VIRTUAL ARCHAEODROME FOR THE ARCHAEOLOGICAL SITE FROM ULPIA TRAIANA SARMIZEGETUSA

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ABSTRACT:

This paper presents an ongoing work within a national project regarding the scientific investigation of one of the most important archaeological sites in Romania: Ulpia Traiana Sarmizegetusa. Although the project has many objectives, in this paper we will focus on the development work of a virtual archaeodrome for the archaeological park. In this regard several field campaigns were organized using the ART4ART mobile laboratory for in-situ non-invasive scientific data acquisition and an online instrument for data reporting and visualizing is currently under development. This work represents a case study of several archaeological assets comprising chronologically layered historical studies, high resolution 3D digital models, ground penetrating radar survey and airborne imaging: LIDAR, multispectral and aerial photogrammetry.

1. INTRODUCTION

The idea of a virtual archaeodrome came from the need of a digital intuitive visual tool for a centralized data management for polyvalent researches in archaeology. Since science started delivering valid cutting-edge technology for non-invasive and not-destructive means of investigation in archaeology, a successful symbiotic relationship between the field archaeologist and modern technology has emerged. Joint campaigns of multidisciplinary technical researchers and expert archaeologists using state of the art investigation and imaging technology, integrated in the ART4ART mobile laboratory (Simileanu at al, 2008), proved to be a reliable model of good practice (Angheluta et al, 2015) in complex projects of different casuistry (Monastery of Tismana – restoration/conservation (Radvan et al, 2016), Targu Jiu – conservation, Basarabi-Murfatlar chalk churches cave ensemble (Ene et al, 2010) – archaeology, Ulpia Traiana Sarmizegetusa – archaeology).

Having access to a plethora of high-end investigation techniques sometimes can be difficult to choose the right combination of complementary methods to deliver concise and clear data about the study case. Usually experience come in handy but also open access online initiatives (Angheluta et al, 2015) can help configuring the right strategy for investigation an archaeological site or an historical monument.

Colonia Ulpia Traiana Augusta Dacica Sarmizegetusa, in its full name, was the first city of the Roman colonized Dacia. The name of the city includes the title *"colonia"* (highest rank of a Roman city), the name of the founding emperor as well as the name of former Dacian capital, Sarmizegetusa, denoting the importance of the city at that time. The walled city covered almost 33ha and 60-80ha outside, sheltering around 20-30.000 people, being thus a medium-sized city in the Roman Empire.

Today it is one of the most important archaeological parks in Romania with a great flux of visitors each year. This project is focused on investigating several important areas within the city (some of which are still buried under crop fields).

Our usual field investigation strategy involves the recording of the 3D surface of the subject (by 3D laser scanning or photogrammetry, depending on the situation and local conditions) and then adding layers of imaging (multispectral, hyperspectral, thermic, laser doppler vibrometry, digital microscopy) and physico-chemical data (LIBS, LIF scanning, FTIR). For this particular case, for the investigation of selected areas of the Ulpia Traiana Sarmizegetusa archaeological site we configured the ART4ART mobile laboratory with ground penetrating radar, photogrammetry, airborne survey (LIDAR, multispectral, thermic, aerial photogrammetry). Although this paper is focused on the description of the design aspects of a virtual archaeodrome for the selected areas, a brief investigation methodology will also be presented.

The virtual archaeodrome is an online digital instrument that collects and provides not only the modern investigation data but also all the previous researches in order to ease the access to all the existent data about different areas of an archaeological site. As it will be described later, it consists in a simple database for data management and a web based user graphic interface for data input and visualization. Data collected may be text documents, research reports, images or 3D models.

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2. IMPLEMENTATION

2.1 Data presentation design

The main goals this online instrument has to satisfy are:

a. centralized data management
b. data visualization of selected areas and objects in those areas
c. easy to use 3D model visualization

The most accessible presentation format for any kind of data management system is the web page format. With the widespread of Internet connectivity all over the world it is easy now to publish any kind of data type for anyone anywhere, even 3D formats, on a variety of devices (from PC's to mobile phones). Having this considered, we opted for a website format for our online tool that communicates with a database for data storage and management.

Today, any human-machine interface is optimized to be easy to learn, intuitive and practical, especially in web design, and lately in mobile app design. In Figure 1 it is depicted a mind map for the Archaeodrome web design. Building a mind map doesn't take long and it can be done with special software, or on paper. Mind maps are easy to understand by others and at the same time helps the designer crystalize his ideas and their structure.

In short, we devised the archaeodrome with several important aspects:
1. authenticated users for data input and management
2. data management forms
3. general information about the project
4. different data type presentation

In order to present the collected data about the areas and objects in the archaeological park in a clear and concise way we structured all the data in a parent-child architecture. Therefore the root is the archaeological site Ulpia Traiana Sarmizegetusa that has a description and perhaps a gallery of images (at least one image). This site has several **locations** the user can choose to view. Each location is presented with a description, images and a list of **investigated objects or areas**.

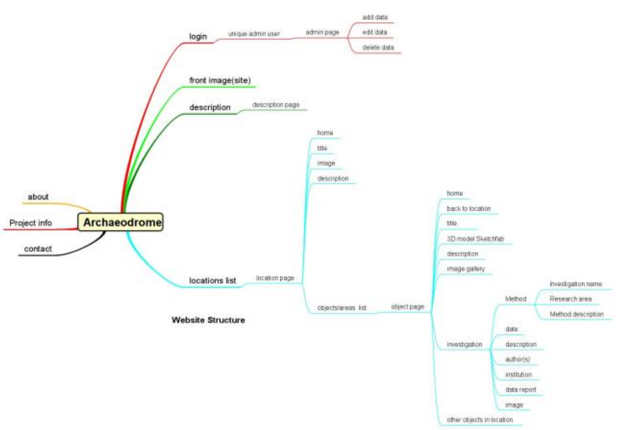

Figure 1 Website structure

The objects/areas page is perhaps the most important. It must display in a coherent and well-structured way all the data regarding the user's selection. This page contains general descriptive information about the object/area: name, code, description and an image gallery. This page contains the embedded interactive visualization of the object 3D reconstruction. The investigations conducted for this specific object/area are listed chronologically in order to a better understanding of the object context and history. Here are included all the investigations starting with its discovery. This is an important asset of this instrument because it brings together data from old researches (some of them not yet digitized) and modern ones. Each type of investigation is characterized by a method (coming from a specific research field) that also has a small description. Other important data here is the date of the investigation, which is important for the research history of the object; a description of the context of that investigation and a report of the results and conclusions; images during the process; authors and their affiliations. The collection of the history of researches conducted is of great value to anyone who is studying the monuments. Historians, restorers and cultural heritage investigators can avoid doubling the same investigations and can conclude new study ideas if they have an easy access to all the data that has been collected so far about the respective monument.

The object/area page is the main focus of the information tree and contains the most data. Besides the information mentioned above this page also directs the user to other objects/areas in the same location.

2.2 Data management

There are two ways to accomplish the proposed data presentation: static and dynamic. Normally this shouldn't be even considered but this instrument can be designed to be static. Meaning that all the location and object/areas pages are physically coded with all the data included. It would be a lot of work but for at that specific moment it would cover all the collected data so why should it be a problem. It is easier to implement but perhaps it would take much longer. Problems appear when new data is found or generated. It would take a programmer to code a new page or edit the existing ones in order to update the information. It can be done but it becomes complicated to hire a programmer (or have the researchers learn web design) each time it is needed a new update.

The solution, which today is a common practice, is the design of a database for the data storage and management in a dynamic web application. This solution requires a good database design and a solid interface between the web application and the database. In this type of development, the data the user is viewing is automatically requested (server side programming) from the database and displayed to the user in a graphic interface (client side programming). The displayed content is automatically updated with data from the database. This is what a dynamic page basically means.

In our case started the database design from the aforementioned structure: archaeological site that contains one or more locations, which in their turn contain one or more objects/areas that are investigated with one or more methods. The relational database structure satisfied the needs for the proposed instrument. The defined entities (as seen in **Figure 2**) are: *site*, *location*, *object_area* and *research_method*. The relationships between these entities is one-to-many, where for example a *location* can contain one or more *objects*, but the same *object* cannot be in more than one *location*. So it is a pretty straight forward design and we tried to keep it that way. For a simplified data management we added a relation table (entity) between the *object_area* and the *research_method*. This table will allow a better and clearer separation of the researching methods. While having a separate list of the methods that can be modified and updated at any time, the operator can input new studies to a specific object by just selecting the corresponding method.

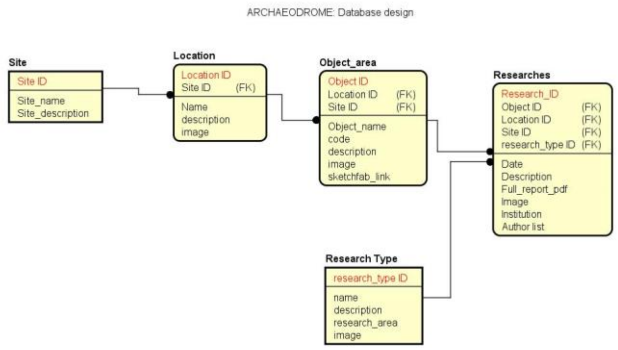

Figure 2 Database structure

These entities and their fields were designed in accordance with the proposed data presentation structure. All the big data like hi-res images, pdf files and 3D models are not stored in the database. Instead they are stored on the server and in the database are stored only references to the files on disk and hyper-links (for the 3D models as we will see later).

Data input can be performed by anyone based on authenticated credentials. The users will access intuitive forms for data submission. No programming skills needed.

2.3 Development tools

There is a great selection of programming platforms today for the development web based applications, each with its own advantages and disadvantages. We chose for the database management system mySQL for no important reasons just because it can do whatever we need in this case. Server side programming for the database-web app communication is realized with PHP. As for the client side programming, the graphic user interface, is realized in HTML5 with CSS stylings and JavaScript scripts for different automated behaviours of the displayed data. So, the tools used are pretty common and easy to use.

2.4 3D reconstruction model viewing

One of the most important technical aspects to be solved was the 3D viewing method. Until recent, 3D models were best viewed as non-interactive hi-res image renderings and animations or in interactive gaming-engine media. Online interactive visualization was not very familiar before the 2000s. In 1997 VRML (Virtual Reality Modelling Language) became a standard file format for representing 3D interactive vector graphics designed for Internet use. VRML files (.*wrl* extension) could be either created (programmatically) or exported from existing 3D modelling software such as the early versions of 3D Studio at that time. But the lack of Internet bandwidth at the time did not help the spread of the technology. However, there were several companies that adopted the technology and developed plugins for web browsers such as Cosmo Player™ (initially developed for Nestcape Navigator browser) or Cortona 3D™.

These plugins (much like today's Chrome™ extensions) had to be installed on the client's computer in order to access a 3D model embedded in a web page. These plugins allowed the visualization of a 3D scene using several mouse commands such as rotate, zoom, pan etc. VRML included animations and scripted interactions such as mouse clicks in the 3D scene on different surfaces to generated new actions within the same scene. We used this technology in the past (Angheluta et al, 2010) to create a tool for online visualization of associated imagistic data on the surface of a 3D reconstruction of historical monuments.

But today's improvements in the web browser technologies and the increasing worldwide internet speed in the last years allowed the development of a friendlier user interface platform for online 3D model publishing: Sketchfab™. It follows the same principle of the familiar website Youtube™: using a personal account 3D models can be uploaded. The platform features scene and lighting parameters editing, adding of annotations, descriptions and the management of personal models in collections. These models can be private for personal visualization (with password) or public. Visualization of Sketchfab™ models do not require any kind of plugin or driver installation.

For the interactive visualization purposes we chose Sketchfab due to its ease of use and especially because it is easy to embed in any custom page, having access to the entire control interface.

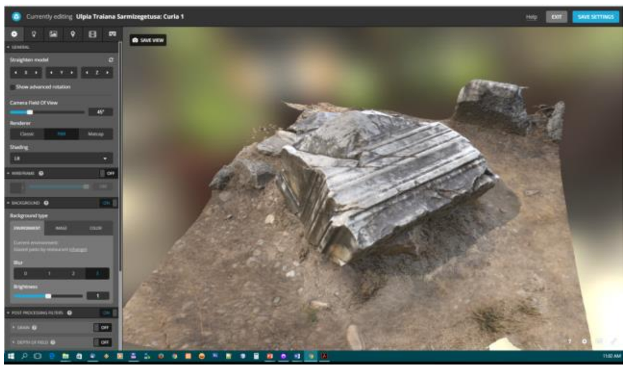

Figure 3 3D reconstruction of a decorative fragment in Forum Novum - scene preparation in Sketchfab

For the duration of the project (until the end of 2017) this web tool will be hosted on our own server. After its completion and testing it can be moved on one of the local museum servers for public access on tablets and info points. Additional features consists in Virtual Reality mode view that can be used with card board googles or dedicated VR gear and an useful annotation system that allows us to place labels with information within the 3D scene.

3. INVESTIGATION METHODOLOGY

The first step in our project was to collect all the data available about the previous investigations conducted in our areas of interest. As we said above this is a critical step in the data acquisition stage in order to create a history of the studied objects/areas.

3.1 Casuistry

Ulpia Traiana Sarmizegetusa was a medium-sized city in the Roman Empire. Its ruins today are still studied and every year new excavations brings new information to light. Large areas of the former capital are, unfortunately, still in private properties under crop fields or even houses. In this project we collaborated with experts from the National Museum of Romanian History and Museum of Dacian and Roman Civilization Deva. We have focused on several areas of interest in the Forum Novum: recently discovered Plamyran Temple ruins, one of the Curia interiors, several architectural details (disabled columns, pedestals). We were also interested in some areas that are not yet studied, in the crop fields. In 2007 were discovered several rooms that preserved mural paintings. Fragments of these frescoes were also a subject of study with physico-chemical methods in this project.

The scientific investigations have been conducted for two consecutive years during field campaigns that lasted for no more than a week, each. The last scheduled campaign, this summer, will be focused on aerial survey.

3.2 Investigation methods

Since 2008 our department's philosophy changed with the development of the ART4ART mobile laboratory. In all our field campaigns instead of bringing the artworks or samples from monuments/archaeological sites to laboratory for study, we are simply bringing the whole laboratory (in mobile version) to the subject. This mobile laboratory was designed to be modular so that it can be equipped with different components depending on the target casuistry (from painting and fine arts galleries to large archaeological sites and historical monuments). For this case the mobile laboratory was equipped with typical survey and imagistic methods that are used with open archaeological sites: 3D imaging, ground penetrating radar, UAV with four different sensors.

3.2.1 3D imaging

The 3D reconstruction method employed was photogrammetry. With a precision comparable with our monochrome terrestrial 3D laser scanning unit, photogrammetry was chosen due to the high level of manoeuvrability around the ruins, even in the hardest accessible corners, allowing us to generate complete 3D reconstructions with photo-realistic textures.

Even though photogrammetry principles are as old as photography, until not long ago sensors like ALS and TLS (aerial and terrestrial laser scanners) seemed to completely eliminate photogrammetry from the race of 3D documentation having certain advantages: fast data collection (hundreds of thousand points per second), range, accuracy, data rate etc. But with the development of automatic block orientation and the improvements in image matching, digital image correlation and stereo correspondences problem in digital image processing (coming from computer vision area) photogrammetry established itself in the recent years as "the most complete and flexible technique for collecting and archiving 3D information" (Forlani et al, 2015).

In terms of accuracy, photogrammetry is precise and comparable to other large-volume, high accuracy coordinate measurement systems. Photogrammetric accuracy depends on several factors: camera resolution, measured area size, numbers of photographs and not least the methodology of image recording. But usually accuracies of 25 to 50 microns can be easily achieved.

The equipment used is a DSLR full frame camera with 36 megapixels and a set of lenses: 20mm, 35 mm, 60 mm with 1:1 macro and another DSLR cropped frame with 18 megapixels with 50 mm and 18-55 mm lenses. Other accessories might include: tripods, a monopod, circular polarizing filters for highly specular surfaces and softboxes to even the lighting or for interiors.

Figure 4 Palmyran temple ruins 3D reconstruction with terrestrial photogrammetry; left - calculated camera positions; right- 3D reconstructed model

3.2.2 Ground Penetrating Radar (GPR)

Ground penetrating radar is a non-invasive survey technique that uses electromagnetic radiation (microwaves) at frequencies between 30 MHz and 30 GHz. The waves are emitted towards the ground soil from the surface in order to record the reflected signal. Stratigraphy changes and artefacts presence can be identified by analysing the propagation of the waves and their response time. The soil can be considered a complex and variable three-dimensional natural body with different biological, chemical, mineral and electromagnetic properties (J. A. Doolittle, 2009). The GPR waves are primarily affected by the dielectric permittivity of the different propagation media.

Figure 5 Aerial view of the areas surveyed with GPR

In the image above are displayed the areas that have been investigated with GPR within the Ulpia Traiana Sarmizegetusa site: the entry access point in the site, the temple areas near the national road and near the necropolis. The depth of interest was around 2 meters in the ground. The raw results are viewed as radargarms (see **Figure 6**).

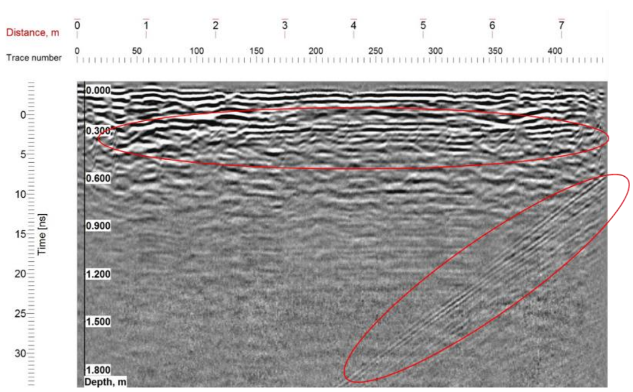

Figure 6 Radargram that identifies at 0.3 m a possible wall or an old pathway; on the right is the reflection of a wall above ground

After processing and interpretation this data can be mapped with the recorded coordinates over the aerial imaging data for a better understanding and identification of the irregularities detected in the investigated soil.

3.2.3 UAV survey

Nowadays affordable UAVs have hit the markets and they are fast growing into being used in many fields like: military, agriculture, security, entertainment (events, movies). The use of unmanned airborne vehicles (UAVs, drones) in archaeology is already happening with many applications including aerial photography, photogrammetry, site documentation and mapping and with the right tools remote sensing. 3D surveying and modelling has a great impact on the documentation of archaeological sites. Plans, sections and facades can be obtained from the 3D data, which are very useful for the conservation and preservation but also for further detailed investigation of the site (Gonizzi, 2013).

The UAV we are using in this project is a custom build octocopter. It has a maximum payload of 20 kg and can be equipped with four different sensors:

- *photo camera*
- *multispectral camera*
- *thermal camera*
- *LIDAR*

The UAV is remotely operated and is also equipped with two GPS antennas for recording accurate coordinates that are used for georeferencing in the processing stage. A LCD display mounted on the remote control is used for real-time visual feedback of what the UAV sensor is “seeing” (except the LIDAR). With a mobile app we can program a flight plan for the UAV. Having a copter based architecture the UAV can be used stationary in a hovering fixed position in order to acquire data for a longer time.

A set of processing software is also used for georeference and interpretive mapping. Using photogrammetry principles and algorithms we can generate georeferenced orthorectified large images (no optical distortions or relief displacement).

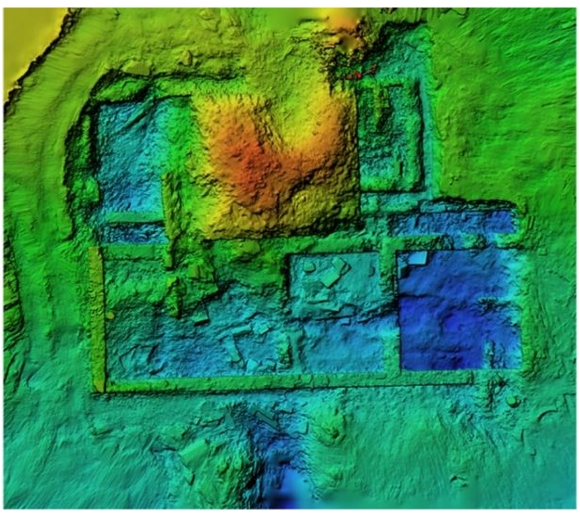

Figure 7 Digital elevation model (DEM) of the Palmyran temple excavation resulted from photogrammetry

3.2.4 Physico-chemical analysis

For the mural fragments found physico-chemical methods can be employed so as to get a better understanding of the chemical and molecular composition of the paint layer and support.

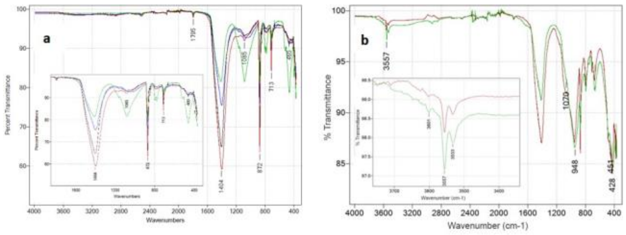

Figure 8 ATR-FTIR spectral details showing diagnostic absorptions bands for the mural painting fragments found on site

Typical methods used for this purpose include portable X-ray fluorescence spectrometry (PXRF), infrared analysis via Fourier transform infrared spectroscopy (FTIR) and laser-induced breakdown spectroscopy (LIBS). FTIR basically identifies the molecular fingerprint of the studied sample (Figure 8), while XRF is used for the detection of inorganic materials and the assessment of the elemental distribution over the investigated sample, without the requirement of sampling (Figure 9).

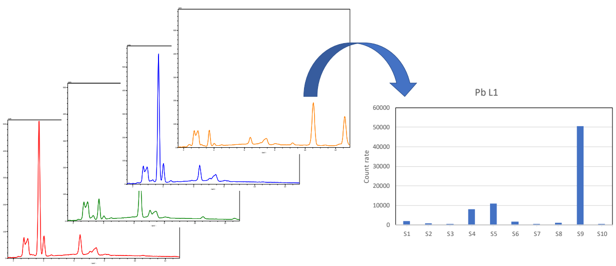

Figure 9 XRF spectral data and elemental distribution

Moreover, when stratigraphy is needed, LIBS can be successfully employed (Figure 10). The recent technological advances have allowed the possibility of creating transportable, portable and even hand-held devices for FTIR, XRF and LIBS analysis, this makes these techniques even more suitable for the task of being incorporated in the idea of an archaeodrome, as they offer the possibility for in situ investigations, in a purely non- or micro-destructive manner.

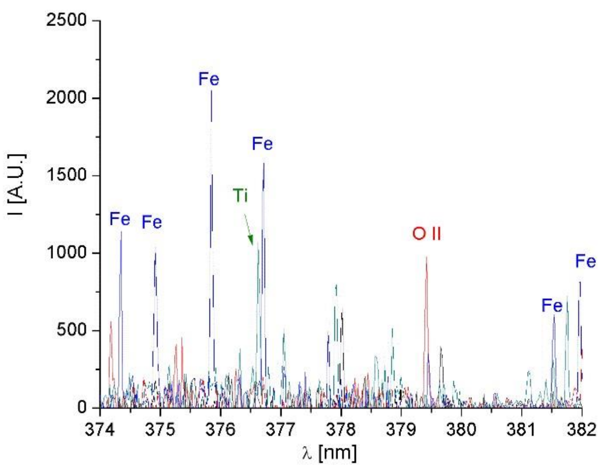

Figure 10 LIBS stratigraphy on a mural painting

4. CONCLUSIONS

The virtual archaeodrome represents a valuable tool for both historian experts and the public at the same time. All the historical researches with all their stages for each of the stored item in the database in association with the current modern investigation data creates not only an ideal data inventory for the historians and archaeologists but it also can further developed to be a valuable tool for experimental archaeology, especially for accurate virtual reconstructions. For the public would not be the first virtual museum to explore but certainly the amount of scientific data will put the exposed items in a different light for the expert community.

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