterns.

• Additionally, we have access to the associated aerial photography gathered by the LiDAR-carrying aircraft at the time of acquisition, captured at much higher resolution than achievable with commercial satellite imagery. Considering our problematic, the tree coverage dominates, obscuring the archaeological sites. At the same time, the imagery can be used to augment the vegetation models with color information, opening possibilities for multimodal approaches.

Regardless of the direction chosen, the candidate will be working in close collaboration with other researchers in the field, at IMAGINE group and beyond. This will let the candidate establish research connections while developing as an independent investigator.

**Employer**

The École française d’Extrême-Orient (EFEO) is a public institution of a scientific, cultural, and professional nature that reports to the French Ministry of Higher Education and Research. Its mission is interdisciplinary research on Asian civilizations, from India to Japan. The EFEO is present, through its 18 research centers, in 12 Asian countries. This allows its researchers to be in the field of their studies and to lead a network of local cooperation and international exchanges between Orientalist scientists.

At EFEO, the lab of Damian Evans studies the archaeological landscapes of Southeast Asia with a special focus on airborne LiDAR scanning. Archaeoscape project (ERC Consolidator Grant #866454), funding this PhD, is a multi-year program investigating the ecological legacies of early societies in tropic forest environments.

IMAGINE is our partner research group at École des ponts ParisTech (ENPC), working in computer vision, machine learning and optimization domains. Loic Landrieu (formerly at IGN) is a machine learning researcher with an expertise in geospatial data applications, such as 3D LiDAR point clouds and satellite image time series.
Role

- Loïc Landrieu, a machine learning research scientist at IMAGINE team (ENPC) will act as the primary PhD supervisor.
- The candidate will join the archaeology lab of Damian Evans at EFEO, and participate in the Archaeoscape project, which funds this PhD, along with two other PhD students.
- As a ML doctoral student in the archaeology team, they will pursue the interdisciplinary research direction and focus on adapting the computer vision approaches to the particular problems raised by geospatial data and archaeological applications. They will work closely with Vladyslav Sydorov, PhD in computer vision and co-director of the Archaeoscape project.
- They will contribute to the scientific activities, and build their own research profile in line with their interests. The aim is to publish in high-impact machine learning and archaeology venues.

Skills and profile

- Master’s degree in computer science or equivalent.
- Extensive background in applied mathematics, machine learning and computer vision.
- Strong programming skills, mastery of Python, DL frameworks (PyTorch) and GNU/Linux.
- Excellent command of English, writing and communication skills.
- (Desirable) Knowledge of French, Southeast Asian languages and cultures.

What we offer

- A world-class research environment with a broad network of scientific partners.
- Funding and opportunities for international conference travel and research in the field across the Southeast Asian region.
- A comfortable workplace in the heart of Paris, with a view on the Eiffel tower.
- Flexible working arrangements, no teaching duties imposed.

Applying

- To apply, please send CV, academic transcripts and a short research statement, outlining your background and interests (~20 lines max) to vladyslav.sydorov@efeon.net.
References


