The Vulci3000 Project: A Digital Workflow and Disseminating Data

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Abstract: This article discusses the methodology of the Vulci3000 Project, which aims to examine the archaeological landscape as well as the urban space of the Western Forum at the Etruscan age site of Vulci, located in Viterbo, Italy. A digital workflow is proposed that efficiently incorporates data types and results into the previous archaeological workflow to create a more encompassing and comprehensive project methodology. This digital workflow will allow a virtual reality platform to be created using the integrated data and interpretations. The methodological focus on the integration of utilized data types points to a wider issue in the archaeological field, that of storing and sharing data on one platform as well as how to disseminate such data to both the academic community and the public.

Introduction
This article discusses a digital workflow for incorporating new technologies and 3D data into archaeological fieldwork and applies this workflow to outline the methodological goals and research questions of the multidisciplinary Vulci3000 Project. This project focuses on Vulci (10–3rd centuries BCE), located in the Province of Viterbo, Italy, which was one of the largest and most important cities of ancient Etruria and one of the biggest cities in the 1st millennium BCE in the Italian peninsula (Cerchiai 2001; Sgubini Moretti 2003) (Figure 1). The first excavations, which focused on the rich cemeteries, took place in the 18th and early 19th century (revealing the elaborate chamber tombs named the Tombs of the Sun, the Moon, the Carved Ceiling and Campanari). Later, in the mid-19th century, Lucian Bonaparte (brother of Napoleon) and the Guglielmi family started new excavations in the Eastern necropolis where the famous Tumulus of Cuccumella was found as well as the Tomb of Isis (Bonamici 1980). A large percentage of Attic vases known in the world today have been found in the Vulci cemeteries. The habitation site is a uniquely stratified and mostly untouched urban context that includes, in the same area, Iron Age, Etruscan, Roman, and Medieval settlements (Arancio 2014; Ward-Perkins 1962). It had an area of c. 126 hectares and an estimated population of thousands of inhabitants in the Classical period (6–5th centuries BCE). It was part of the Etruscan dodecapolis, the Etruscan Federation of the most important cities of Etruria. Vulci was highly important in terms of exchange, political and social rank, production of valuable goods, and trade with the entire Mediterranean Basin. It was in the second half of the 4th century BCE in which Vulci started to face the impact of Roman expansionism. In 280 BCE, it had to forfeit a large part of its territory, and this was the beginning of its decline.

Figure 1. Map from Google Earth locating Vulci in relation to the other nearby Etruscan centers of Tarquinia, Cerveteri and Bolsena, as well as Rome for reference.
There are several thousands of tombs in the necropoleis (8–4th centuries BCE) surrounding the city; while many have been looted, most of them are unexcavated. Famous aristocratic tombs include those such as La Cuccumella, the Francois Tomb and, more recently, the Tomb of Silver Hands (Carosi and Regoli 2014; Regoli 2014). The most important monuments of the city are concentrated and currently exposed in the so-called Western Forum in the southwestern part of the plateau: the Great Temple, the House of Cryptoporticus, the House of the Fisherman, and the Honorary Arch. The Great Temple, Etruscan first and Roman later, plays a central role in the monumentalization and ritualization of this public space. The relationships between the Great Temple and the surrounding area are crucial for understanding development and transformation of the city (Bartoccini 1963). It is, in fact, very likely that the city’s size during the Roman occupation was reduced drastically with the highest concentration of buildings around the Forum in the southwestern part of the site (Gazzetti 1985).

With a focus on the Forum area in the southwestern part of the site, the Vulci3000 Project has three specific and interrelated goals: 1) to study and contextualize the site in the archaeological landscape; 2) to provide wide-ranging survey data and subsequent interpretations to support an initial, but extensive excavation season; 3) and to create a virtual reality platform for Vulci’s museum. The project aims, with its methodological goal, to create a new digital workflow in order to incorporate new technologies and 3D models, which can smoothly integrate and supplement archaeological survey and excavation work. This multi-scale, multi-dimensional approach to generate a digital workflow will enable us to apply the resulting process to any project. One of the challenges is combining the traditional archaeological workflow with a new, more technologically and digitally based focus. How might new technologies such as laser scanners, drones, optical scanners, 3D models, and reconstructions, be used to enhance the archaeological questions a survey or excavation proposes to answer? Beyond configuring a new, more digital workflow, a second methodological goal is to define a method of disseminating the collected and processed data. This dissemination, focused on both scholars and the general public, will utilize web GIS platforms and virtual reality platform installations at site museums and other locations.

Digital Workflow and Data Recording
The digital workflow reflects on how to incorporate new technologies and 3D data in a multidisciplinary archaeological project. Below is the methodological approach applied to the Vulci3000 Project:
- **Data Recording**
  - Remote Sensing
    - GPR
    - Magnetometry
    - Drone Aerial Photograph
  - 3D Scanning
    - Image Processing and GIS Integration
- **Data Processing**
- **Dissemination, Visualization, and Communication**
- **Data Archiving and Repository**

Remote Sensing
The methods of remote sensing most pertinent to the Vulci3000 Project focus on ground penetrating radar (GPR), magnetometry, as well as drone and aerial photography. GPR uses multiple sensors to send electromagnetic radio pulses into the ground, which are then reflected by materials they encounter (Goodman and Piro 2013). Different materials (such as clay, stone, etc.) reflect the pulses back to an antenna at differing strengths and lengths of time. The strength of the pulses and the time they took to reach the antenna can then be interpreted to provide a general image of structures beneath the surface at various depths (Goodman and Piro 2013; Rapp and Hill 2006:116). The results of GPR can vary, depending on such factors as soil type, strength of equipment, and frequency used, but can provide a map of the unseen, buried features of a site. For the 2015 survey at Vulci, a 16-channel GPR IDS Stream-X 200 MHz (Subsurface Radar Tomography Equipment for Assets Mapping) was used to collect 3.8 hectares of GPR data surrounding the Western Forum between 2 and 2.5 meters from ground level (Catanzariti and Morelli 2015:3–4) (Figure 2). Synchronization with a GPS device allowed the data to be georeferenced in real-time and provided an accuracy of less than two centimeters. This process
yielded promisingly clear results, allowing for the confirmation of previously suggested features, the interpretation of new features in the area and the interpretation of vertical profiles of specific areas (Figure 3).

![Figure 2](image1.png)

Figure 2. It was necessary to pull the 16-channel GPR IDS Stream – X 200 MHz (Subsurface Radar Tomography Equipment for Assets Mapping) with a car in order to record 3.8 hectares of data.

![Figure 3](image2.png)

Figure 3. This slice of GPR data shows several clear archaeological features, including a main road and a few possible building footprints.

Magnetometry offers a different perspective than GPR. While GPR provides information about features of denser material, such as stone, magnetism can provide information about additional materials, such as burned materials or areas, decayed organic materials, iron, and brick (Campana and Saito 2014:1–2; Clark 1997:64–98; Rapp and Hill 2006:113–115). A remote sensing technique that measures and maps patterns of magnetism beneath the ground, magnetometry can illuminate patterns that may reflect archaeological significance, although often this requires comparative evidence in order to interpret the meanings of the magnetometry patterns. Results from this process depend on the local geology as well as the quantity and magnetic strength of buried sources, such as stone or burned materials. The magnetometry collected at Vulci in 2014, for the most part, yielded patterns that are relatively indistinct or diffuse and are therefore unable to provide details about specific features underneath the ground (Campana and Saito 2014:1–5) (Figure 4). Field E, a privately owned area southwest of the archaeological park, provided the clearest data with no noise, but the high grass prevented readings and coverage necessary for extensive archaeological work (Campana and Saito 2014:22–25) (Figure 5). Nevertheless, patterns in data that offer less clarity due to noise may still be amenable to interpretation when read in conjunction with both GPR and aerial photographic data.

![Figure 4](image3.png)

Figure 4. Results from the magnetometry survey in the area just south of the Great Temple illustrating the diffuse nature of the data.

![Figure 5](image4.png)

Figure 5. Field E magnetometry results show a clear archaeological feature in the southwest corner, which Campana and Saito interpret as possibly being a road.
Both old and new aerial photographs were used to supplement the other remote sensing techniques. Aerial photographs are used to interpret crop marks that cannot be distinguishable from the ground but are visible from the air. The visibility of crop marks depends on a multitude of factors, such as weather, type of crop, time of the year, etc. Our digital workflow calls for high quality aerial photographs in order to interpret crop marks for determining features at the site, to provide a high quality orthographic image for maps, and to create a 3D landscape model of the site. Historical aerial photography can offer a perspective from the past, illustrating different landuse and practices that may provide information not available in modern aerial photographs (Tartara 2013:123–124). Old aerial photographs required extensive georeferencing due to their oblique angles but were able to provide a wealth of information due to the clear and distinguishing crop marks (Pocobelli 2003) (Figure 6). Additional high-resolution aerial photography was collected via a Panasonic GH4 camera mounted on a DJI S900 high-power hexacopter drone during the 2015 survey (Figure 7). This large, high-powered drone is capable of carrying not only a digital camera, but also other devices such as DSLR, multispectral cameras, or a LiDAR system. Data from 19 drone flights yielding over 3,500 photos covered the entirety of the Vulci plateau. Combined with GPS reference points collected with an SX Blue II differential GPS, the aerial photos were georeferenced and served as a further point of comparison with GPR and magnetometry data (Figure 8). Ensuring the compatibility of various remote sensing data housed in one platform is important for conducting a comprehensive analysis and is therefore crucial to the methodology of this project. Advances in technology, such as with drones, allow for new viable methods of efficiently collecting data.

3D Scanning
The collection of and interpretations from 3D data offer new methods of analysis from unique perspectives. Laser scans completed at Vulci thus far using a Faro Focus 3D Laser Scanner include several monuments and features, including the Tomb of Silver Hands. Laser scans can provide models of the current state of site features for visualizations as well as bases for reconstructions.

Figure 6. This old aerial photograph was taken through several programs in order to be properly sized due to its original oblique nature, as seen in the original (bottom), and georeferenced due to the difficulty of finding specific markers before the final placement in ArcGIS on top of the drone aerial data (top).

Figure 7. The drone, flying automated flight paths, collected over 3,500 pictures of the landscape, providing an additional look at Vulci’s environment.
The resulting point clouds from the laser scans yield realistic results, but also demonstrate the careful and time-consuming collection process (Figure 9). The 3D model of a feature can also provide for posterity in the case of damage or destruction, as was the case for the Tomb of Silver Hands, which partially collapsed several years after its discovery. Laser scanning is essential to the Vulci3000 Project because it is a large-scale digital recording system, recording objects, structures, and landscapes. Such a large scale is necessary to study an entire urban center like the Western Forum as well as the archaeological environment of the site. Optical scanning at Vulci yielded new 3D data from a different method. The DPI-7 optical scanner allows tablets to capture and process data from depth cameras with a working range of 0.6 to 3.3 meters in real-time using the 3D imaging software Phi.3D, which outputs a point cloud. Using an optical scanner, such as the handheld DPI-7, limits the user to inside and shaded spaces, but utilizes a user-friendly interface to provide accurate yet quick results. The 3D scans by the optical scanner have yielded promising results, as seen with the scanning of the interior of the Francois Tomb. This method of capturing 3D data is both less intrusive and less harmful to the tomb, in which are still preserved colorful decorative elements. The integration of 3D data with 2D interpreted results offers a process that leads to a more complete analysis and holistic reading of the information. This methodology using the described data recording techniques demonstrates that data can be integrated into a single platform to provide a more complex and thorough interpretation.

**GIS Integration and Image Processing**

The workflow begins with the data recording of aerial imagery through planned drone flights. A grid plan is laid out over the site, dividing the area into sections coverable by one drone flight. These sections must overlap by approximately 60% in order for the images of the different flights to effectively align. For each section, numbered targets are strategically placed throughout the area in order to record GPS locations for georeferencing the aerial photos. These GPS points are recorded using real-time kinematic (RTK) GPS from the global navigation satellite systems (GNSS), providing an accurate GPS position in real-time. Both the GPS coordinates and the images are uploaded in groups by flight into Agisoft Photoscan for image processing. The GPS coordinates allow the images to be georeferenced in space and to each other. This georeferencing of the images along with the combining of all images into one group will allow this data to be brought into GIS programs and used in tandem with other remote sensing data (Figure 10).

Image modeling using Agisoft Photoscan was chosen for the Vulci3000 Project because of its capability to create 3D models of large areas, such as landscape models. The workflow inside Photoscan from here creates a sparse point cloud, from which a dense point cloud is built. Based upon this dense point cloud a geometric mesh layer is created, over which a texture layer can then be laid. The end result is a high-resolution 3D landscape created from drone photography. The 3D landscape
model of the current environment at Vulci offers new orthographic images for further image processing and integration with other remote sensing data, as well as a base 3D landscape on which to begin building and placing additional models and reconstructions.

Figure 10. The combined 3,500 photos in Photoscan, the photo and placement of each photo marked by a blue rectangle, shows the full aerial coverage of the Vulci plateau.

As a result of the image processing in Agisoft Photoscan, the remote sensing data (GPR, magnetometry, drone aerial photography) are all layered together in ArcGIS. The interpretations gleaned from each set of data is both increased as well as put into context when studied side by side with the other remote sensing data of the same area. Each technique offers new perspectives and additional types of information, which help to ameliorate the shortcomings encountered with each technique. The information interpreted from the remote sensing data, in combination with additional old maps, plans, and aerial photographs, allows for a more complex analysis and leads to the final integration of all data both onto the online archive as well as into Unity 3D.

Simulation, Visualization, and Communication
The results of the Vulci3000 Project are best communicated visually through maps, models, reconstructions, and virtual reality. Visualization of data in various ways offers new perspectives and offers a stage for wider-ranging discussions. Visuals, such as 3D models, are able to communicate information to a broader audience as well as more fully communicate some ideas and theories that are better suited to a visual medium. For example, the aerial photography captured via drone was used to create a realistic landscape model, on which the Great Temple, a main feature of the Western Forum, was modeled (Figure 11). The visualization of this reconstruction on top of the present-day landscape and archaeological evidence both contextualizes the building and offers a visual communication method optimal for 3D data.

Figure 11. The reconstruction of the Great Temple placed over the current ruins on the landscape model provides a comparative and comprehensive visualization.

The Vulci3000 Project and Duke University takes this visualization one step further with the use of virtual reality platforms: Oculus Rift with Unity 3D and the DIVE (Duke Immersive Virtual Environment). Virtual reality platforms follow after 3D data processing and 3D modeling in the digital workflow. The 3D models once created in programs such as Unity 3D, a game development platform used for high quality 3D modeling, can then be used in conjunction with VR applications. Because the 3D modeling community at Duke uses Unity 3D as the common denominator program, 3D models are easily shared and connected to various VR applications. The methodology of this project converged interpreted data into one platform – Unity 3D – in order to facilitate the ease of later pairing the models with VR applications.

One VR option concerns the use of Oculus Rift in combination with the Unity 3D platform: this provides a virtual portable and individual virtual reality experience. The Oculus Rift, a virtual reality headset, allows a sharper quality and interactive method for an increasing number of people to interact with 3D models and landscapes. Models in Unity 3D, such as the landscape model and the Great Temple, can be viewed in virtual reality,
offering a new perspective on visualization (Figure 12). Another VR option is the DIVE, a fully immersive virtual environment. Six projection screens create a large box, onto which high quality projectors project various views of a 3D model. This thus creates what the viewer, from the inside with accompanying glasses, can perceive of as being inside the virtual environment. This unique experience tracks the movement of the viewer via the glasses and the model moves correspondingly. Interacting with 3D virtual environments in this manner provides a new perspective of the model, one that is more interactive and inclusive.

![Figure 12. View of the landscape model and temple reconstruction in Unity 3D in virtual reality through the Oculus Rift.](image)

**Data Archiving and Repositories**

The problem the proposed methodology moves to ameliorate with this digital workflow revolves around the question of how to store and share data. With the advent of new technologies that bring with them larger quantities of data, data management and storage is an increasingly frustrating issue. Online spaces for spatial data, such as the various webGIS sites, offer a partial solution. Rendering data in browser through a webGIS site is supported by WebGL, a javascript API that bypasses the need for a plug-in and allows the rendering of 2D and 3D data on the web. Uploading raw and interpreted data to an online repository and a webGIS server allows the data to be hosted in a space accessible to more people than if it were only stored to a local server. This means that data that would normally go underutilized in its original context could fuel new perspectives and theories by members of the larger academic community. In order to promote this community of collaboration, the Vulci3000 Project stores its data on such a server.

The project’s current online platform is an open-source site called Geonode. Once the raw data is processed, the results are uploaded to the Geonode server. Geonode is the main interface and is supported by a geo-server. The connection between the geo-server and Geonode allows for a central repository of data and access via the interface without requiring direct access to the database. This method of access provides search capabilities and quick visualizations of the data layers for researchers, while at the same time protecting the behind-the-scenes database system. Such an interface allows both researchers and other interested parties to view the data in a spatial context, save maps, and choose which layers to download (Figure 13). A benefit of this interface is that Geonode has different levels of authorized accessibility, which allows for the uploading and downloading of various files. This key feature is useful for an international team that wishes to be open with data, especially because some files are nearly impossible to send, due to size capacity, in many other digital formats. A virtual, collaborative environment through the web allows for wide ranging access – a place where people from all fields and locations can learn and suggest new ideas and theories about the project (Pietroni and Forte 2007). While anyone can email and request a free account in order to access the site and download content, it is possible to set various access levels for different groups and people. It is important to share data and results in as close to real-time as possible, but it is also crucial to maintain control over the dissemination of one’s datasets.

In this modular approach to an open-source, online platform, it is possible to tie multiple platforms or interfaces to the same geo-server. This approach means that the project is not limited to using the same interface or staying married to one particular mega-program. A further goal is to create an online, story-oriented website for public viewing and exploration through an interactive map, not just of the data already recorded but also of the story
behind the Vulci3000 Project. At the same time, Geonode interface will be kept available for scholars and those who wish to download data. The flexibility of this modular approach will allow the Geonode platform to continue to grow, expanding into new forms, which is especially important in our quickly developing, technologically-oriented society.

Figure 13. This example view of a map through the Geonode interface illustrates some of the various layers and possibilities for visualization.

Conclusion
The methodology laid out in this paper with the suggested digital workflow, which incorporates new technological methods and results into the current archaeological workflow, allows for the integration of all types of recorded data into one platform. This complete integration offers a holistic interpretation that is unattainable with split data. The spatial integration of data in a common domain allows for its overlap within the same space, a process that cannot be realized if data analysis occurs only through separate platforms. The deliberate multi-path approach of this methodology offers a long-term solution, looking to the future of data integration and analysis. Although present webGIS sites and webGIS repository sites do not offer a complete integration of all 2D and 3D data, a plug-in for Geonode – Cesium – could provide a solution. While Geonode, with its modular approach, supplies a bi-dimensional and interdisciplinary solution for 2D data on the web, the addition of Cesium could allow for a holistic solution in combining and providing access to both 2D and 3D data on the web. That the development of a lasting tool, which could provide this integration, has not yet been realized stems from the lack of standardization and guidelines for repositories and archaeological archives. Inconsistent methodologies and overly numerous approaches to archiving archaeological data scatter and further delays multi-disciplined work to create standardization and long-term solutions.

It is fair to recall in this situation the difficulty and massive impact of this large amount of data and the problems associated with processing such quantities. Big data has increasingly become a vexing issue for a number of disciplines, archaeology being no exception (Anichini and Gattiglia 2015; Gattiglia 2015). The large amount of data recorded with tools not available in the past is problematic for both the workflow and for managing the data in real-time. Real-time management as well as storage after processing requires high processing power, an extensive server space, continued maintenance, a new grouping of skills, continued human input and power, and a financial burden. The methodology and integrated digital workflow of the Vulci3000 Project offers a promising solution to the problems of dealing with data outlined in this article. As the field must adapt its workflows to include and make use of new technology, the field must also adapt its methods of analysis and storage of both raw and interpreted data.

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