Application of Georeferenced Archaeological Information Systems for Archaeological Digital Heritage - The Auxiliary Fortress of Carnuntum (Lower Austria)

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***Abstract* — Non-destructive prospection methods provide a powerful toolbox to explore Archaeological Heritage while it is still protected untouched below the actual surface. Due to recent technical developments in high resolution large scale non-invasive archaeological prospection by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) like motorized multi-channel Ground Penetrating Radar (GPR), multi-sensor Magnetometry or Airborne Remote Sensing it became possible to efficently explore square kilometers of archaeological landscapes in high detail. Using a georeferenced Archaeological Information System (AIS) to compare, combine and interpret the archaeological information embedded within prospection and excavation data enable spatio-temporal analyses to derive the cultural development of an archaeological landscape.**

***Index Terms* — integrated archaeological interpretation, geophysical prospection, data fusion, spatio-temporal analyses, Roman Auxiliary Fortress, Carnuntum, Cultural Heritage, Virtual Archaeology, scientific transparency, preservation, re-usability**

I. INTRODUCTION

The preservation of Archaeological Heritage at a large scale is one of the primary challenges to preserve it for future generations. The traditional way of archaeological investigations – the excavation – is an irreversible destructive process and is normally conducted on a limited extent compared to the extension of an archaeological site or even landscape. Therefore all available non-invasive methods should be used in advance and at the large scale covering complete sites or even landscapes demanding the development of efficient geophysical prospection and remote sensing methods.

The digital 3D documentation of each single surface during the destructive process of a stratigraphic archaeological excavation has to be seen as state-of-the-art. Not only the digital documentation of currently excavated sites is of importance, also the digital recording of archaeological structures unearthed and preserved by historical excavations and currently endangered by destructive processes like erosion, natural catastrophes, mass-tourism or vandalism is of special significance.
Both processes – prospection and excavation – conducted within a fully digital workflow transfer the physical record preserved above or below ground into a virtual record with geometrical and attribute information to be seen as the basic subject of what we would call Virtual Archaeology (VA). Virtual Archaeology is an appropriate way to visualize and explore archaeological sites or landscapes within a virtual environment providing the tools for intuitive interaction with the respective datasets.
The current definitions like the **Principles of Seville** [1] or **The London Charter** [2] see VA mainly as a tool for the reconstruction of archaeological structures and show several short-comings in regard to a more general understanding of VA including comprehensive data fusion, intuitive data exploration, sophisticated spatio-temporal analysis, 3D mapping and 4D simulation clearly demanding an extension of the current definitions.

Such a virtual environment integrating digital prospection and excavation data together with further geographic or historical information for the virtual analysis and interpretation can be summarized by the term **Archaeological Information Systems (AIS)** proposed for the first time by Irwin Scollar and discussed since by many scholars [e.g. 3, 4, 5, 6].

Dealing with geographical information demanding georeferenced datasets for data combination or fusion the core of such an AIS is preferably based on a geographical information System (GIS).

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A well-defined comprehensive workflow for a spatio-temporal analysis of the different archaeological datasets is crucial to gain reproducibility and comparability of results. The aim of this paper is to present a standardized workflow based on data comparison, combination and fusion for an enhanced visualization and virtual analysis of georeferenced data applied to a particular example – the Auxiliary Fortress of Roman Carnuntum (Lower Austria). We also present a recently designed application, the **Arch4DInspector**, for the visualization and exploration of the derived spatio-temporal interpretations.

II. THE AUXILIARY FORTRESS OF ROMAN CARNUNTUM

The Roman town of Carnuntum was explored within a long term case study currently hosted by the LBI ArchPro [7]. Through the last years **high resolution data** from **Ground Penetrating Radar (GPR)** surveys and **Magnetic Prospection** were acquired, visualized and interpreted [8, 9] and combined with datasets from previous investigations (e.g. airborne remote sensing, aerial archaeology [10, 11], excavation, sampling and historical data) resulting in an almost complete picture of the nowadays sunken capital of the Roman province Pannonia Superior.

The fortress selected from this datasets is perfectly suited to line out the potential of the combination of non-invasive archaeological prospection and excavation methods. Despite the long-term excavations in the housing development area, large parts of the buried fortress are only explored by various prospection methods. To combine the prospection results and the information from the previous excavations it is necessary to use a **Geographic Information System (GIS)**, to compare the different datasets within a virtual environment. New specific tools for imaging of prospection data (**APSoft 2.0**) and software extensions for the GIS-based combination and analysis (**ArcheoAnalyst**) of the large datasets had to be developed and implemented by the LBI ArchPro to ensure the best visualization of the prospection data and to provide high-resolution georeferenced imagery for the archaeological interpretation.

The example of the **Auxiliary Fortress of Carnuntum** (Lower Austria) was chosen, because it provides a huge variety of different data sources like:

- Archaeological excavation maps
- Interpretations of non-invasive prospection methods
    - Ground Penetrating Radar (GPR)
    - Magnetic
    - Aerial photos
    - LiDAR
- Contemporary Roman accounts
- Archaeological analogies
- Historical maps

Fig. 1. Comparison of interpretations of different datasets: excavation results (A), aerial photography (B), Magnetic (C) Ground Penetrating Radar (D) of the eastern part of the Auxiliary Fortress of Carnuntum (© LBI ArchPro)

The respective archaeological prospection methods have their advantages and disadvantages providing therefore only specific information. In combining and integrating the interpretation results of these different methods with the archaeological record produced by the excavations an almost complete representation of the underlying archaeological monument emerges (Fig.1).

To visualize and analyze the different georeferenced datasets they are integrated within an **Archaeological Information System** (AIS). This AIS is based on a geodatabase where all the available georeferenced raster, vector and attribute data is combined for the comparison and analysis of spatial-temporal relationships of the different data sets. By combining and integrating different data-sets within the AIS it is possible to merge the different basic archaeological information and derive new data applying standardized interpretative mapping processes. Generally 2.5D features like walls, ditches, streets etc. are derived from the combined data.

These architectural features usually belong to a temporal phase were several units once formed a structural complex like a roman house, a military barrack or a gate tower. By comparing these structures with detailed excavation results or contemporary analogies it is possible to understand there former function and to provide in this way the basis for a comprehensive virtual reconstruction through time.

Using data fusion and digital image combination makes it possible to visualize representations of no longer accessible archaeological monuments, like in our case the nowadays overbuild areas of the excavated Auxiliary Fortress with the prospection results from the protected eastern front of the fortress (Fig.2).

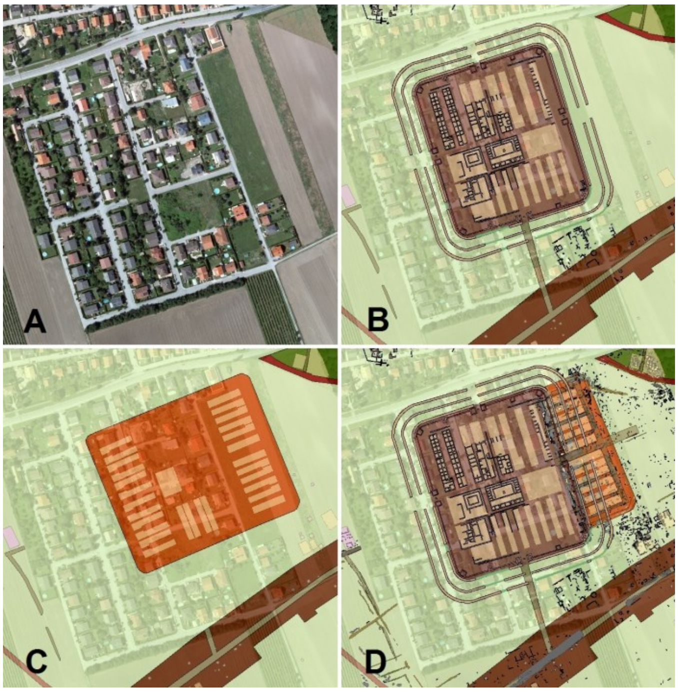

Fig. 2. Recent aerial photo (A), Excavation data of building phase II-IV (B), Excavation data of building phase I (C), Combined Interpretation of different datasets from the Auxiliary Fortress of Carnuntum (© LBI ArchPro)

By combining the interpretative mappings derived from the combination and/or fusion of different non-invasive archaeological prospection methods and comparing these results with adjacent excavation data it therefore was possible to explore also the non excavated areas of the Roman Auxiliary Fortress to such an extent, that it was possible to expand the **spatial and temporal relations** observed during the excavation process **to the whole monument** enabling for a reconstruction of different phases of the monument. The integrated interpretation of several archaeological datasets forms the basis of different three-dimensional visualization, representing the development of the Auxiliary Fortress through time. This multi-phase 3D reconstruction is part of the newly designed **Arch4DInspector**, an application in which it is possible to view and explore various georeferenced archaeological datasets in high detail and visualizing the single structures separated in chronological phases for the deductive reasoning in respect to the complete monument (Fig. 3).

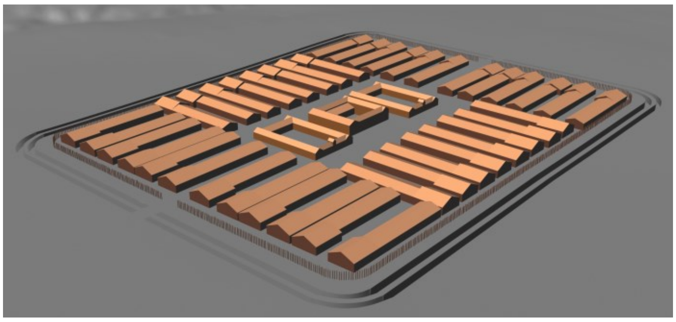

Fig. 3. Modeling process of building phase I of the Auxilary Fortress of Carnuntum in 3ds Max 2014 (© LBI ArchPro, Torrejón).

III. CONCLUSION

Investigating large scale archaeological landscapes with non-invasive prospection methods provide the opportunity to explore buried Archaeological Heritage at a large scale and transform the real 3D landscape with its buried stratification into a virtual representation.

High resolution motorized multi-sensor geophysical prospection together with most accurate positioning data is providing the potential to compare and combine the georeferenced imagery and interpretative mappings derived from prospection with any other georeferenced archaeological information.

Exploring large archaeological landscapes by non-invasive prospection methods seems to be the future way to preserve and explore our buried archaeological heritage. Only by using such technologies and the integration of any preexisting archaeological data it is possible to investigate huge areas in such a detail to be able to understand the temporal evolution of an archaeological landscape in its regional and historical context.

For the **reproducibility and transparency** of the spatio-temporal analysis and the derived interpretations an AIS is providing the virtual environment needed to store and manipulate the different georeferenced datasets. All further analysis in terms of data exploration, visualization, simulation and reconstruction is based upon this virtual environment created through and within an AIS consisting of basic GIS functionality and different 3D viewers and 4D analysis tools (e.g. ArcheoAnalyst, Arch4DInspector). In this sense not only the reconstruction of archaeological monuments has to be seen as VA but also every investigation of archaeological datasets embedded within such a virtual environment, preferably a powerful georeferenced AIS.

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