Unearthing Patterns in Venetian History:
Developing an Online Tool for Discovering Patterns in Subterranean Archaeological Sites

An Interdisciplinary Qualifying Project
Submitted to the faculty of
Worcester Polytechnic Institute
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

Submitted by:
William Godsey
Natalia Kononenko
Xiaozhu Liu
Lucy Stuehrmann
Sponsoring Agency:
Studio Zandinella
Submitted To:
Professor Aaron N. Deskins
Professor Fabio Carrera

Submitted Date:
https://sites.google.com/site/ve16archeo/
ve16-archeo@wpi.edu

Abstract

Archaeologists in Venice would benefit from digital tools to improve their efficiency in data collection, visualization, and correlation. To aid in archaeological research, we developed a three-part prototype system, consisting of a web app, online database, and a map-based website, for the archaeological firm Studio Zandinella. The first aspect of the project was an online database that allows archaeologists to store and visualize archaeological data. The second part of the system was a data collecting system that records information on the database. The third part of the system was a map-based website that visualizes the contents of the database. These tools will allow Venetian archaeologists to better conduct research and find patterns of data across archaeological sites in Venice.

Executive Summary

The city of Venice and its lagoon have played a major role in the history of both Europe and the world as both a political force and the cross road between the east and the west over the last two millennia, drawing the attention of countless visitors and scholars. Amongst these scholars are archaeologists, scientists who study the material remains of past cultures, and their work is of the utmost importance to the proper documentation of Venice's rich culture and history. Unfortunately archaeological work and research is very time and labor intensive. The goal of this project was to assist Venetian archaeologists with collecting, visualizing and cross-referencing archaeological data from subterranean and submerged archaeological sites in Venice and the surrounding lagoon.

The objectives of the project were as follows:

1. To design and create a data recording systemto collect archeological data.

2. To design and create a web-based system to visualize archaeological data.

3. To experiment with analytical cross-referencing techniques based on the collected data.

The first aspect of our project was the creation of a data recording system that would assist Venetian archaeologists with recording archaeological data from the field. The first step taken was to meet with Studio Zandinella and discuss app design. From these discussion we were able to determine that Venetian archaeologists use a complex set of paper records that are required by the Soprintendenza, the local government authority for archaeologists. The studio emphasized the need to reduce the current workload of archaeologists working in the field. From here the application was designed with both usability and efficiency in mind, and as such any information that is recorded on the system will be automatically uploaded to the previously mentioned online database. In the below figure you can see several screenshots of the mobile version of the

application, displaying its data collection functionality, and how it has been designed for clarity and ease of use while still being able to effectively and accurately record data from the field.
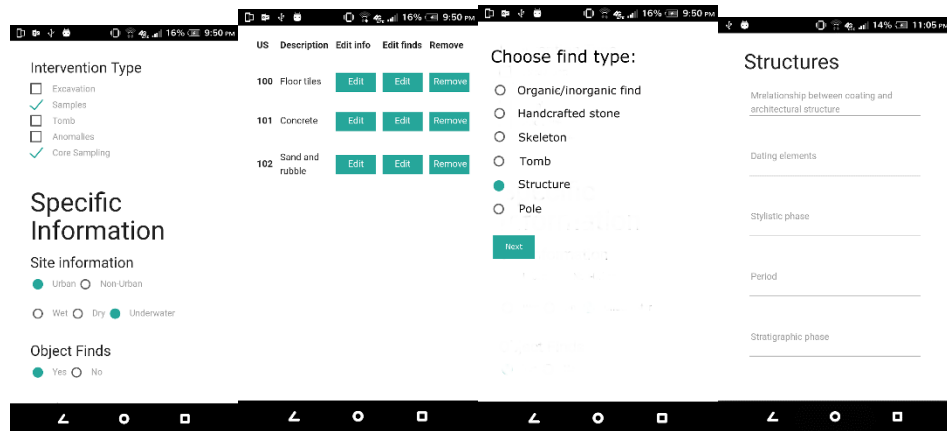
Screenshots of the data recording system's user interface

As can be seen in the above figure to further ensure the effectiveness of the system the team designed the data entry forms on the application to correspond with the previously mentioned government forms which can be found in **Appendix C**, and to partially autofill said forms on the database with the relevant information to further increase the ease and efficiency of archaeological data recording. In order to improve the effectiveness of the data recording system the team integrated some of the unique technological features of the mobile device platform as was suggested by our advisors in our team meetings. These features included using the phone's camera to easily and automatically upload photographs to the online database to further improve the visualization abilities of the system. The second of these features is the use of a device's onboard GPS functionality to allow archaeologists to easily and accurately record the exact geographic location of the site on which they are working. The data collected by the web application is stored in an online database that makes it easily accessible. With the integration of the additional features in addition to the form-based data recording abilities of the data recording application, the team has been able to create a system that will allow Venetian archaeologists to easily record, manage, and visualize their data.

The second of the team's objectives focused primarily on the creation of a map-based website that would allow archaeologists to easily visualize said data. The first of step towards accomplishing this goal was for the team to meet with our sponsor, Studio Zandinella, to discuss the current methods that archaeologists use for data management and visualization. For populating the database and map-based website the team used the data collected by amateur archaeologist Ernesto Canal, who spent several decades visiting and documenting archaeological sites in Venice in his book, "Archeologia della Laguna di Venezia", to demonstrate the usability of our system for both storing and visualizing archaeological data. The below figure is the map of Venice and its lagoon created by Ernesto Canal displaying all of the archaeological information that he collected during his career.
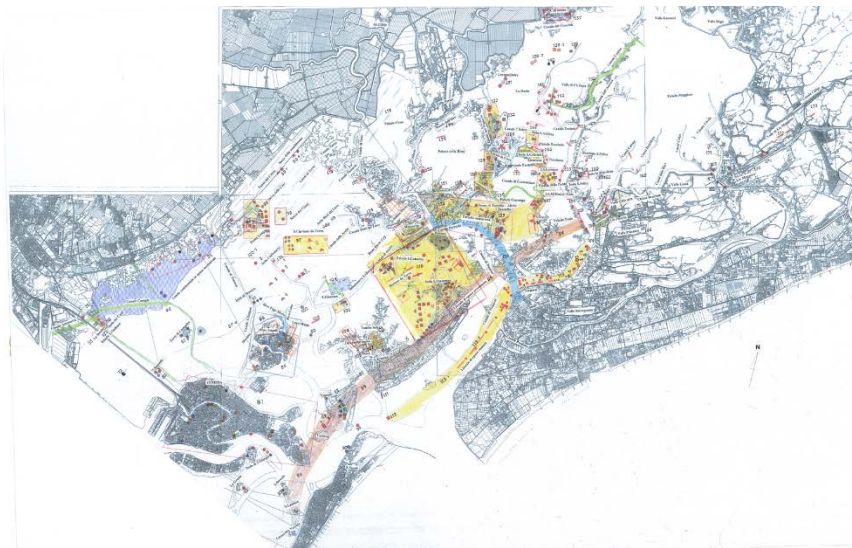

Ernesto Canal's Map

The below figure is a screenshot of the map generated digitally by the team displaying some of Ernesto Canal's information, highlighting the capability of the system to accurately and clearly visualize archaeological information.
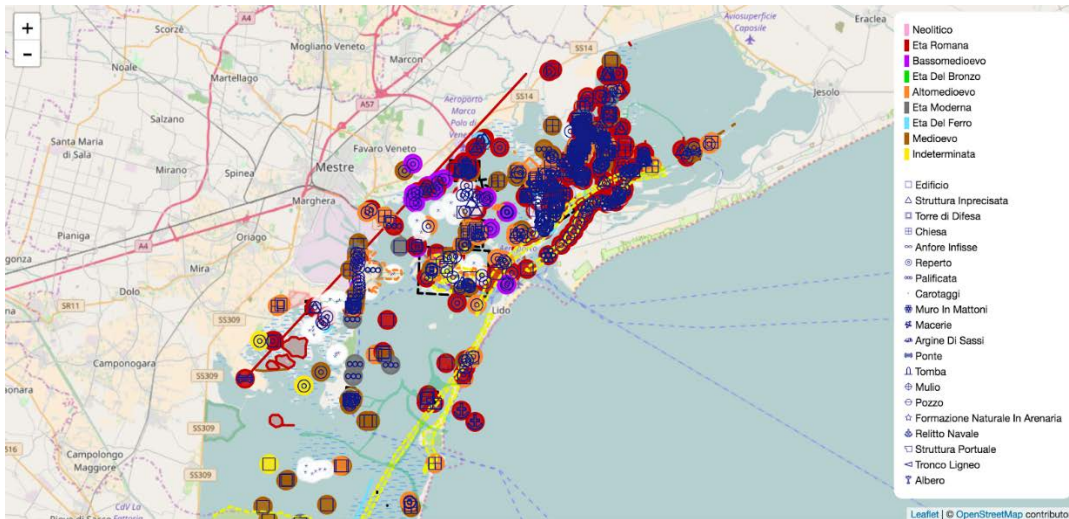
Screenshot of the map-based website

The below figure is a screenshot of the map-based website displaying the system's ability to zoom in on any particular area of the map to further visualize the available data, while also displaying the pop-up feature of the system allowing for easy accessibility to more information on any given site displayed on the map.
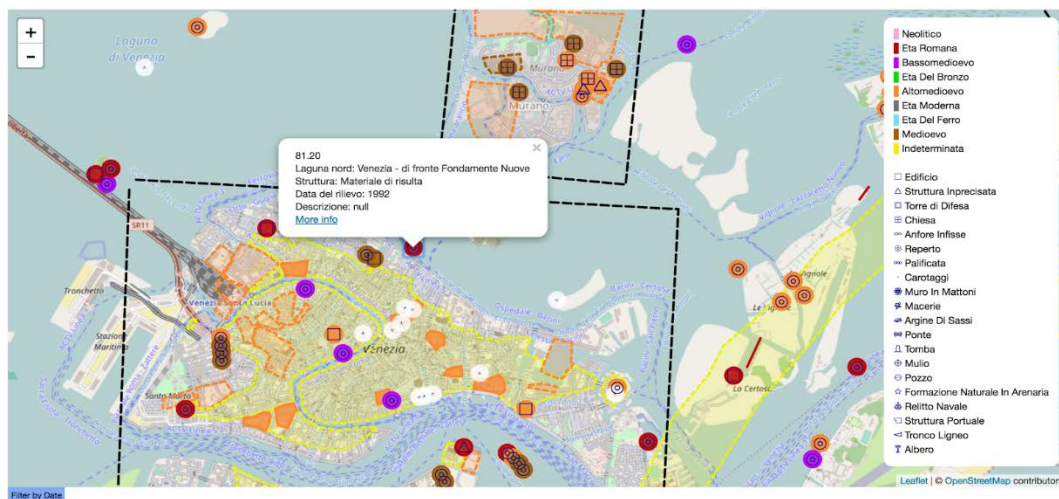
Screenshot of the map-based website's data visualization abilities

Currently the system is able to accurately store and manage all forms of archaeological information and will provide archaeologists with a powerful tool for visualizing their collected data. In particular the use of Ernesto Canal's collected information has allowed the team to highlight the

efficiency and power of the system as a research tool, as anyone using the system could properly visualize and make the connections that took Ernesto several decades, in just a fraction of that time.

Screenshot of the system's data filtering capabilities using medieval sites

The third goal of this project was to experiment with data cross-referencing techniques using the collected data, which in this case was data from Ernesto Canal's book. Experimentation primarily took the form of using the map-based website for filtering by site type and age to help with visualizing connections and patterns amongst archaeological data. The uppermost of the two figures below is a screenshot showing only medieval sites. This screenshot was generated using the filtering tool. The lower figure shows filtering by type of site. Here only shipwrecks are shown on the map.

This functionality allows Venetian archaeologists to spend significantly less time and energy analyzing data and making predictions as to the locations of potential sites than was previously possible. It also allows archaeologists to easily research and visualize information that

would otherwise take significant time and effort to complete, further improving the abilities of archaeologists to pursue their work.
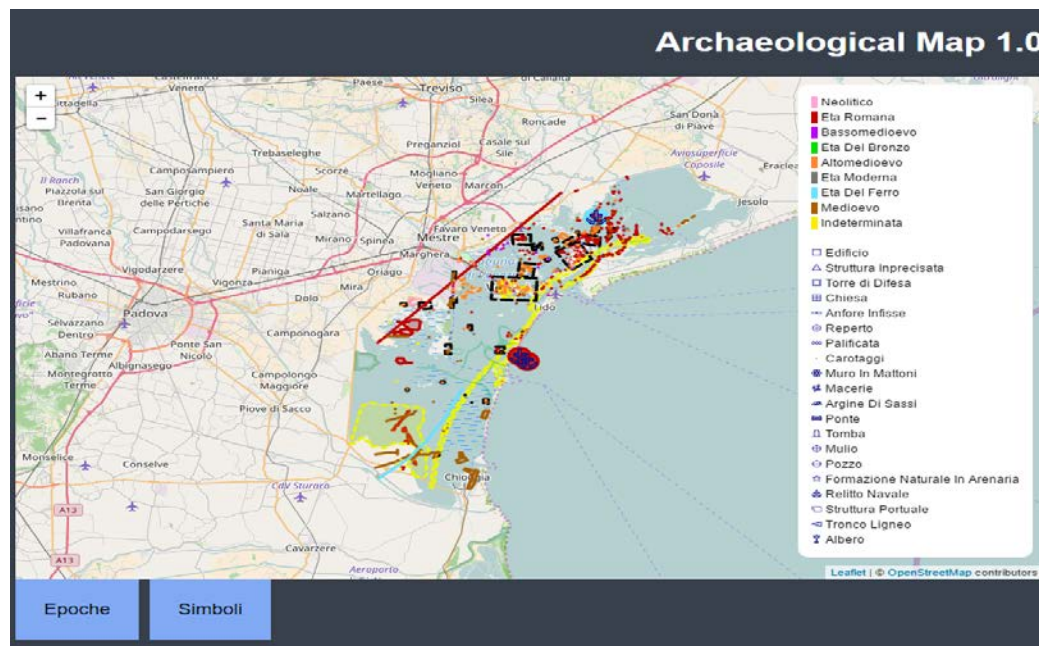
Screenshot of the system's data filtering capabilities using shipwrecks

This system as a whole, while still a prototype, has met the objectives of our project for assisting archaeologists with their researching abilities in terms of data recording, management, and visualization. We have also created a strong foundation for both Studio Zandinella and future IQP teams to build upon. As it stands, Studio Zandinella is now able to use the data collection system to store and manage data, and can use our system to better manage data and conduct archaeological research. Future IQP teams will be able to improve the data collection and analyses system, thus increasing the usefulness of the system as a research tool. Overall, the team has created a tool that will not only assist archaeologists with their current efforts towards data recording, management, and visualization, but also has the potential to do so for many years to come.

Authorship

Section	Primary Author(s)	Primary Editor(s)
Abstract	Lucy Stuehrmann	Lucy Stuehrmann, Will Godsey
Executive Summary	Will Godsey	Natasha Kononenko, Xiaozhu Liu
Introduction	Will Godsey, Natasha Kononenko, Xiaozhu Liu, Lucy Stuehrmann	Will Godsey, Natasha Kononenko, Xiaozhu Liu, Lucy Stuehrmann
2.1 Archaeology Overview	Lucy Stuehrmann	Will Godsey
2.2 Archaeological Considerations of Venice	Will Godsey, Natasha Kononenko	Will Godsey, Natasha Kononenko
2.3 Digital Archaeology	Xiaozhu Liu	Will Godsey, Xiaozhu Liu
3.1 Collecting Archaeological Data	Lucy Stuehrmann	Natasha Kononenko
3.2 Visualizing Archaeological Data	Natasha Kononenko, Lucy Stuehrmann	Lucy Stuehrmann, Natasha Kononenko
3.3 Experimenting with Cross-Referencing Archaeological Data	Xiaozhu Liu, Lucy Stuehrmann	Natasha Kononenko
4.1 Designing and Creating the Data Collection System	Will Godsey, Natasha Kononenko	Xiaozhu Liu
4.2 Visualization System	Will Godsey, Xiaozhu Liu	Natasha Kononenko
4.3 Using Tools for Archaeological Analysis	Lucy Stuehrmann, Xiaozhu Liu	Natasha Kononenko
5.1 Field Application	Lucy Stuehrmann	Natasha Kononenko, Lucy Stuehrmann
5.2 Visualization System	Lucy Stuehrmann	Natasha Kononenko
5.3 Analysis	Lucy Stuehrmann	Will Godsey

This work was completed equally by all members of this team and represents extensive work done by all members of this team.

Table of Contents

List of Figures

1. Introduction

Archaeology is the study of past cultures through the material remains left behind by these cultures (AIA, 2016). Archaeology allows humanity to gain a better understanding of its past, which assists in understanding why cultures are structured the way they are today. Each new archaeological find gives archaeologists fresh insight into the past, serving as a piece of a greater puzzle. Like any other puzzle, the full picture is often only visible when all or many of the pieces have been assembled. When researchers attempt to bring information together, difficulty can arise in understanding of past cultural and societal changes, as many current data recording methods do not allow for easy data analysis and visualization. These problems associated with data analysis and visualization are caused by archiving methods that put emphasis on the analysis of individual pieces rather than emphasizing analysis of the connections between sites and finds. Today, most archaeological data is manually recorded, then organized by parameters including age, site type, place of origin for artifacts, and location, and are then filed for future reference in paper-based archives. Such practices are well-established and commonplace, and the resultant analog databases kept by archaeologists continue to grow with each new discovery (Perrin K., 2014). The larger an analog database is, the harder it becomes to analyze and organize the contained information to clearly understand connections between archaeological findings, as such efforts are highly reliant on the abilities of researchers to find, analyze, and visualize all of the relevant information (Cai L., 2015). This means that for sites of high archaeological significance, which can contain thousands of separate data points, traditional methods for data analysis can become a Sisyphean

task, as it becomes incredibly difficult for archaeologists to manage and work with so much information.

Venetian archaeologists face previously mentioned difficulties as well as additional challenges caused by human activity, urbanization, tidal changes revealing new sites or flooding current sites, and excavation site difficulties. Human activities in particular contribute to the destruction of archaeological sites, as cruise ships dump waste directly into the lagoon, which damages submerged relics, causing difficulties in recording and preserving these sites. (Hastings, D., 2014). This heightens the importance of swift and efficient archaeological excavation and data gathering. Venice also faces the unique challenge of being a massive archaeological site with a large and active civilian population. Archaeologists must work around citizens and often need to re-bury sites after the initial excavation is finished. This means that inaccessible subterranean sites are frequent, and often only one excavation is possible. Since the government requires specific paper forms to be submitted, archaeologists document their results in paper-based, difficult-to-navigate files (Afezolli, 2010). Due to these factors, researchers in Venice face distinct challenges in conducting research and gathering archaeological data.

Our sponsor, Studio Zandinella, which is a Venetian archaeological firm, as well as most Venetian archaeologists, meticulously document and catalogue their findings using paper-based recording systems. After the recording process, data is archived, and only re-examined when deemed necessary. This system has created colossal collections of data that require an equally considerable investment of energy for the members of the Venetian archaeological community to transcribe into another archiving system. Extensive efforts must be made to not only ensure the accuracy, but also the completeness of such a switch due to the sheer volume of information involved. These practices for cataloguing and documentation also create upkeep and managerial

challenges due to the necessity of manually tracking and organizing multitudinous paper records. As data gathering and management represent important aspects of archaeological work and research, it is necessary to modernize these data collection systems and provide a tool to visualize this data, including geographical analysis of different archeological finds.

Studio Zandinella has identified specific improvements that could be made to their current data management methods. They currently use an archaeological information system that utilizes extensive paper records, which are difficult to search through. An additional difficulty involves cross-referencing, which refers to the act of comparing data about multiple sites or finds to understand possible patterns or connections. Cross-referencing is difficult to complete as a result of the physically large nature of these paper archives. Studio Zandinella has no digital system to assist with archaeological research, however, other Venetian archaeological firms are actively working to digitally catalogue the various Venetian sites using a map based web-system, but due to the specialized needs and preferences of each archaeological studio, none of the currently created systems adequately meet Studio Zandinella's needs.

The primary focus of our project will be the creation of a prototype digital system to ease the documentation, visualization, and analysis of archaeological data. The team will also design a database and data-entry system to assist in decreasing user error in cataloguing, as the web app will enable archaeologists to ensure that all necessary information is gathered and recorded on-site. Data can then be visualized in a map-based form, giving archaeologists further insight into archaeological sites in Venice.

2. Background

In order to assist Venetian archaeologists with the development of an archaeological data management and research tool, a thorough understanding of general archaeological practices and research has to be developed. Once archaeological processes and practices are understood, Venice-specific challenges with archaeological research are discussed as well as current recording and research practices in the global archaeological community. The section also discusses digital archaeological practices and techniques which will assist in the creation of an online data management and research system.

2.1. Archaeology Overview

Archaeologists collect, analyze, and record data using established technical methods that follow guidelines set by archaeological organizations, universities, and governments. This section establishes important archaeological definitions, explains data collection and analysis procedures, and briefly covers differences between traditional and Venice-specific archaeological sites and techniques.

2.1.1. Definitions

Archaeologists attempt to understand and explain the practices and behaviors of past cultures and societies by analyzing the remains of those societies. These finds are typically discovered by archaeologists through the excavation of archaeological sites (Dean M., 1995; Drewett, 1999). An archaeological site is defined as "Any place where human material remains are found; an area of human activity represented by material culture." (AIA, 2016) In this definition, material culture refers to any material remains, such as bricks and pottery shards, left by past societies (AIA, 2016). Sites take many different forms, but we are primarily concerned

with underwater, urban, and subterranean sites, as those are most common to Venice. Archaeologists face different challenges for investigating each of these site types, which are further investigated in Section 2.1.3. At these sites, archaeologists uncover relics and remains of past civilizations, that can be classified broadly as artifacts, ecofacts, and human remains. Artifacts are defined as "Portable object[s] manufactured, modified, or used by humans." (AIA, 2016) These differ from ecofacts, which are defined as "archaeological finds that are of cultural significance, but were not manufactured by humans. These include bones and vegetal remains that can tell [archaeologists] about past diet or environments." (AIA, 2016) Ecofacts, in turn, differ from human remains, which are defined as human bones, tissue, or body parts (AIA, 2016). The differences between these relic types is important to understand, as they necessitate different recording, analyses, and legal processes (AIA, 2016). For example, in Venice, human remains are reported using a separate, more extensive, set of forms than an artifact or ecofact, as seen in **Appendix C,** while ecofacts undergo radiocarbon and chemical analysis**.** Remains are uncovered at sites, and are then typically meticulously catalogued, recorded, then moved off-site where they are analyzed and interpreted (Drewett 1999).

2.1.2. Analyzing and Correlating Archaeological Data

Once archaeologists have collected artifacts from an archaeological site, they begin analyzing these relics to uncover relationships between sites and finds. Archaeologists use several different methods and techniques when analyzing archeological sites, the most significant of which is dating (Perrin, K., 2013; Drewett 1999). Dating remains is one of the most widely-used and important methods used to analyze finds (AIA 2016, Zeuner, F.E, 1951). This process involves establishing a time period where the remains originated and is crucial to archaeological analysis because it allows archaeologists to establish chronological records for sites. (Drewett 1999; Perrin, K., 2013;

AIA, 2016; Avila, C., 2010). To date finds, archaeologists use many different techniques, which can be generalized into two categories: relative and absolute dating (AIA 2016; Afezolli, D., 2009). Relative dating is the process by which finds are analyzed in relation to each other to organize them from least- to most- recent, whereas absolute dating involves the use of scientific processes, such as radiocarbon dating to establish specific dates for finds. (AIA 2016; Rowe, J., 1959; Zeuner, F.E., 1951). Both absolute and relative dating are highly important to archaeological analysis, as absolute dating allows archaeologists to firmly establish when specific societies resided in the site area while relative dating allows archaeologists to determine change in societal practices, cultural considerations, and technological advancement throughout time.

Once remains have been dated and analyzed, archaeologists can then compare their finds to other sites' finds to establish trends and correlations between locations. Archaeologists typically compare information from various locations to determine how manufacturing techniques, cultural practices, and economic practices spread over time throughout a geographical region (Grunow, 1961; Smith, 1987; South, 1978). In order to do this, they track metrics such as pottery form, ceramic structure, art motifs, and architectural similarities between sites (Drewett, 1999). By tracking these and other such metrics, archaeologists determine how civilizations spread and changed throughout history, which is crucial to understanding how human societies have evolved and adapted in the past. This process of correlation is therefore extremely important to archaeologists, and comprises a large portion of archaeological research, which therefore heightens its importance to this project.

2.1.3. Types of Venetian Archeological Sites
Beyond a basic understanding of archaeological methods and analysis, it is important to note several archaeological challenges regarding underwater, subterranean, and urban archaeological

sites, as the majority of Venetian archaeological sites are either located in the lagoon, buried beneath the city, or located in urban areas (Venice and its Lagoon, 2016). Challenges faced when excavating and analyzing sites in underwater, subterranean, and urban location typically revolve around increased difficulty in accessibility to sites and data recording, which can both be addressed through the creation of online, efficient data recording and management systems for Venetian archaeologists. Archaeological techniques used when investigating these locations also differ from techniques used when investigating traditional archaeological sites, and must be understood, as these difficulties also heighten the need for online data collection tools.

Conditions unique to underwater sites can increase uncertainty when analyzing archeological finds. Fluctuating sea levels can affect dating and location analysis and materials tend to degrade differently underwater, which can greatly complicate analysis and evaluation of these remains (Dean M., 1995; Bailey G., 2008). Furthermore, it is highly difficult for archaeologists to return to underwater sites, as underwater archaeology is more expensive than traditional archaeology due to the increased cost of excavation tools, which causes difficulties when collecting new data from old sites (Barstad, J., 2002). As many Venetian sites are underwater, these considerations heighten the need for efficient data collection systems for Venetian archaeologists.

Venice also contains several subterranean archaeological sites, which introduce challenges that are similar to those faced in underwater excavation but involve distinctly different solutions. Subterranean, or below-ground archaeological sites, typically are sites that have been buried by human or geographic activity (Hesselberth, C., 1948; AIA 2016). They can range from underground catacombs to caves to burial locations (Hesselberth, C., 1948; Schiffer M., 1994). As these sites have been buried, they are difficult and costly to excavate using traditional, excavation-

based methods (Levy T., 1996). Furthermore, subterranean locations can be dangerous to explore in-person due to ground instability (Hesselberth, C., 1948; Drewett 1999). Therefore, archaeologists must conduct analysis in subterranean locations quickly, efficiently, and with an emphasis on archaeologist safety. As these sites are difficult to re-examine later, archaeologists also require visualizations of subterranean sites to assist with later research and analysis.

Challenges involving urban archaeology are also crucial to understand for the successful development of this project. Urban sites, or sites located within areas of high human population, face accessibility challenges as well as legal and analytical difficulties (AIA 2016; Dalgish, C., 2005). Sites can be inaccessible due to normal human activity in these areas, or can be impossible to excavate due to their location in proximity to city infrastructure such as subways, water mains, and roads.There are also more stringent legal procedures for urban excavation that can hinder archaeological efforts, as there are risks that excavation could damage buried water mains, power lines, or other city infrastructure if improperly conducted (Dalgish, C., 2005). Furthermore, urban excavation must be conducted swiftly so as to not interfere with the day-to-day life of citizens, which heightens the risk of artifact damage and data loss (Staski, E., 2008). These factors mean that archaeologists conducting urban excavations usually only have one chance to excavate a site and typically cannot return later to urban sites to conduct further excavations. Urban archaeologists must therefore gather all relevant data during a single, brief excavation. In Venice, urban excavations typically are only a few days in duration, which means data recording must be swift, efficient, and highly organized, which can be accomplished using electronic data collection and management systems (Studio Zandinella). All of these factors complicate archaeological excavation and analysis in Venice, and increase the need for highly efficient and robust data collection, management, and analysis systems.

2.2. Archaeological Issues in Venice

There are several factors that archaeologist must take into consideration while working within Venice to avoid possible issues on the worksite and with the collected data. The city has served as a center for many cultures over hundreds of years, and is home to many sites of significance, such as San Marco and the Doge's palace (Ortalli & Scarabello, 1999). The city's rich history piques the interest of professional archaeologists, as well as visitors from around the world. The influx of tourists, as well as geographic considerations relating to urbanization and sea level fluctuation, cause challenges for Venetian archaeologists. These difficulties directly affect the work of archaeologists, and hopefully will be addressed by the creation of streamlined data management and research tools.

2.2.1. Historical Wealth of Venice

Archaeologists typically reference historical documents to conduct research into practices and past cultures. In Venice, there is a wealth of such documents, as traders, artists, and historians created extensive document records that were kept throughout the history of the republic, giving today's archaeologists insight into the business, legislature, philosophy, politics, and events of the past (Ortalli & Scarabello, 1999). Without referencing these period documents, archaeologists would face difficulty in discerning the significance of any Venetian archaeological find, as they would lack some of the historical context for their finds. These records, when used in conjunction with archaeological sites, are of the utmost importance to Venice and the archaeologists working there, as they represent a large portion of the city's cultural and historical heritage (Venice and its Lagoon, 2016). Historical records also need to be more accessible to Venetian archaeologists, which will be addressed through the creation of a digital data management system.

2.2.2. Venice-Specific Difficulties

Archaeologists in Venice face several difficulties relating to tourism, urban excavation, flooding, and weathering. Venice is home to hundreds of thousands of Venetians and host to millions of tourists, so archaeologists must work to accommodate tourist activities in the city. Tourism is the greatest issue facing the city today, with 30 million visitors arriving each year that test the infrastructure and capacity of Venice (McKenna, 2016). Tourists have unintentionally put the city's architecture at risk of destruction through vandalism, looting, and pollution (McKenna, 2016; Hastings 2014). This makes it very difficult for archaeologists to fully record and visualize information, as tourist activities destroy sites and pollute lagoon-based archaeological sites, often negating the efforts to preserve such sites (Hastings, 2014).

Venice's native population further hampers the efforts of the city's archaeologists, as they must accommodate for the people living and working there regularly. Venice is currently home to roughly 55,000 locals living on the island, and even more tourists on a daily basis, creating a logistical problem for archaeologists working there, making it particularly difficult to document findings. Archaeologists must coordinate with locals to gain access to what is often private residential property for excavation, usually limiting the amount of time and access that archaeologists have to various sites (Hastings, 2014). Some sites can only be accessed once due to their location and surroundings, directly impeding the abilities of archaeologists to accurately and fully document their findings (Hastings 2014). As a result of this limited accessibility, it can be near impossible to fully record and visualize the information relevant to these urban sites (Hastings 2014).

In addition to social issues, Venetian archaeologists face geographic difficulties relating to regular flooding of Venice. Periodic flooding, alongside changing sea levels, has caused the height at which buildings were constructed throughout Venice's history to fluctuate (Soika, n.d.). As a

result, the standard methods of relative dating, the process by which finds are compared to other finds found at similar depths below the surface to make an estimate regarding the age of the find, do not apply to Venice. Archaeologists must instead compensate for inaccurate depth-based dating by accessing various records on water levels throughout Venice's history and adjusting relative dating to account for sea level fluctuations (Avila, C., 2010). This complicates the process of archaeological documentation, as it adds extra, complex steps to analysis. Venetian archaeologists working in the field often also face the issues of a very limited time frame in which they can work as a result of the changing tides (Avila, C. 2010). For example, Studio

Figure 1: Archaeological Site Filling with Water during an Excavation

Zandinella, our sponsor, was conducting an archaeological excavation when flooding due to high tides caused their excavation to be temporarily halted, leading to a delay in data gathering and analysis. The site is shown, in the process of flooding, in **Figure 1.** Therefore, tools must be developed to assist in alternative processes of archaeological correlation in Venice.

Venice's unique maritime location also exacerbates the issue of weathering, the processes by which the city is damaged by everyday-wear-and-tear, far beyond the average rate. Early

Venetian construction involved building platforms upon wooden foundations, unifying many of the lagoon's islands into a single landmass ("The Conservation of Venetian Building Materials: Wood," 2008). Not many of these initial constructions have survived, succumbing to weathering and rot ("The Conservation of Venetian Building Materials: Wood," 2008). Many of these early sites are located underneath current buildings, and are extremely difficult to access and document ("The Conservation of Venetian Building Materials: Wood," 2008). Venetian archaeological sites are therefore important to document properly and efficiently, as limited accessibility and near constant damage from natural factors limits the ability of archaeologists to conduct several excavations on a single site.

2.3 Studio Zandinella

As part of our work in Venice, we collaborated with an archaeological studio, a group of archaeologists working under one head archaeologists, called Studio Zandinella. The studio specializes on archaeological excavations, archaeological advisory, rescue excavations, forensic anthropology, historical research, and anthropometric analysis (Archeoveneta, n.d.). Studio Zandinella is comprised of four archaeologists: Dr. Alberto Zandinella, Dr. Secilia Campagnol, Dr. Andrea Cipolato, and Dr. Erika Mattio (Archeoveneta, n.d.). We worked primarily with Dr. Alberto Zandinella, who studies medieval and post-medieval archaeology, as well as wetland archaeology. We also worked with Dr. Erika Mattio, who studies anthropology (Archeoveneta, n.d.). In the past, Studio Zandinella has undertaken subterranean excavations in locations throughout Venice, including numerous septic tank installations and small scale excavations that were later refilled. Their small-scale excavations typically occurred over the course of three or four days, which means that their data collection and recording systems need to be highly organized and efficient. Therefore, the archaeologists of the studio desired efficient and searchable

data management systems to aid in swift and accurate data recording. They also needed advanced data entry systems for on-site real-time recording, which our project aimed to provide through the creation of a web app (Archeoveneta, n.d.). Furthermore, as archaeologists, Studio Zandinella has a vested interest in preserving historical discoveries and data from destruction, which our project also assists with through the collation of large quantities of archaeological data.

2.4 Digital Archaeology

Although there are many Venice-specific challenges with recording and analyzing archaeological data, the process of archaeological collection and data management is similar throughout the global archaeological community. Due to the huge amount of effort involved with traditional methods for archaeological data recording, and the abilities of computers for statistical analysis, organizations such as IDAMP, the Institute on Digital Archaeology Method and Practice, use digital tools for data management and encourage use of digital tools (Carter, 2016). This has lead to increased pressure in the archaeological community to transition to digital tools for recording and management of data, however, most archaeologists use either proprietary or paper-based data management systems (Liritzis, 2015).

Figure 2: Photo of an Archaeological Find

Digital archaeology is archaeological study by using digital tools for data collection, interpretation and dissemination, also allows archaeologists to better visualize and analyze data (Richter, 2014). Digital analysis techniques usually involve statistical analysis to develop models and maps to assist archaeologists with finding data trends and connecting information between sites (Richter 2014). Since the results of digital analyses can be visualized directly, the comprehensibility is improved for audiences without a background in archaeology (Richter, 2014). With the use of such models and images like **Figure 2**, findings and their present status can be more easily displayed, which improves the ability of archaeologists to convey the significance of their work and correlate data between separate sites. Digital archaeology can not only assist in the visualization of archaeological findings, but also can help to document and analyze collected data. Due to the great amounts of time and effort associated with traditional methods for location-based data analysis, Geographic Information Systems have now become one of the most commonly used tools in archaeological studies, to help alleviate the effort involved with these processes.

2.4.1 Geographic Information System

Geographic information systems (GIS) are computer-based systems that can easily store, analyze, visualize, and process geographic data (Maliene, 2011). Since the 1990's GIS has become more commonly used amongst archaeologists as the relevant information for the system, the longitude and latitude, are necessary components of the archaeological recording process, making the integration of GIS relatively easy (GIS Spatial Data Types, 2016). There are several main applications for GIS in the field of archaeology, including the creation of maps, calculation the density of population and analyzing of data regarding geographic coordinates, all of which provide useful analysis and visualization of archaeological data (Straumann, 2015).
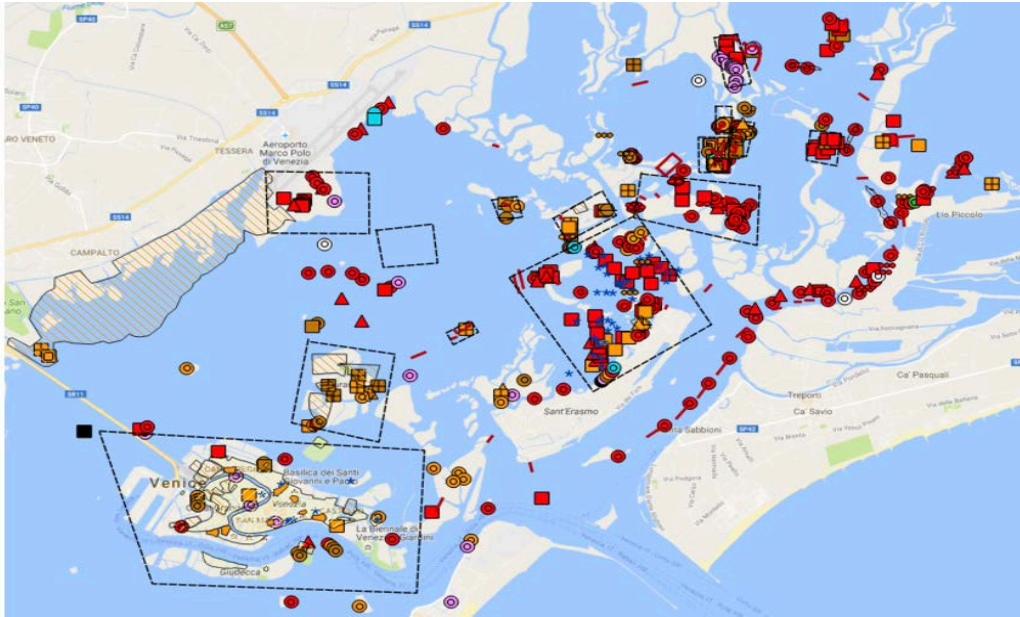
Figure 3: *Screenshot of map with customized marker made in qGIS*

GIS can be used to make maps of archaeological data. For example, in **Figure 3**, a software called qGIS has been used. Compared with other GIS softwares, qGIS has smaller size, it is available online and it can make maps, which has been one of the most commonly used functions of the technology in the archaeological field. Studio Zandinella and other archaeological firms could greatly benefit from the use of GIS systems, as it would greatly improve their abilities to visualize and analyze their archaeological records. Any archaeological records that Studio Zandinella has, can be digitized and uploaded to the geographic information system, allowing all of the recorded information to be visualized on a map. As a result archaeologists would always have easy access to all of the available data. Moreover, by searching for keywords, archaeologists would be able to easily cross reference their records for finds tagged with the aforementioned keywords, allowing professionals to see connections between finds and sites that they might otherwise have not seen.

Another way for archaeologists to use GIS to find potential connections among different sites is to use spatial data analysis. Spatial data includes the site location, size and shape, and by

studying how the landscape has changed, archaeologists can gain newfound insight into how the sites were constructed by people in the past, making it all the easier to see visualize the information gathered as these sites (Anschuetz, Wilshusen, Scheick, 2001). With the information about the location, finds and collected samples, archaeologists can create a digital model using qGIS to show how the sites are distributed (Beauvais,2006). The visualization will help archaeologists find the patterns and trends in order to help locate potential sites (Basic use of GIS, 2012).

2.4.3 Difficulties in Data Digitization

Although there has been increased use of digital data management and analysis systems in recent years, most archaeologists still do not use digital systems to assist with archaeological research and data gathering. Most major archaeological organizations, including the European Archaeological Consilium, which helps set standards for archaeological best practices in Europe, recommend paper recording of data as a primary means of data storage and management (EAC, 2014; AIA 2016; Drewett 1999). This contributes to slow adaptation of digital systems in the community, and increases paperwork and inefficient data organization in European archaeological systems. Further difficulties arise with digital data management and analysis due to the fact that archaeologists who do use digital data recording and analysis systems typically do not share their data unless publishing (Hodgkinson, 2012). This means that potentially useful and important databases are proprietary and are not accessible by other researchers, which increases difficulty when conducting analyses and research (Drewett 1999; EAC 2014). Digital data management is therefore typically an underleveraged field in archaeological recording and analysis. Italian archaeological organizations also tend not to use digital data management systems, as the organizations in charge of regulating archaeological finds typically require archaeologists to fill out and file paper forms, which does not provide archaeologists with a strong impetus to switch to

16

digital data recording (Perrin 2014; European Preventive Archaeology 2007). This emphasis on

paper reporting therefore leads to further under-leveraging of digital data management in Italian

archaeology.

3. Methodology

This project assisted Venetian archaeologists with collecting, visualizing and analyzing archaeological data from subterranean and submerged archaeological sites in Venice and the surrounding lagoon.

The objectives of the project were as follows:

1. To design and create a data recording system to collect archaeological data.

2. To design and create a web-based system to visualize archaeological data.

3. To experiment with analytical cross-referencing techniques based on the collected data.

—Creation of a web-based system for data visualization allows archaeologists to see location-based connections between archaeological sites and site data. It allows archaeologists to easily find information relating to specific sites and finds, as well as search for patterns in archaeological data. Instead of splitting data entry and visualization into two distinct websites, we have designed a single web-app that serves both purposes. The data collection section is designed to serve as a tool for archaeological data collection during excavations, to assist archaeologists in data organization and off-site recording, and to streamline the data recording process. It saves data to a web-based database with recorded information, and then populates the visualization section of the web-app with the stored data, as seen in **Figure 4.** The web-based visualization tool was designed to assist archaeologists with data analysis by showing connections and patterns between sites throughout the lagoon. The two sections of the web application, which were connected by the database, led to the creation of a synthesized, streamlined system for data entry and analysis.
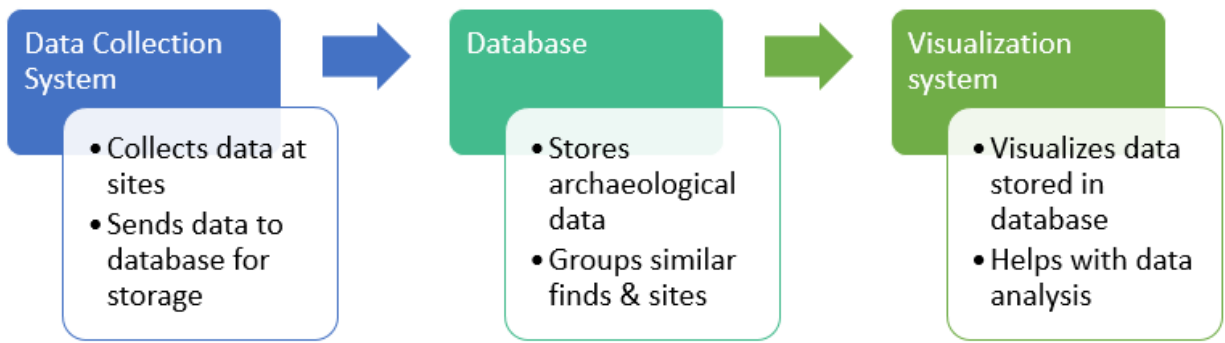
Figure 4: Workflow showing how the web system works

Since urban archaeology sites are difficult to access, and excavations must be finished quickly, as discussed in **Section 2.2.3**, efficiency was an important factor in the design process. This system was an attempt to aid Studio Zandinella by increasing the efficiency of their recording and research processes.

3.1. Creating a Tool for Collecting Archaeological Data

In order to assist Venetian archaeologists with data collection, the team needed to design and create a tool that would replace the current, paper-based, system for recording field information. The first step in the process was gathering data from Studio Zandinella and examining previous archaeological records in order to establish the datasets that need to be collected using the application. Later, we designed the interface of the data entry section of our web application to follow the format of currently used paper records and forms. The data recorded consists of site information, site locations, and details about layers and finds located at these sites. We then created a web-based database that contains all the data that is recorded by the application. The team also worked with Studio Zandinella to ensure that the system met our sponsor's requirements and met their needs satisfactorily. We obtained feedback from them throughout the term, which we used to modify our system.

19

3.1.1. Establish Data Collection Parameters

The team's initial plan was to accompany the studio's archaeologists to an archaeological excavation in order to gather as much observational data as possible. Due to complications related to timing and legality of allowing non-archaeologists to visit active sites, there was not an opportunity to visit any archaeological excavations. As a result, in order to properly determine what data we needed to record using the data recording system, the team examined Studio Zandinella's paper records and obtained feedback on what data is crucial for recording through meetings with the studio's archaeologists. Each one of the paper records, or forms, used by archaeologists in Venice has a corresponding data entry page on the app, containing all the datasets in the paper forms.

In addition to sites and finds, archaeologists also keep track of the different ground layers, which consist of the underlying stratified layers of stone, earth, and other material beneath the surface of Venice, encountered during the excavation process. They also keep track of any finds or anthropological data gathered in the field, which we needed to record in our web app. In addition to gathering information about current recording processes, we met with our sponsor to discuss tools they would like to see integrated in the data collection system. These possible features included the use of the mobile phone's GPS system and camera to record location data and photos.

3.1.2. Develop Web Interface

When we finished establishing what data the system needed to collect, the team designed the user interface for the web app using an iterative development process. As we developed the web application, we focused on efficiency when entering data, user-friendliness, and relevance to archaeological data collecting. In order to begin designing the data entry system to be user-friendly

and efficient, we used Google Forms, Google's survey application, to prototype the data entry interface that was later used by the web app. These forms contained the exact fields that were established for the app. These prototype data entry forms can be seen in **Appendix B.** Once we decided on a system that would allow archaeologists to enter data rapidly and easily both on- and off-site, we translated the forms into HTML webpages. The HTML forms can also be seen in **Appendix B.** As an unreadable and difficult to use app would cause data entry to be less efficient, the design of the user interface was extremely important to ensuring that the app was as useful as possible. In order to ensure that the app had high usability, we discussed the webpage layout with the sponsor throughout the design process, and modified the forms using their feedback. When we finalized the design, we began designing a database to hold all of the information collected through the app.

3.1.3. Design Database for Sites and Finds

At this stage of the process, the necessary data that needed to be stored for each type of site and find had been established. The next step, as a result, was to create a database that contained all of this information in order to make the web application capable of storing information online. The database we designed for this objective holds information specifically relating to sites, layers, and several types of archaeological finds including skeletons, artifacts, and structures. The database was created using Firebase, Google's database and information management system. Firebase, which can be found at https://firebase.google.com, is the database application used by the Venice Project Center for most projects. Due to the fact that the technical experts at the project center were well-versed in Firebase, and the system was easy to use, we decided it was the best choice available to us for database creation. The database was also designed to allow for efficient

exporting of data to the visualization website, which can be found at archeo.veniceprojectcenter.org. The database also grouped
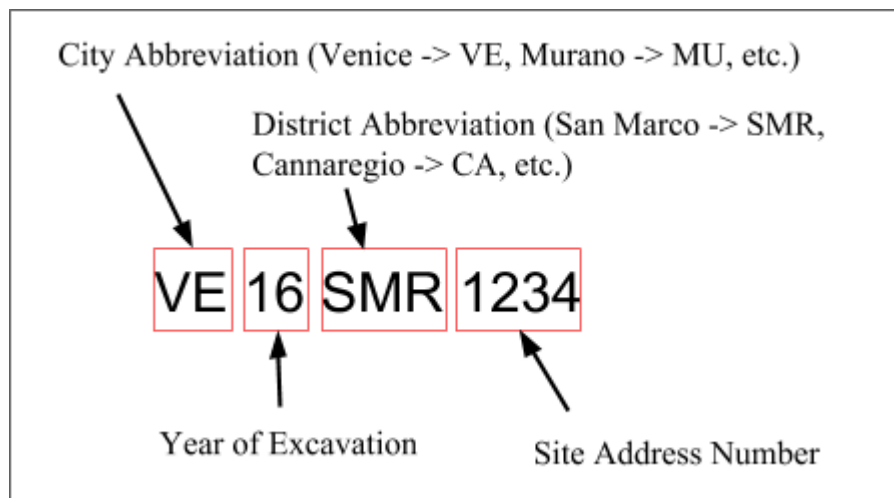

Figure 5: Catalog Number System in the site form

and organized data using a catalog number system. This system provided a unique identifying number for a site based on the system used by archaeologists for data recording. Each site included a unique catalog number in the format shown in **Figure 5.** These catalog numbers directly corresponded with the catalog numbers used by Studio Zandinella when recording site information. After the site information is saved to the database, layer information can be saved, and each layer is given a unique 3-digit identifying number, which is called the US number. Each layer is linked to the site it belongs to, and is grouped with that site. Each find, similarly, is linked to a layer and given a unique numeric identifying number, and is grouped with the appropriate site. We decided to use this tagging system as it would allow the visualization website to easily recognize differences between sites and finds, and display information properly. Furthermore, this cataloging system was similar to what archaeologists use for paper records, so it increased usability by providing a similar cataloging system. It also allowed for easy searching of records, and allowed us to hierarchically organize data for a site, which assisted in data organization and system usability.

3.1.4. Populate Database with Venetian Archaeological Sites

Once we designed the database, we populated it with information gathered by Studio Zandinella and other Venetian archaeologists. We decided to populate the database with more than 500 site records gathered by the studio. This is not an indication of the maximum capacity of the database, but merely a demonstration of its abilities for data storage and management. In order to use this data, we first gathered paper records from a book on Venetian archaeology entitled "Archeologia della laguna di Venezia", which was published by Ernesto Canal, a retired Venetian archaeologist who greatly contributed to Venetian archaeological efforts (Canal Ernesto Tito, 2015). This book gave us a large amount of information to populate the map and database with, which gave us a starting point for quick data entry. The book also represents several decades of archaeological data gathering, which means it provided us with a large amount of highly varied information to use. Although Ernesto Canal's book was extremely useful for initial data entry, it only contained site information, not thorough documentation of finds and records. Although this lack of information is not ideal, as we prefer to fully populate the database with both site and find information, it did not affect the operation of the database.

3.2 Visualizing Archaeological Data

In order to accomplish the second objective for this project, we created a map-based section of the web application that allowed Venetian archaeologists to visualize previously recorded archaeological data. This section shows a map with locations of archaeological sites based on information saved in the database. We used various mapping programs to create a map-based website for Venice that showed the locations of archaeological sites. The team also worked with Studio Zandinella to ensure that the system met our sponsor's requirements and met their needs

satisfactorily. We obtained feedback from them throughout the term, which we used to modify our system.

3.2.1. Create a Map-Based Visualization System

After creating, organizing, and populating the Firebase database, we developed and tested a map-based visualization system, which can be found at archeo.veniceprojectcenter.org. Data visualization, especially location-based visualization, is useful for archaeological analysis and research, as explained in **Section 2.4.** In order to create this system, we used online maps for reference and built an interactive map of the city and the surrounding lagoon using qGIS. QGIS is a tool used widely to create vector-based maps for navigation, surveying and archaeology. More information on qGIS can be found in **Appendix A.** Once we created the initial map layer with qGIS, we converted it to GeoJSON and embedded it in our website. GeoJSON is a file format widely used for geographical information storage and web-based visualization, and is compatible with Firebase, so we used it for storing and displaying the geographical information for our website. We also used Leaflet, a set of JavaScript tools for displaying GeoJSON information on the Internet, to display geographical information. When designing our map-based visualization, we wanted to prioritize usability and user-friendliness. We decided to make the system work similarly to Google Maps by creating clickable markers for sites that displayed more information when selected, as such systems are widely-used and well-understood by the general populace.

3.2.2 Receive Feedback and Refine Visualization

Throughout the design process, we presented iterations of our design to Studio Zandinella for feedback and revisions. We met with archaeologists to ensure that our site was easy to use and that the information we mapped was accurate and comprehensive. Furthermore, we showed each

iteration of the visualization design to our sponsor to ensure that each change improved the usability of our system. We also collected feedback from the studio in the form of informal discussion and used the feedback to modify the visualization system to better fit the sponsor's needs.

3.3. Experimenting With Cross-Referencing Archaeological Data

In order to finish our last objective and build connections between different excavated sites, we developed additional features for data visualization and analysis for our website. We focused primarily on development of a filtering feature to isolate specific sites based on stored information, as we believed this would be helpful for recognizing patterns in data and finding connections between different sites throughout the entirety of Venice. In addition to developing a filtering feature, we also experimented with techniques for grouping sites and showing information in a way that facilitates pattern recognition.

3.3.1. Filtering Features

Filtering refers to the process of removing sites from the display to better show trends and patterns in archaeological data. We decided that this was a necessary feature for our website, as it would help show connections between different sites and would assist archaeologists in grouping sites and recognizing historical trends in archaeological data. We decided to design two separate filtering buttons, one for site era and one for site type. The site era filter was designed to help archaeologists see how humans have settled and spread throughout Venice and the lagoon throughout history. The site type filter aimed to assist archaeologists in finding clusters of similar site types, for example, finding clustered groups of building ruins or shipwrecks. Therefore, these

two filtering buttons would assist archaeologists in both recognition of historical data trends and in grouping and connecting various archaeological sites around the lagoon, and thus would assist with our goal of helping with data analysis and cross-referencing.

3.3.2. Assisting with Pattern Recognition

In addition to creating filtering features to help with data cross-referencing and correlation, we also decided to design our system to help with pattern recognition, as that would facilitate data correlation. Designing our display to allow archaeologists to see patterns and connections between different sites and datasets would allow them to better conduct research and understand how sites relate to each other. In order to assist with pattern recognition, we color-coded our sites and added symbols to each site to show site types. We decided to color-code by site era, as that would allow archaeologists to understand what epoch each site originated from, and we decided to show site types using symbols to help archaeologists group similar sites. In order to ensure that archaeologists could understand what the symbols and color-coding meant, we decided to include a key on our map. This system would help archaeologists recognize patterns and see connections between different sites.
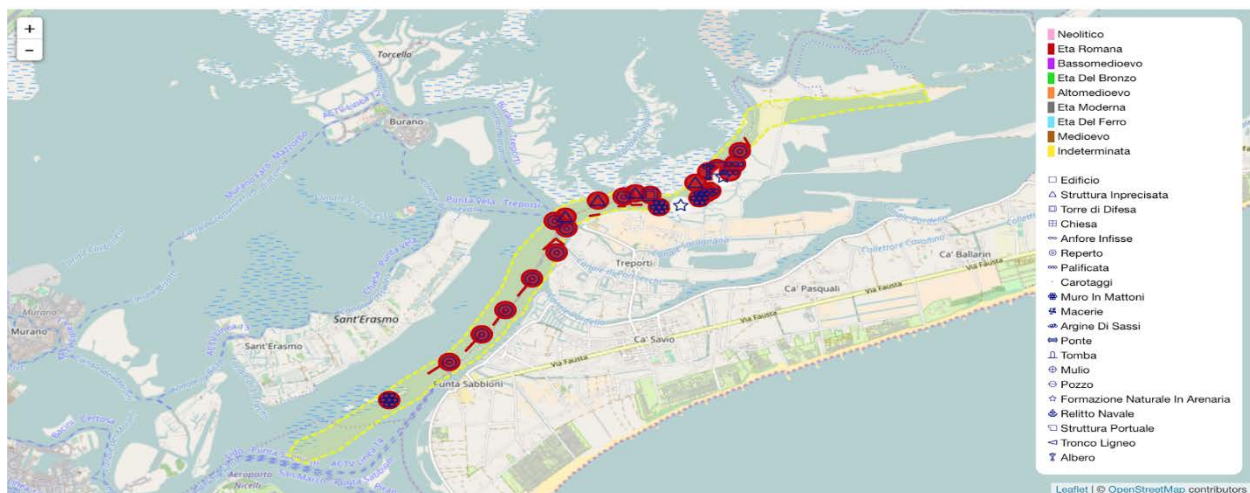

Figure 6: *Highlighted area that includes several site*

26

After implementing the color-coding system and the symbol system, we decided to include the various features Ernesto Canal identified through his research on our map. Ernesto Canal showed connections between data by surrounding similar sites with highlights, as seen in **Figure 6.** This was a useful way to show connections between different sites, so we translated these features to our visualization website to help archaeologists group sites. This system would assist greatly with data analysis.

4. Results and Analysis

We implemented the methodology and processes discussed in **Section 3** to complete the design of our system. We developed a prototype system for data collection using an iterative design process, then compared it to the paper forms it replaced to evaluate its usefulness to archaeologists. We prototyped our visualization system as well, which was completed using qGIS and Leaflet to create a map that was then embedded in our web application. Once that prototype was complete, we evaluated the accuracy of the system through meetings with our sponsor and tested its efficacy at displaying data and assisting in archaeological visualization. We tested this by navigating through the visualization system and evaluating its usability and user-friendliness. When this was completed, we developed several tools to assist with analysis, including two sets of filtering functions to show connections between data sets. Finally, after developing filtering tools to assist with archaeological analysis, we tested the website's ability to assist with analysis in order to estimate the usefulness of our system to archaeological research. We tested this by using our system to find possible ancient settlements and geographical features. The system performed well when used, and accurately and correctly filtered out separate sets of data. When we had determined that the system would be useful for identifying patterns in archaeological data and for location of ancient settlements and geographical features, we tested its usefulness for making predictions related to likely locations of archaeological sites by using the system to formulate hypotheses regarding locations with a high probability of containing numerous finds. We found that our system assists with this predictive process as well, and could prove highly useful for archaeological data analysis.

4.1 Designing and Creating the Data Collection System

The first step that we took towards the creation of a system to assist Venetian archaeologists with their work was to create a prototype of an online system to help them effectively collect and store data. We did this by first evaluating current archaeological recording systems and determining which forms and records were necessary for data recording. We found seven different forms that were crucial to archaeological data recording, which we converted to HTML forms. Once we finished these forms, we created a database to hold the data that would be collected by a finished recording system.

4.1.1 Current Archaeological Recording Systems
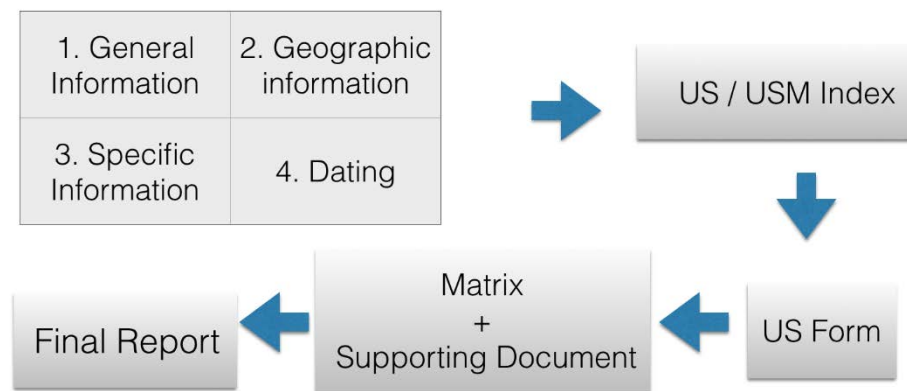
Figure 7: Archaeological data recording procedures for studio Zandinella

In order to begin the design of the data collection system, we conducted thorough research on exactly what data archaeologists collect from excavations. This task was accomplished by meeting with Studio Zandinella several times to discuss the procedures and examine the forms that they use for archiving and reporting purposes. Their data collection processes are outlined in **Figure 7,** and begin with recording of basic information about an excavation. Archaeologists then record information regarding site location as well as more specific information including site type, measurements, find types, photographic information, and map information. They then record basic

dating information. All of this information is recorded in a field journal, which can be seen in **Figure 8.**
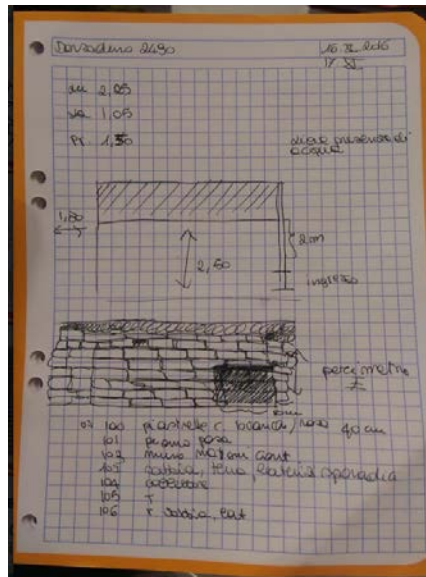

Figure 8: Archaeological field journal

The data stored in the field journal includes measurements of the excavation dimensions, sketches of the excavation, and data regarding soil layers at the site. Once archaeologists collect this data in the field, they translate it to a site form, which documents all the general information about a site as a whole, including date of excavation, age of the site, location, and site description. The full form used to record site data can be found in **Appendix C.** In addition, the journal is used to populate the US forms and indices, which record data regarding soil layers. Each layer of soil is marked by a number, established by a uniform numbering convention used in the world of archaeology. The top layer of a site is marked as layer 100, and each consecutive layer is given a number based on its depth: The deeper in the ground a layer is, the higher the number on it would be. A sample US index and US form can be found in **Figure 9.**

Figure 9*: Sample of US index(left) and US form(right) that are used by Venetian archaeologists*

US	Descrizione	Posizione	coperto da	tagliato da	riempito da	gli si appoggia	copre	taglia	riempie	si appoggia a
230	RIEMPIMENTO		205	206			219		231	
231	TAGLIO			208	230					219
232	SCHELETRO		240							239
233	RIEMPIMETO 236									
234	BUCA CIRCOLARE				209			223		
235	TAGLIO CICOLARE				209			223		
236	TAGLIO CIRCOLARE				233			223		
237	RIEMPIMENTO 236								238	239
238	TAGLIO SCAVO CANAL				237			205		
239	STRUTTURA IN LATERIZI					237				
240	RIEMPIMENTO 241		205				221-232		241	
241	TAGLIO				240	221-232		209		

Once the US forms and indices are completed, the archaeologists generate a matrix, which shows relationships between different layers, and attach supporting documents relating to finds, scientific analysis, and dating information. All finds discovered during the excavation are split into six general categories: Organic/Inorganic finds, structures, skeletons, tombs, poles and handcrafted stone, as each type of find requires different types of recording and different analysis methods, as discussed in **Section 2.1**. Each type of find corresponds to a specific form that needs to be filled in when documenting the find. Once these forms are filled in and attached to the matrix and US forms and indices, they are compiled into a report describing the site and the importance of the site. This report is sent to the Soprintendenza di Archeologica, who oversees

Form Name	Data Recorded
USR Form	Structure data
Anthropological Form	Skeleton data
Tomb Form	Tomb data
Organic/Inorganic Finds Form	Artifact and ecofact data
Handcrafted Stone Form	Stone finds data
Pole Form	Data on wooden pole finds

Figure 10: *List of forms used by archaeologists in Venice*

archaeological efforts in Venice. All of the forms filed are listed in **Figure 10,** and are copied in **Appendix C.**

4.1.2. Final Data Collection System

After fully understanding the process used currently by archaeologists to record data, we developed our data entry portion of the web application. The completed product records eight different types of data: sites, layers, structures, anthropological data, tomb data, organic/inorganic finds data, handcrafted stone data, and pole data. Each type of data follows a separate format, which directly follows from the forms currently used by the studio. Each form was designed with user-friendliness and usability as a priority. In addition to the data recorded by the studio's paper form, the design also includes newly introduced features that utilize the capabilities of modern mobile phones. The app contains a GPS plugin that generates the user's position in terms of longitude and latitude, and an option to upload a picture taken on a mobile phone. These features are located in the forms, and eliminate the need to manually record location data and carry additional devices to the excavation. All HTML forms used can be seen in **Appendix B.** In these forms, archaeologists can document various information about the site using text fields, radio

buttons and checkboxes that are provided in the site form, which can been seen in **Figure 16**. After

filling in the site form, users can click the "Next" button to view all the layer information of the

site. The page contains the mobile version of the layer matrix, where layers can be added, edited

or removed by clicking right button. On the "edit info" page, the user can record any information

about the layer itself, such as the type of ground it contains, depth and consistency. When choosing

"edit layer", the user can edit the finds that are located within the layer. If a new find needs to be

added to a layer, the user is given the ability to click an "add" button and choose the type of find

they would like to record. The web application then generates the correct form depending on the

type of find, which the user will be prompted to fill in. The addition of new finds to a layer can be

seen in **Figure 12**.

Figure 11: Sample of app version of site form interface (left) and US matrix (right)

Figure 12: *App interface for find type (left) and forms of the selected type (right)*

4.1.3. Structuring the Database

The prototype data collection system is designed to allow future developers to link directly to our database, which was designed using Firebase, Google's database creation tool. The database needed to be structured in a specific manner, which would allow the finalized version of the app to easily store data and would allow other systems including the visualization system to interface with the database.
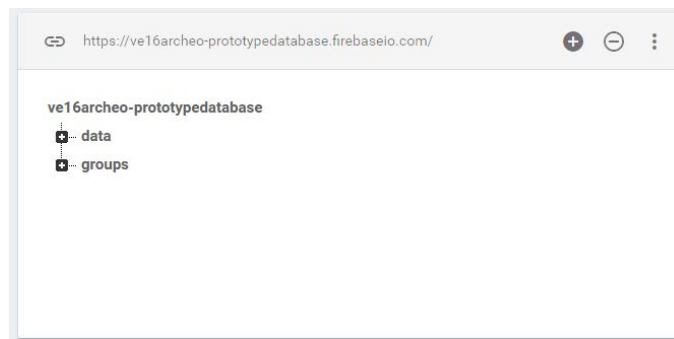
Figure 13: *Google firebase hierarchy tree*

The database had two primary trees, data and groups, as seen in **Figure 13.** The data tree contained

a list of unique keys, each of which was linked to a specific set of data. Each key contained a site,

layer, or find, and all pertinent data for this object. For example, **Figure 14** shows a site saved in

the database and the data saved for the site.
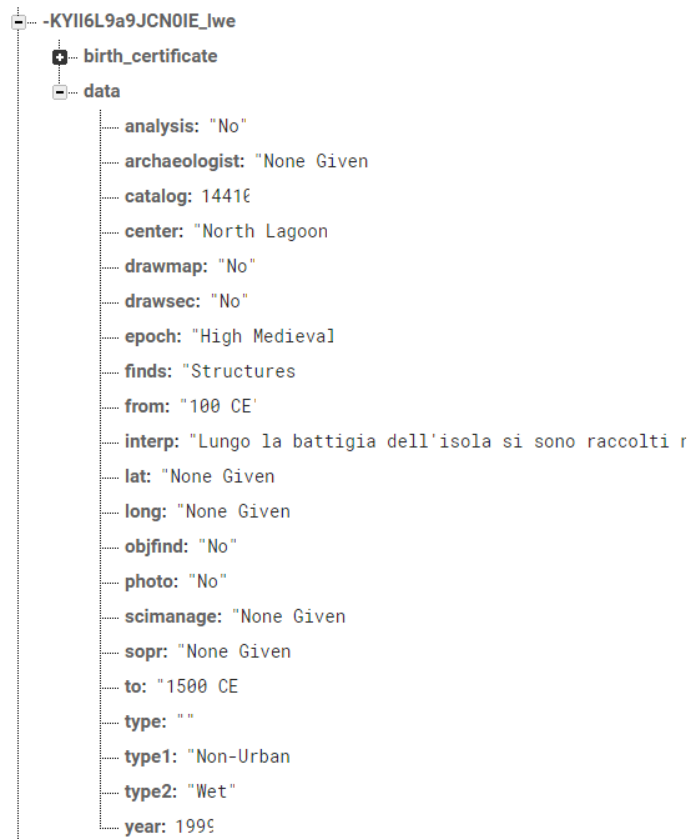
Figure 14: Saved data for a site in firebase database

Once data was saved under a key in the "data" tree, each key was sorted into a group in the

"group" tree. The groups corresponded to the eight types of data saved by the app, and can be seen

in **Figure 15.**
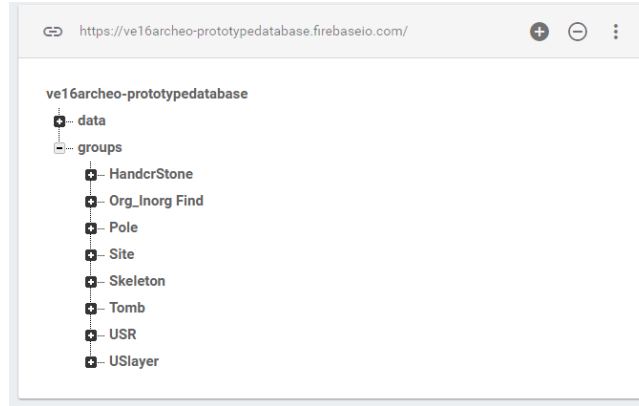
Figure 15: Eight types of data stored in the database

Each group contained a list of unique keys that referenced the specific type of data saved by the app, as seen in **Figure 16.** These keys were generated automatically when saving data to the database using the data collection system.
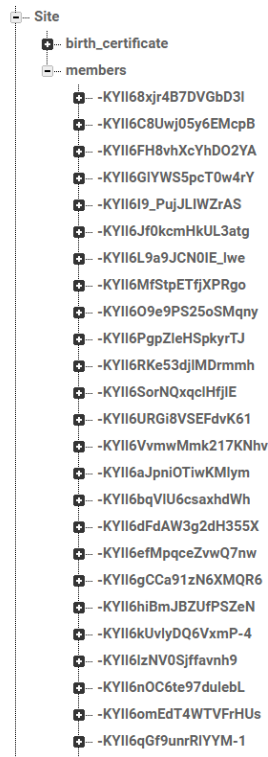
Figure 16: List of site keys saved in Firebase

Each group and data key also contains a birth certificate, which shows metadata about the creation of the dataset or group, including recorder, type of data, and date of recording. This information

helps with data organization and helps to preserve an organized data structure. It also assists with reading data saved to the database, and assists with recognition of specific datasets. The overall layout of this database is ordered specifically to ensure efficiency when saving data to the database and when exporting the data to the visualization system.

4.1.4. Populating the Database
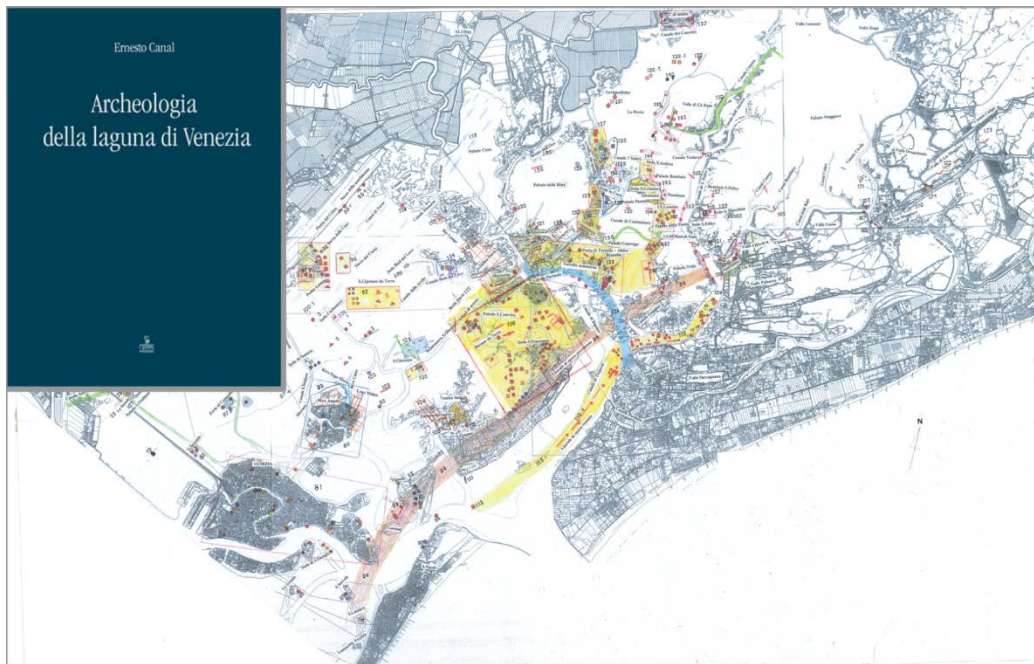
Figure 17: Map displayed in Ernesto canal's book

To demonstrate the usability and effectiveness of the database, the system was populated with records provided to the team by Studio Zandinella and the book "Archeologica della laguna di Venezia", which is shown in **Figure 17**. As discussed earlier within the methodology this number of records currently stored is not indicative of maximum capacity, as the system is fully capable of handling far more information, but the amount of site data can serve as an adequate records reference when archaeologists use them on field. Instead of entering each record by hand, as entering 1000 records would take a large amount of time, we created a spreadsheet using Google Sheets and imported the data directly to the database. In order to do this, we used JavaScript to

complete a basic function that would automatically generate unique keys and save the data to the database. This information stored in the database will be used in future versions of the application to populate the visualization system.

4.2 Visualization System

The final stage of creating the web-based system was the implementation of a prototype map-based website that can be found at archeo.veniceprojectcenter.org. The creation of the map was accomplished through the use of qGIS using the methods discussed in **Section 3.2.1** of the methodology. More information regarding qGIS can be found in **Appendix A**. After the map was created, filters and legends were added to the map, which is shown in **Figure 18**. In addition to being able to filter out irrelevant sites while using the map-based website, users are able to click any specific site to generate a pop-up window previewing some of the important information from that site. That information includes the site name, the site number, the year of excavation, and a brief description of the site. Future versions of the website will also feature a password system, where only individuals with adequate clearance would be able to view certain information or edit the site records.

4.2.1 Completed Visualization System
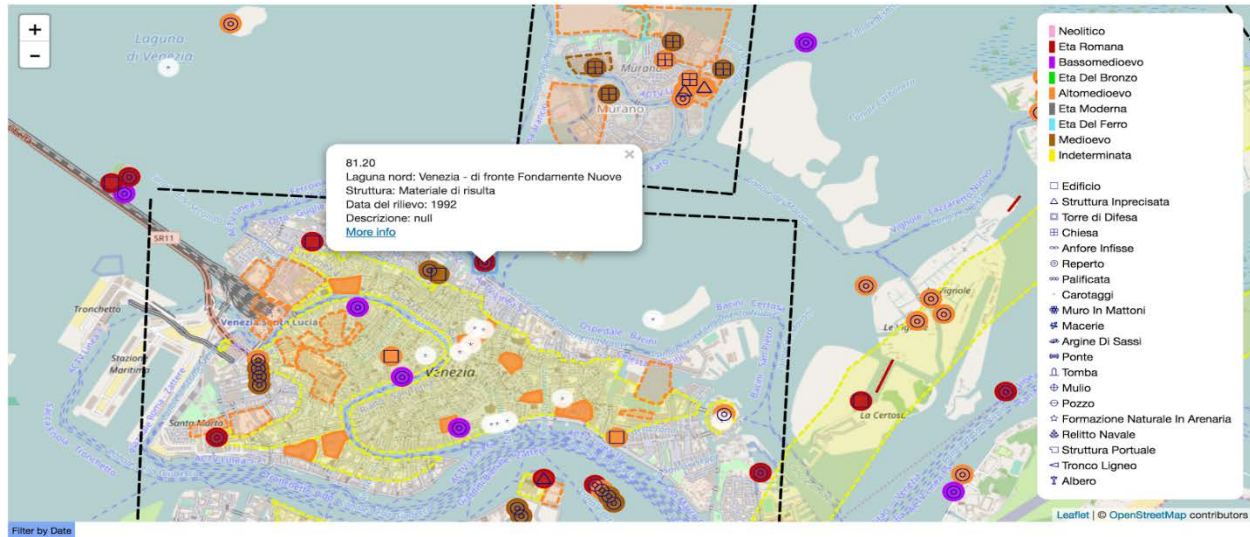
Figure 18: Example of qGis mapping of the sites mentioned in Ernesto Canal's book

As seen in **Figure 18,** the interface operates similarly to Google Maps, as it shows site locations with a clickable icon. Other features include the ability to zoom in/out on the map and drag the map using the cursor to see different locations throughout the lagoon. In addition, we designed a sidebar for implementation in a future version to show more information regarding sites. In future system versions, clicking on "more info" in the popup shown in **Figure 18** results in a sidebar appearing with more information regarding the site. This will allow archaeologists to see any and all data recorded for a site. The main interface also has options for filtering of sites by separate criteria, including age of site, and type of site, as seen in **Figure 19.**
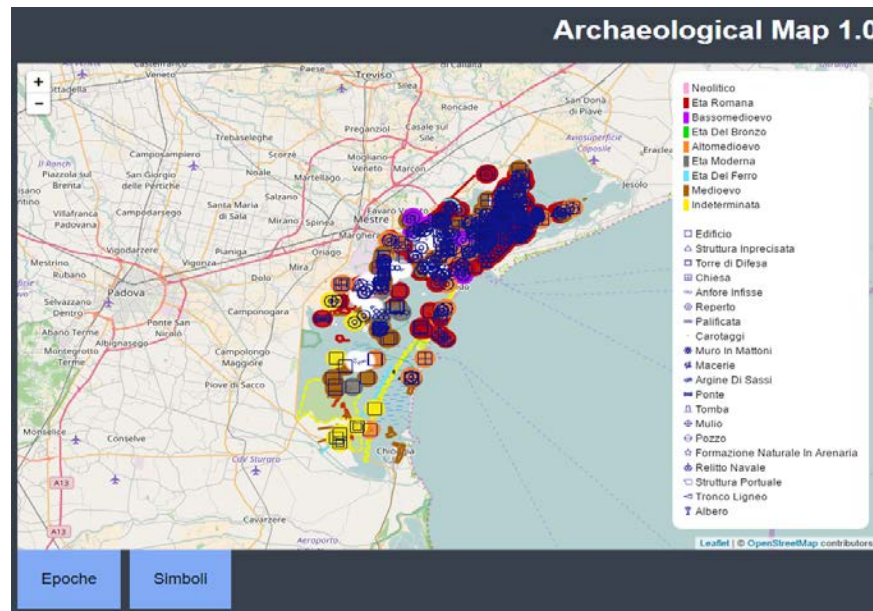
Figure 19*: Website map with filtering option*

This filtering system allows archaeologists to better see connections between sites and allows archaeologists to better conduct research and see trends and patterns in archaeological data. This assists archaeologists in visualizing locations of Venetian sites. In addition, the website is designed such that future versions will allow archaeologists to log in using a password and edit the contents of the database. This aids with data recording as well as with correction of any mistakes that could have occurred during data entry.

4.2.2 Feedback

Once we finished mapping the sites, we met with Dr. Erika Mattio, one of the archaeologists who works for Studio Zandinella, to ensure that sites were properly located on the map. These meetings were highly important, as we needed to verify that Ernesto Canal's data was correct and we had properly mapped the sites he discovered. Through several meetings during which we checked the position and number of each site on the map, we determined that the sites were placed in the proper locations on the map and that we had correctly marked and labeled each

site he excavated. We also received feedback from the archaeologists of Studio Zandinella regarding our site layout and design. From these meetings, we determined that our qGIS map was accurate and displayed enough data to be useful to archaeologists. We also determined that the design was user-friendly enough to be useable by the archaeologists.

4.3 Using Tools for Archaeological Analysis

The third aspect of the project was to provide archaeologists with additional tools for data visualization and correlation of data from different locations. We did this by creating two filter tools to show sites based on era and type of site. This would assist archaeologists with data analysis and identification of historical trends. We also tested the system to see if it assisted with pattern recognition by making predictions and attempting to identify features and patterns in site data. Overall, we found that our system was able to assist with recognition of data trends and with grouping of sites into features and settlements. We also found that our system would be useful for generating hypotheses regarding potential locations for excavation.

4.3.1 Filtering and Pattern Recognition

We implemented one major feature to assist with archaeological analysis, which was the inclusion of filtering systems into the site. Using our filtering system, archaeologists could filter sites by era, or "Epoche", and by site type, or "Simboli". These types are listed in **Figure 20.**

Figure 20: Map Legend showing site eras and symbols

Each filter button, when clicked, showed a dropdown with several filter types, which were also displayed on the map legend, as seen in **Figure 20.** Clicking on a filter option changed the sites shown, which would assist with pattern recognition. Examples of this can be seen in **Figures 21 and 22,** which show how our filtering system can show specific types of site and specific site eras. Once we implemented the filtering system, we tested it to ensure that it displayed each filter correctly, then attempted to assess how useful this feature could be to archaeologists. By moving through eras using the filtering feature, we were able to ascertain that the north of the lagoon was land during the medieval era, due to the high prevalence of medieval-era buildings in the northern lagoon, and we were able to identify areas that could have been settlements at one point in history due to high concentrations of buildings. This feature could, based on our testing, be highly useful for archaeological research.
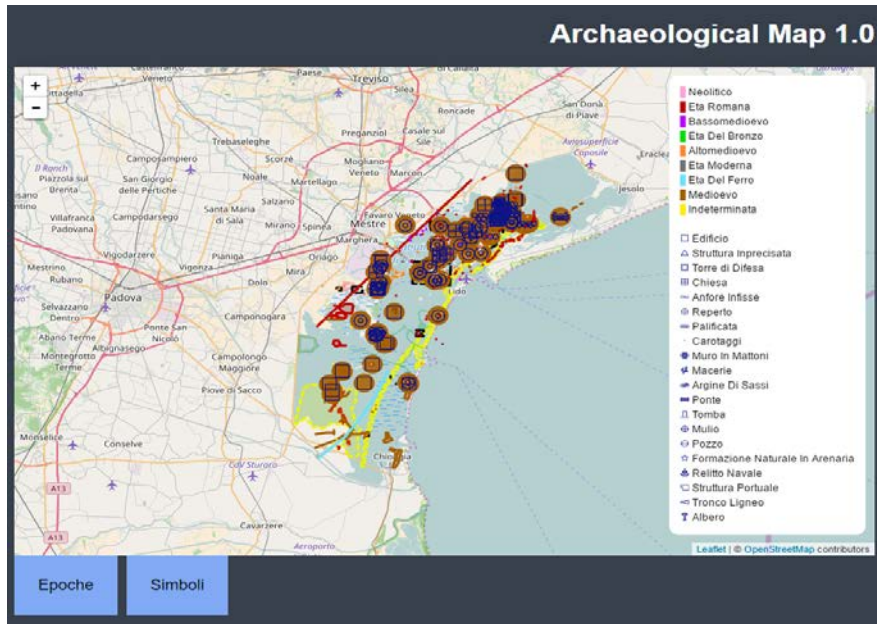
Figure 21: *Map only shows sites from Medioevo after filtering - cluster in northern lagoon shows likelihood that the area was land during the medieval era*
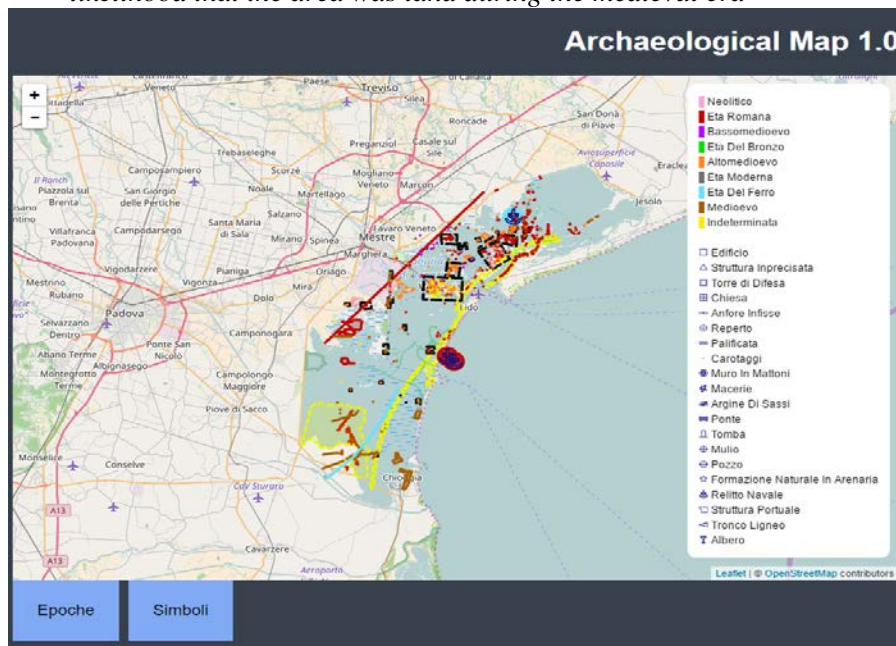
Figure 22: *Map only shows shipwrecks after filtering*

In addition to a filtering feature, we estimated the usefulness of our project for archaeological pattern recognition. In order to estimate how effectively our project assisted with pattern recognition, we attempted to locate patterns in the data displayed by our visualization website. We started by attempting to identify possible ancient settlements based on our data. One of the best
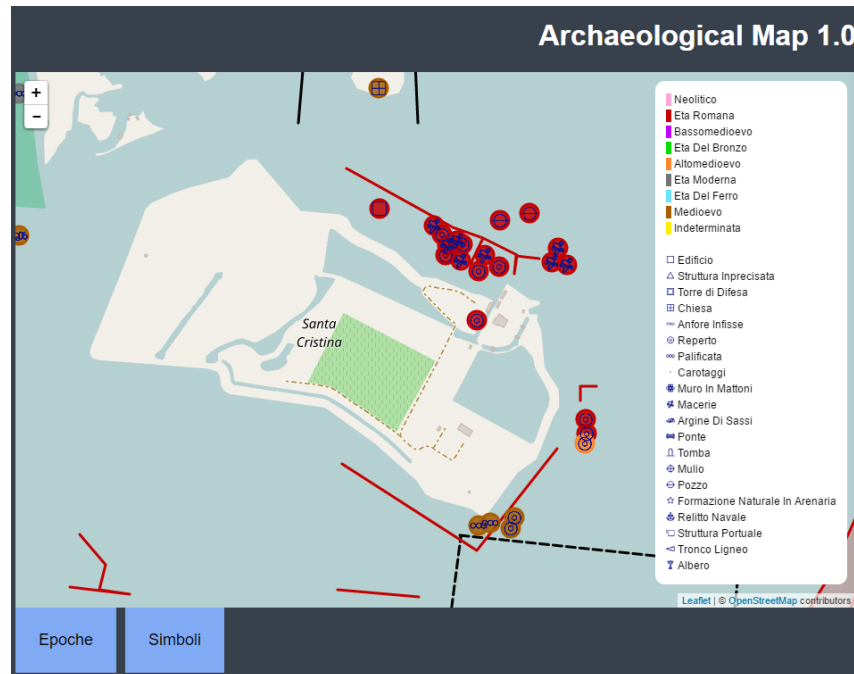
Figure 23: Roman settlement of the northern coast of Santa Cristina

examples of this can be seen in **Figure 23,** which shows a set of Roman artifacts found off the coast of Santa Cristina, a small island in the northern lagoon. The artifacts included two wells, rubble, evidence of roads and buildings, and Roman-era artifacts. Based on the clustering of the sites, we determined that this likely showed a Roman settlement. It took us less than 5 minutes of searching through the map to locate and recognize this pattern, which shows that the system is useful for identifying patterns and clusters in archaeological data.

After we used our system to locate and group one settlement, we decided to conduct further testing to determine if our system would be useful for predictive analysis. Predictive analysis refers to the process through which archaeologists evaluate locations to determine their archaeological potential (McEwan, 2012). Archaeological potential refers to the likelihood of a site to yield archaeological finds. The process of predictive analysis is useful to archaeologists, as it allows them to determine which locations are most likely to contain a wealth of archaeological data. In

order to evaluate our system's usefulness to this process, we examined other locations around the lagoon, including the island of La Cura, which is shown in **Figure 24.**
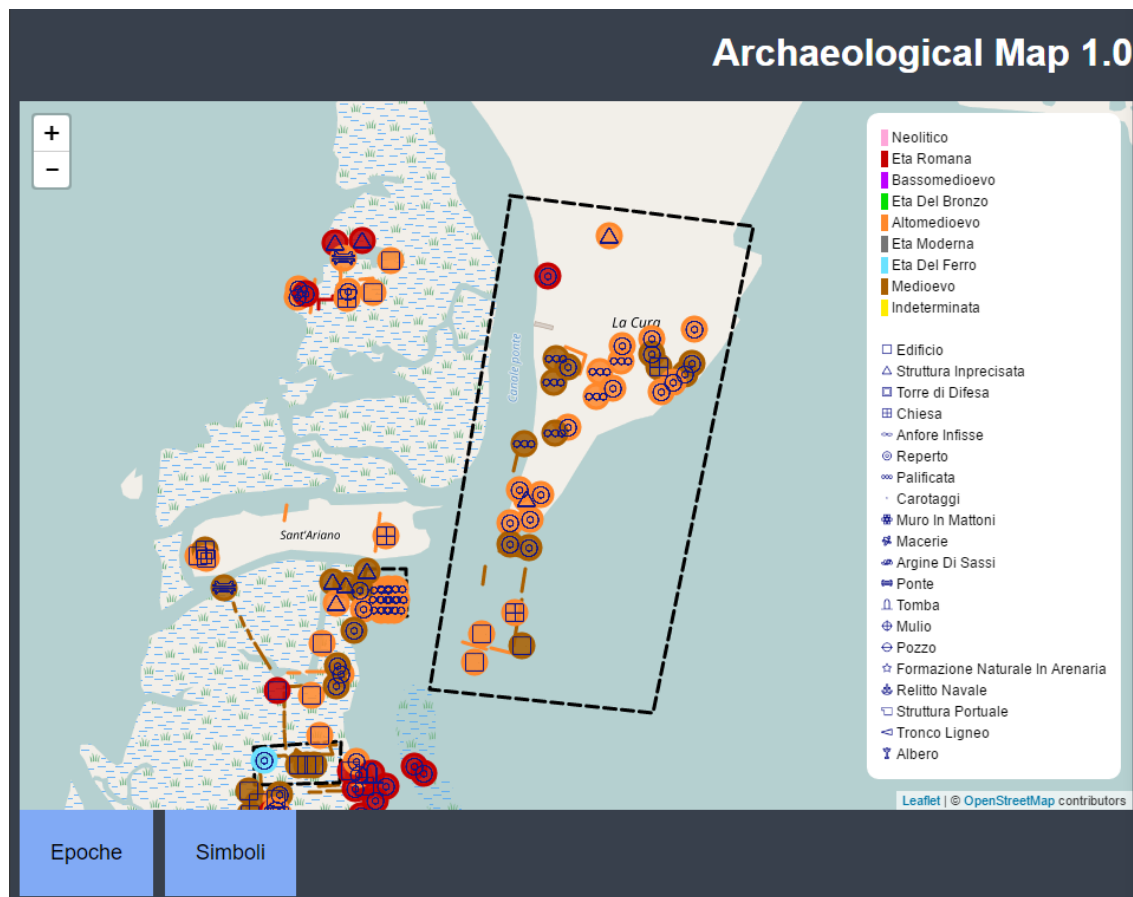
Figure 24: Island of La Cura showing medieval sites

When viewing the island from our map, as seen above, it becomes evident that there was a medieval settlement on the island. Most of the sites are from the high medieval and medieval period, which can be determined using the key, and there are several buildings, churches, and palificata on the island. Palificata were wooden poles used to prevent houses from flooding by holding them above the water (Eporedia, n.d.). Palificata can be seen in **Figure 25.**
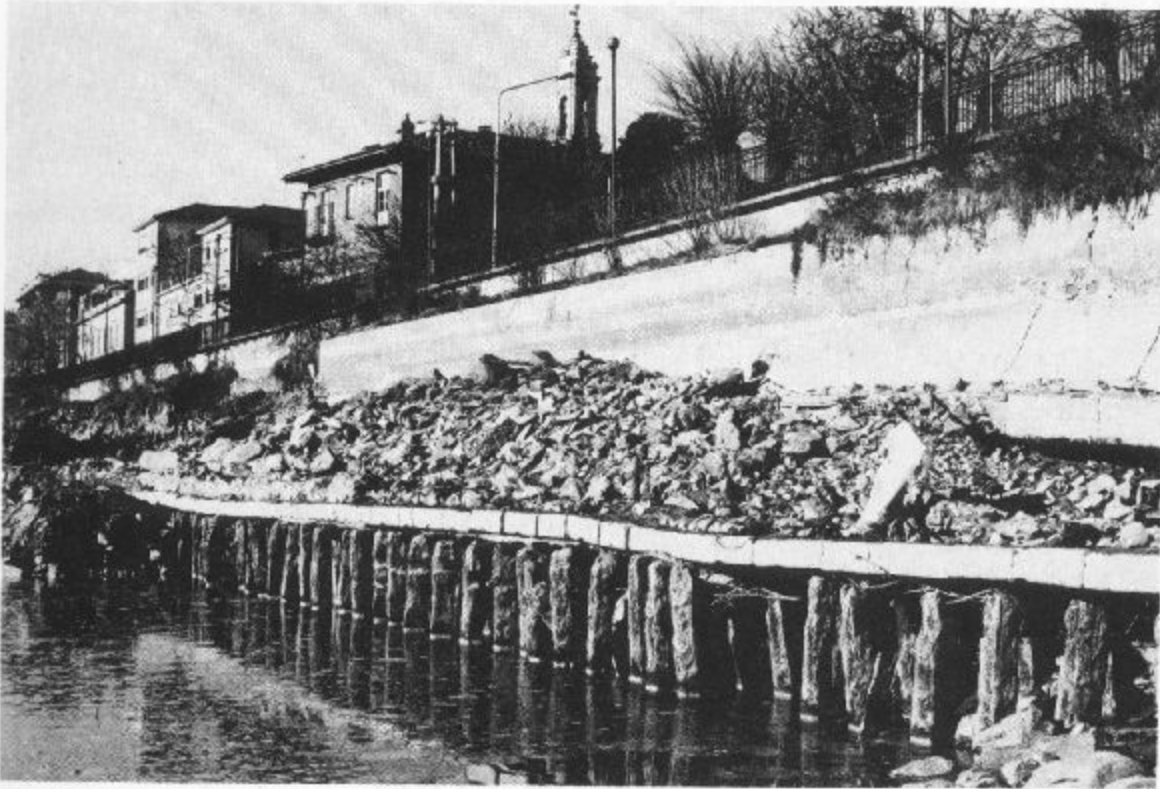
Figure 25: Palificata holding a road out of the water

Based on this information, we deduced that an archaeologist excavating at the location shown in red in **Figure 26** would likely find medieval artifacts and evidence of medieval buildings. We also deduced that archaeologists excavating in the area would likely find religious artifacts and medieval building structures, due to the presence of both two medieval churches nearby and the presence of other medieval buildings in the area. Furthermore, we predicted that aquatic excavations in the nearby lagoon would also yield a high number of palificata and medieval artifacts, as well as several building remains.
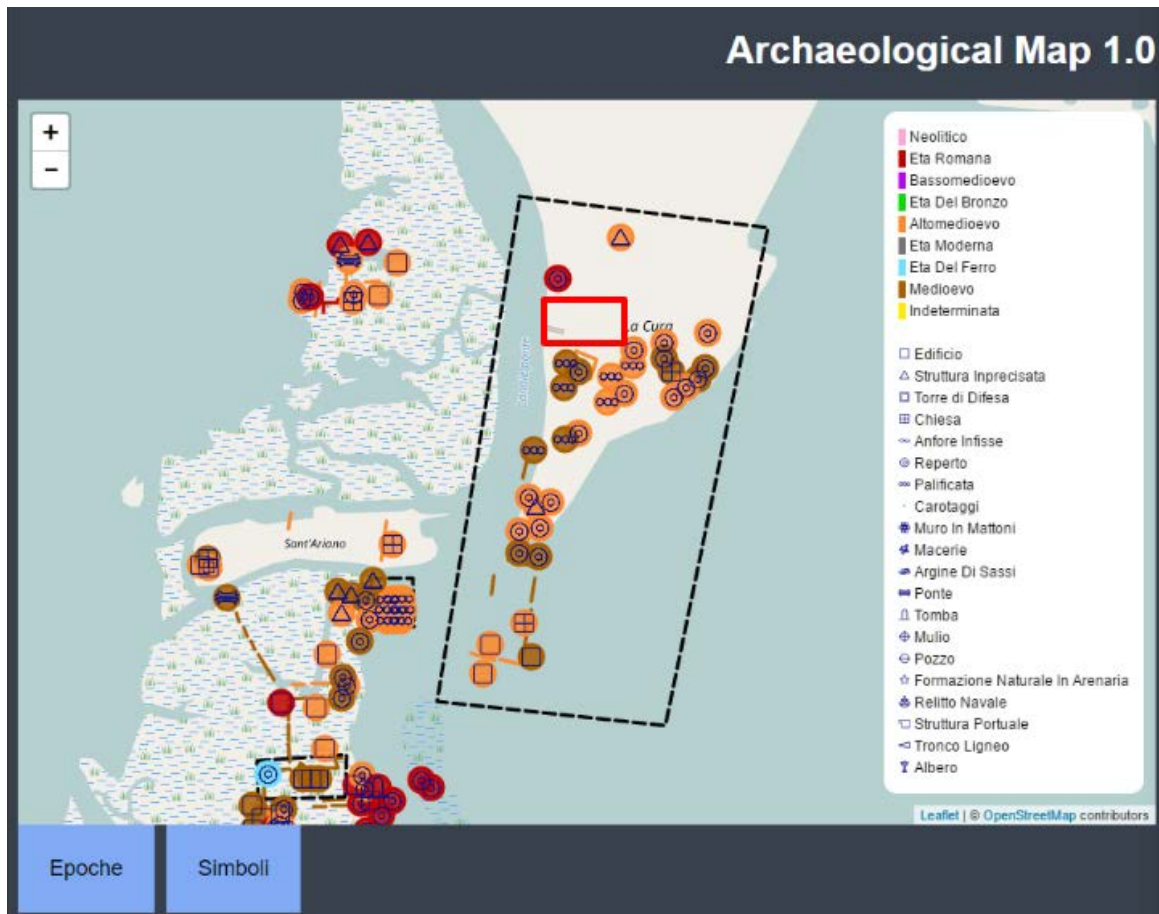
Figure 26: Location recommended for archaeological excavation

We were able to determine this information in less than 15 minutes of searching our map, which shows that our map is easy to use for archaeological prediction. In addition, we were using the system with little to no archaeological experience, and were still able to draw connections and formulate reasonable hypotheses using the system. This demonstrates that our visualization system could be highly useful for archaeological predictive analysis in addition to being useful for pattern recognition, site grouping, and data analysis.

5. Conclusions & Recommendations

The primary goal of this project was to aid Venetian archaeologists in their documentation and research work through the creation of online research and data management tools. The primary issue facing these professionals today was that their current practices for documenting and managing archaeological data did not adequately meet the need for streamlined research tools. Our project provided them with a prototype of a streamlined online system for data management, visualization, and analysis. We created a 3-part system that consisted of a data collection application, an online database to assist with data storage and management, and a map-based visualization system for use with data analysis and archaeological research. The collection application, based on our testing and design, was extremely useful for data recording and management, and followed an intuitive user-friendly format that was easy to learn. The database this system linked to was organized in a logical way that allowed for the modification, organization, and storage of numerous types of data. Our website both visualized data in a way that was easy to understand and use, and assisted greatly with pattern recognition, spatial organization of data, analysis of historical data trends, and recognition of historical settlements and features in archaeological data. Although our system worked well as a prototype, it still requires work by other IQP teams to advance it to a more sophisticated level both in terms of web design and usefulness.

5.1 Field Application

Overall, our prototype field application proved useful as a basis for future data collection applications. We were able to design forms to enter site, layer, find, tomb, skeleton, structure, pole,

and handcrafted stone data in an intuitive and useful manner. The layout for our application closely matched the archaeological forms required for archaeological reporting, and recorded all data fields written on these forms. This ensured that our system would both follow a format familiar to archaeologists and that it would provide a starting point for future IQP teams to assist with archaeological research and data collection. Our app was also designed to allow future IQP teams to easily link it to our database. We found that saving the data online would ensure that, in the event of a system failure, archaeological data would be preserved for future use.

Although our prototype data collection app was successful in providing a base design and framework for future versions, there were several features and areas that require improvement. The most pressing issue was linking the app to the database so it could store information in a meaningful and useful manner. Both the database and the app were set up to allow future IQP teams to easily link the two systems together, so we recommend that the next IQP team focus on integrating these systems. The next most important issue revolved around the fact that internet access was necessary to add information via the app. Many archaeological sites do not have access to internet, so it would be difficult for archaeologists to update data in the field using our app. We recommend that future IQP groups design an offline mode for our data collection app that saves data until it connects to the internet and can be uploaded to the database. In addition to the issue of possible lack of internet access, we also identified a need for a feature to auto-generate PDF versions of the archaeological forms required for reporting based on the data we collected and stored in the database. Such a feature would be extremely useful to archaeologists and would decrease the amount of paperwork necessary for archaeological reporting. We recommend that future teams create a function to auto-generate PDF forms to assist archaeologists with completion of paperwork. We also recommend that future teams implement photograph uploads through our

data collection app, as this would assist archaeologists in saving large photo libraries for sites. The final problem we identified with our system was the fact that archaeological forms sometimes change in format and data required for reporting changes occasionally. We attempted to address this problem by ensuring that the app would be easy to customize and change, but future IQP teams will need to modify the app to match the format of future forms. Finally, we recommend that future IQP teams test our application in-field exhaustively and market it to archaeologists for general use in Venice. As more archaeologists use our application to record data, our system will be able to manage and display more data and be more useful to archaeologists for research.

5.2 Visualization System

Our prototype visualization system was highly successful in displaying archaeological data for use in archaeological research. We logged over 1000 sites with basic data relating to site type, era, and location. The site was able to display this large amount of data in a satisfactory manner, and was able to show additional data about each site in popups. The visualization was intuitive and easy to use, based on our experimentation with it, and the legend was easily readable and provided useful information for archaeologists. We also found that we had properly located each site on the map and properly recorded data about each site. Our sponsor indicated that this system would be useful to them for research as well.

For a prototype, our system worked well for visualizing archaeological data. However, there were several features and website options that could be implemented to improve on the system. Firstly, the website needs to be linked to the database as well. This would be the top priority for future IQP teams. Secondly, the website needed a more clean and sophisticated website layout. We recommend that future projects create a more sophisticated HTML layout for the

website to increase the usability and improve the aesthetic of the website. Furthermore, our website only currently displays Ernesto Canal's data, as we used his data for our map. We recommend that future IQP teams encourage archaeologists to use our system and add data to the database through our data collection app, as that will then show more data on the map and be more useful to archaeologists in the future. We also recommend that future IQP teams experiment with other forms of data visualization, including 3-dimensional modeling of layers recorded using US forms, and visualization of site density.

5.3 Analysis

Our visualization system provided several useful options for data analysis. The first of these options was the filtering feature, which allowed archaeologists to filter data by era and type. This assisted archaeologists with easily identifying trends and patterns in historical data and assisted with locating clusters of similar finds to assist with research and identification of spatial features. In addition to the filtering system, our visualization system assisted in recognition of data patterns due to the fact that it showed data that was organized geographically on a map. The use of highlights to show possible geographical features or clusters of sites also assisted with data analysis, as it allowed archaeologists to more easily see relationships between different sites and connections between different finds. As the system allowed us to find possible settlements and features in an extremely brief period of time, it proved highly useful for basic pattern recognition and data analysis.

Although our system helped greatly with basic data analysis, future IQP teams could add several features that would allow for more sophisticated data analysis and prediction. The first of these features involves the use of a slider to show changes in sea level throughout the history of

Venice. A slider that showed sea level changes would allow archaeologists to track how the topography of the region has changed over time, and would assist them in predicting where ancient settlements could be located throughout the lagoon. Such a slider would also help archaeologists develop hypotheses revolving around how humans spread throughout the lagoon and how the region's geography influenced the development of societies and cultures throughout the region. Another feature we recommend adding to the visualization website to assist with archaeological research involves predictive algorithms. Predictive modelling allows archaeologists to identify areas that would likely yield high amounts of significant archaeological finds if excavated, and is extremely useful to archaeologists for research. We were unable to create predictive models for our site, as they involve extremely advanced and complex computer algorithms, but future IQP teams could build on our prototype and implement these predictive models. We also recommend that future groups include more sophisticated filtering systems that allow for filtration by more than just site era and type, as more filtration options would assist greatly with the progress of archaeological research. Our final recommendation for this section of our project is that future IQP groups should include a "search" function on the website that would allow archaeologists to search for specific archaeological sites and only display the searched sites on the map.

There is evidence that our prototype system would be highly useful to archaeologists for data collection, visualization, and analysis. It allows archaeologists to easily record, store, and manage data, and assists archaeologists in finding connections and relationships between archaeological sites throughout the lagoon. As a prototype system, it provides a base level of functionality that is still useful to archaeologists, and provides a base on which future Venice IQP groups can improve to further assist with archaeological research. We believe that our system, as

it is refined and expanded upon by future groups, will become more and more useful to archaeologists throughout the city of Venice.

References

Afezolli, D., Allen, B., Hepworth, J., & Kazanovicz, A. J. (2009, December 18). Unearthing the Roots of Venice: From Relics to DNA. Retrieved September 18, 2016, from https://web.wpi.edu/Pubs/E-project/Available/E-project-010510-121008/unrestricted/Origins_Report_Final.pdf

America, A. I. of. (2016). AIA news. Retrieved September 23, 2016, from https://www.archaeological.org/education/glossary#l

Ammerman, A. J. (1996). Probing the depths of venice. *Archaeology, 49*(4), 38-43.

Anschuetz, K. F., Wilshusen, R. H., & Scheick, C. L. (2001). An Archaeology of Landscapes: Perspectives and Directions. Journal of archaeological research, 9, 157-211. http://users.clas.ufl.edu/davidson/Proseminar/Week%2013%20Space%20and%20Place/2001%20Anschuetz%20et%20al,%20arch%20of%20landscapes.pdf

Archaeology 101. (2016). Retrieved September 16, 2016, from https://www.archaeological.org/pdfs/education/Arch101.2.pdf

Archeolex. (2015, August 1). Retrieved September 18, 2016, from http://www.archeosub.it/leggi.htm
Archeoveneta: Dove trovarci. (n.d.). Retrieved September 2, 2016, from http://www.archeoveneta.com/dove.html

Avila, C., De Zulueta, E., Mukhanov, S., & Sokk, M. (2010, December 18). Exploring the History of Venice: Relics, Records, and Relations. Retrieved September 18, 2016, from https://web.wpi.edu/Pubs/E-project/Available/E-project-122710-031051/unrestricted/Final_Report_B10_Origins.pdf

Bailey, G. N., & Flemming, N. C. (2016). Archaeology of the continental shelf: Marine resources, submerged landscapes and underwater archaeology. *Quaternary Science Reviews*, *27*(s 23–24), 2153–2165. doi:10.1016/j.quascirev.2008.08.012

Barstad, J, & Ruppé, C. (2002). *International handbook of underwater archaeology*. New York: Kluwer Academic/Plenum.

Basic Use of GIS. (2012, August 6). Retrieved November 27, 2016, from https://www.gislounge.com/basic-uses-of-gis/

Beauvais, G. P., Keinath, D. A., & Hernandez, P. (2006). Element distribution modeling: a primer-or-Musings upon depicting the geographic arrangement of biota, with ample reference to the harsh lessons of the dark master experience. *Wyoming Natural Diversity Database. Wyoming*.

Beltrame, C. (n.d.). The Underwater Archaeological Heritage of the Venice Lagoon. Retrieved September 16, 2016, from http://www.venicethefuture.com/schede/uk/340?aliusid=340

Brainerd, G. W. (1951). The place of chronological ordering in archaeological analysis. *American Antiquity, 16*(4), 301-313. doi:10.2307/276979

Boshoff, J. (2003). *The South African Archaeological Bulletin,58*(177), 38-39. doi:1. Retrieved from http://www.jstor.org/stable/3889156

Cai, L., & Zhu, Y. (2015). The Challenges of Data Quality and Data Quality Assessment in the Big Data Era. *Data Science Journal*, *14*, 2. DOI: http://doi.org/10.5334/dsj-2015-002

Calderon, M. (1989). Underwater archaeology in the Philippines. *Philippine Quarterly of Culture and Society, 17*(4), 322-325. Retrieved from http://www.jstor.org/stable/29791991

Canal Ernesto Tito. (2015). Retrieved October 14, 2016, from
    https://venipedia.it/it/persone/veneziano-dellanno/canal-ernesto-tito

Canning, S. (2005). 'Belief' in the Past: Dempster-Shafer Theory, GIS and Archaeological
    Predictive Modelling. *Australian Archaeology,* (60), 6-15. Retrieved from
    http://www.jstor.org/stable/40287774

Carter, B. (2016, September 6). Wanna collect data digitally? Retrieved September 23, 2016,
    from Institute on Digital Archaeology Method & Practice,
    http://digitalarchaeology.msu.edu/news/

Cook, S. F., & Heizer, R. F. (1953). Archaeological dating by chemical analysis of bone.
    Southwestern Journal of Anthropology, 9(2), 231-238.

Dalgish, C. (2005). Urban myths: Rethinking the archaeology of the modern scottish city.
    Scottish Archaeological Journal, 27(2), 147-183.

Dean, M. (1995). Archaeology underwater: The NAS guide to principles and practice.
    Portsmouth: Nautical Archaeology Society.

Drewett, P. L. (1999). *Field Archaeology: An Introduction*. Retrieved from
    http://www.archaeology.ru/Download/Drewett/Drewett_1999_Field_Archaeology.pdf

Eporedia. N.d. Citta Romana d'Importanza Strategica. Retrieved December 10, 2016 from
    http://www.eporedia.eu/pg026.html

European Preventive Archaeology. (2007). National Office of Cultural Heritage. Retrieved
    September 23, 2016, from
    https://www.coe.int/t/dg4/cultureheritage/heritage/Archeologie/EPreventiveArchwebversi
    on.pdf

Firth, A. (1996). Theorizing the Management of Archaeology Underwater. *Historical
    Archaeology, 30*(2), 85-92. Retrieved from http://www.jstor.org/stable/25616458

Foote, K. E. (2015). Geographic Information Systems as an Integrating Technology: Context,
    Concepts, and Definitions. Retrieved October 14, 2016, from
    http://www.colorado.edu/geography/gcraft/notes/intro/intro.html

Gianolio, S., Mermati, F., & Genovese, G. (2014). Image-based 3D modeling for the knowledge
    and the representation of archaeological dig and pottery: Sant'omobono and sarno project's
    strategies. *The International Archives of Photogrammetry, Remote Sensing and Spatial
    Information Sciences, 40*(5), 243.

GIS Spatial Data Types: Vector vs Raster. (2016, July 30). Retrieved November 27, 2016, from
    http://gisgeography.com/spatial-data-types-vector-raster/

Grunow, O. (1961). The 34th international congress of americanists. *Current Anthropology,
    2*(3), 265-268.

Hastings, D. (2014). Combating Visitor Pressure: Impact of Tourism on the Conservation of
    World Heritage Sites. Retrieved September 5, 2016, from
    https://dlib.lib.washington.edu/researchworks/bitstream/handle/1773/27123/Hastings_wa
    shington_0250O_13213.pdf?sequence=1&isAllowed=y

Hesselberth, C. (1948). Subterranean archaeology.*Journal of the Illinois State
    Archaeological Society, 6*(2), 38-38. Retrieved from
http://www.jstor.org/stable/43762950

High water in Venice: frequently asked questions (FAQ). Retrieved September 22, 2016, from
    The City of Venice,
    http://archive.comune.venezia.it/flex/cm/pages/ServeBLOB.php/L/EN/IDPagina/22795

Hodgkinson, A. (2012, March 30). The archaeological applications of GIS Spatial Technology

and Archaeology. *Archaeology in the Digital Era, 2*, 59-88.

Holdaway, S. (1995). Archaeological analysis and the role of statistics: A reply to veth. *Archaeology in Oceania, 30*(3), 137-138.

Ingbar, E. (1994). *Plains Anthropologist, 39*(148), 235-237. Retrieved from http://www.jstor.org/stable/25669271

J. W. (2015, November 3). Understanding what makes a visualization memorable. Retrieved September 29, 2016, from http://www.storybench.org/understanding-what-makes-a-visualization-memorable/

Johnston, G. (2016, May 18). Dating Techniques In Archaeology. Retrieved September 16, 2016, from http://www.archaeologyexpert.co.uk/archaeologicaldating.html

Kvamme, K. (1990). One-Sample Tests in Regional Archaeological Analysis: New Possibilities through Computer Technology. *American Antiquity, 55*(2), 367-381. doi:1. Retrieved from http://www.jstor.org/stable/281655

Kyle A. Knabb, Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, & Thomas E. Levy. (2014). Scientific Visualization, 3D Immersive Virtual Reality Environments, and Archaeology in Jordan and the Near East. *Near Eastern Archaeology, 77*(3), 228-232. doi:1. Retrieved from http://www.jstor.org/stable/10.5615/neareastarch.77.3.0228

Levy, T., Witten, A., & Alon, D. (1996). Denizens of the Desert.*Archaeology, 49*(2), 36-40. Retrieved from http://www.jstor.org/stable/41770590

Liritzis, I., Al-Otaibi, F. M., Volonakis, P., & Drivaliari, A. (2015). Digital Technologies And Trends In Cultural Heritage. *Mediterranean Archaeology & Archaeometry*, *15*(3), 313-332.

Maliene, V., Grigonis, V., Palevicius, V., & Griffiths, S. (2011, January 17). Geographic information system: Old principles with new capabilities. Retrieved October 14, 2016, from http://link.springer.com/article/10.1057/udi.2010.25

Marwick, B. J. Archaeological Method Theory (2016). Retrieved September 10, 2016, from http://link.springer.com/article/10.1007/s10816-015-9272-9

McEwan, D. (2012). Qualitative Landscape Theories and Archaeological Predictive Modelling—A Journey Through No Man's Land? *Journal of Archaeological Method and Theory, 19*(4), 526-547. Retrieved from http://www.jstor.org/stable/23365977

McKenna, J. (2016, July 15). UN threatens to place Venice on endangered list unless Italy bans cruise ships. Retrieved September 05, 2016, from http://www.telegraph.co.uk/news/2016/07/15/un-threatens-to-place-venice-on-endangered-list-unless-italy-ban/

Merali, Z. (2002, August 19). Saving Venice. Retrieved September 19, 2016, from Scientific American, http://www.scientificamerican.com/article/saving-venice/

Mukhanov, Sofia; DeZulueta, Elizabeth Marie; Avila, Corrie Elizabeth; Sokk, Maarja-Liisa; Carrera, Fabio; Cocola, James. (2011). *Exploring the history of venice -- relics, records, and relations*. Worcester, MA: Worcester Polytechnic Institute.

Nguyen, M.-L., & Archaeological Institute of America. (2009, December 7). Site preservation news. Retrieved September 23, 2016, from https://www.archaeological.org/news/advocacy/76

Ortalli, G., & Scarabello, G. (1999). A Short History of Venice. Pacini Editore S.P.A.

Orton, C. (2007). Digging Your Own Grave: Generic Skills from an Archaeological Simulation.

Archaeology to Delight and Instruct: Active Learning in the University Classroom, *49*, 143.

Palomero, F., & Palomero, I. (2013). San sebastian de silos: The church dedicated or consecrated around 1088 through the documentation and archaeological remains. *Imago Temporis.Medium Aevum, 7*, 139-174.

Perrin, K., Brown, D. H., Lange, G., Bibby, D., Carlsson, A., Degraeve, A., … Von Bieberstein, A. R. (2014). *A Standard and Guide to Best Practice for Archaeological Archiving in Europe* (EAC Guidelines 1 ed.). rue des Brigades d'Irlande 1 5100 Namur, Belgium: Europae Archaeologia Consilium (EAC). http://european-archaeological-council.org/files/arches_v1_gb.compressed.pdf

Phuong, D. Q., Faylona, Marie Grace Pamela G, & Parry, D. (2009). A conservation perspective on the ba dinh archaeological site. *Bulletin of the Indo-Pacific Prehistory Association, 29*, 61-67.

Quartermaine, J., Olson, B., & Killebrew, A. (2014). Image-Based Modeling Approaches to 2D and 3D Digital Drafting in Archaeology at Tel Akko and Qasrin: Two Case Studies. *Journal of Eastern Mediterranean Archaeology & Heritage Studies, 2*(2), 110-127. doi:1. Retrieved from http://www.jstor.org/stable/10.5325/jeasmedarcherstu.2.2.0110

Richards, J. (1998). Recent Trends in Computer Applications in Archaeology. *Journal of Archaeological Research, 6*(4), 331-382. Retrieved from http://www.jstor.org/stable/41053162

Richter, A. (2014, July 18). So What is Digital Archaeology? Retrieved September 23, 2016 http://popular-archaeology.com/blog/adventures-in-digital-archaeology/so-what-is-digital-archaeology

Roosevelt, C. H., Cobb, P., Moss, E., Olson, B. R., & Unlusoy, S. (2015, May 29). Excavation is Digitization: Advances in Archaeological Practice. Retrieved September 19, 2016, from http://www.tandfonline.com/doi/full/10.1179/2042458215Y.0000000004

Rowe, J. H. (1959). Archaeological dating and cultural process. *Southwestern Journal of Anthropology, 15*(4), 317-324.

Sconcerto. Archivio storico: Dati di livello di marea a Venezia. Retrieved September 21, 2016, from http://www.comune.venezia.it/archivio/25419

Shrestha, B. (2016). Nuclear isotopes and uses. Retrieved October 14, 2016, from http://chem-guide.blogspot.com/2010/04/nuclear-isotopes-and-uses.html

Smith, M. E. (1987). The expansion of the aztec empire: A case study in the correlation of diachronic archaeological and ethnohistorical data. *American Antiquity, 52*(1), 37-54. doi:10.2307/281059

Smith, M. D., Longley, P., & Goodchild, M. (2012). Geospatial Analysis - spatial and GIS analysis techniques and GIS software. Retrieved October 14, 2016, from http://www.spatialanalysisonline.com/output/

Soika, G. (n.d.). *A. Supplemento al vol. XXVII del bollettino del Museo di Storia Naturale di Venezia*

South, S. (1978). Pattern recognition in historical archaeology. *American Antiquity, 43*(2), 223-230. doi:10.2307/279246

Staski, E. (2008). Living in Cities Today. *Historical Archaeology, 42*(1), 5-10. Retrieved from http://www.jstor.org/stable/25617479

Straumann, S. [Recording Archaeology]. (2015, October 7). *Interpreting the Archaeological Record by the aid of GIS – The Insula 30 of Augusta Raurica (CH).* [VideoFile]. Retrived from

https://www.youtube.com/watch?time_continue=472&v=5k3x2x8PlhM

The 50th Anniversary of GIS. (2012, Fall). Retrieved October 14, 2016, from http://www.esri.com/news/arcnews/fall12articles/the-fiftieth-anniversary-of-gis.html

The Conservation of Venetian Building Materials: Wood. (2008, December 11). Retrieved September 19, 2016, from Venice: An Online Exhibit Produced in ARTH 470z at the University of Mary Washington, http://venice.umwblogs.org/exhibit/the-conservation-of-venetian-building-materials/wood/

Tugby, D. (1965). Archaeological Objectives and Statistical Methods: A Frontier in Archaeology. *American Antiquity, 31*(1), 1-16. doi:1. Retrieved from http://www.jstor.org/stable/2694017

Venice and its Lagoon. (2016). Retrieved September 18, 2016, from http://whc.unesco.org/en/list/394

Verhagen, P., & Whitley, T. (2012). Integrating Archaeological Theory and Predictive Modeling: A Live Report from the Scene. *Journal of Archaeological Method and Theory, 19*(1), 49-100. Retrieved from http://www.jstor.org/stable/41408809

Zeuner, F. E. (1951). Archeological dating by radioactive carbon. *Science Progress (1933-), 39*(154), 225-238.

Appendix A: Archaeological System Summaries

This appendix, and the tables and summaries contained within, represent our analysis of fifteen different computational systems for archaeological research and data management. The below table summarizes features of these systems, and more information relating to each system is located in their summaries.

System Name	GIS	Integrated Data Management	Carbon Dating	Browser-based	Built-in Editors	Mobile App Support	Drawing	Publishing	Correlation By Date	Correlation By Location	Other Correlation	Import Existing Data
OxCal			x						x			
Integrated Archaeological Database		x		x	x		x	x		x	x	x
Site Recorder 4	x	x			x		x	x		x		x
Comparative Archaeology Database	x	x						x				x
tDAR		x		x				x				
QGIS	x			x				x		x		
Kobo Tool				x		x						
ExeGesIS - HBSMR	x	x		x				x		x	x	
SHARD		x										
ARK - The Archaeological Recording Kit		x		x	x							x
Intrasis	x	x			x				x	x	x	x
Nabonidus		x							x	x	x	
SingulArch-Pocket	x	x			x			x		x		x
BASP posthole		x			x		x		x	x	x	
Bcal			x									

OxCal

OxCal is a program designed by Oxford University's C. Bronk Ramsey for use in radiocarbon dating and analysis. The program provides radiocarbon calibration and allows archaeologists to summarize and analyze absolute radiocarbon dating data. It is both available as a download and as a browser-based application and allows the user to enter analysis data either as command files or through the user interface. This program is only available to the University of Oxford, so the team could not use the program. However, screenshots provided on the website show that the program uses graphs to display radiocarbon data for ease of analysis. This program is most applicable to the analysis and research stages of the archaeological process.

OxCal can be found at the following link: https://c14.arch.ox.ac.uk/oxcal.html
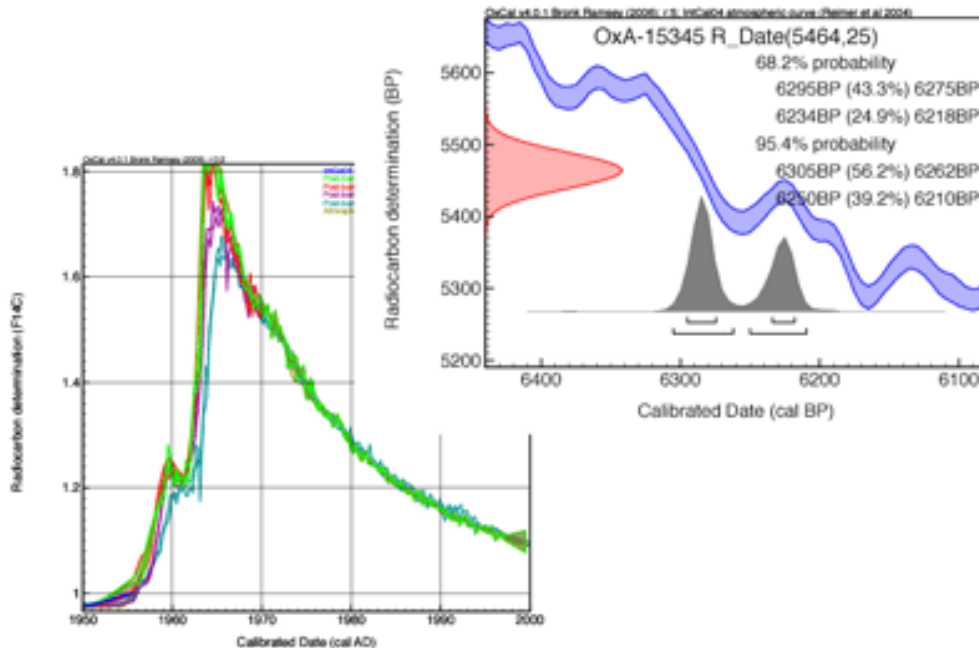
Integrated Archaeological Database

The Integrated Archaeological Database System or IADB is a web-based databasing system that provides support to archaeologists for data management throughout the course of an archaeological project. This database software provides support through excavation recording, analysis of finds, research, publication, and data archiving. It was created by a group of Scottish archaeologists to address a lack of online archaeological databasing tools. The system is web-based and designed to work with Firefox. It focuses on data recording and establishing links between records. The system itself is proprietary and requires purchase to use, but the website provides a number of screenshots and a free, limited-access demo that allows users to browse a completed archaeological site record. Below are several screenshots provided by the website of forms and pages.

Project 1048: Find SF00021

Project 1048: Find SF00021   View ▼

| Acc Code | 1048 | Quantity | | Spot Date | | ▶ |
| Context | 1021 | Set | 17 | Group | 8 | Phase | 2 |

Keywords	Chipping	▼	Date Terms		▼
Material		▼	Date Range	0	0
Related To		X (Eastings)		Y (Northings)		Z (AOD)	

Dimensions
[New Record]

	Data	Diam	Length	Width	Thick	Height	Weight	Area	Volume
✓									

Description

Bark Chipping - tree type is unidentifiable therefore Wood Conservation Lab recomend discard?

Conservation Work Record

Single thick fragment of bark. Good condition- may be detached from one of the larger structural timbers rather than an individual find.

Save | Delete | Previous | Next | Print | Close

Project 1048: Set 17

Project 1048: Set 17   View ▼

Title/Summary: Set 17 consisted of deposits which built up against the wicker fences of sets 11, ...

Set 17 consisted of deposits which built up against the wicker fences of sets 11, 12 and 14 showing that these structures were still in use. The deposits were highly organic and probably represent the dumping of occupation derived material. In the north-western portion of the trench the deposit consisted of friable, waterlogged dark greyish black organic silt, with moderate light greenish grey silty clay lenses, occasional small sub-rounded limestone pieces, charcoal and oyster shell, and very occasional mortar flecks (context 1021). In the south-eastern portion of the trench a compact, highly organic, friable, dark brownish grey clayey silt with occasional small lenses of pinkish grey clay and very occasional flecks of mortar, small sub-rounded stones, charcoal flecks and oyster shells (context 1022) was laid down. Within context 1022 was an irregular fragment of timber 0.63m long and 0.16m to 0.25m in diameter, with bark attached (timber number 007) which lay horizontally north-east to south-west. This seems to be a discarded fragment of unworked timber.

Group	8
Phase	2
On Matrices:	

Save | Delete | Previous | Next | Print | Close
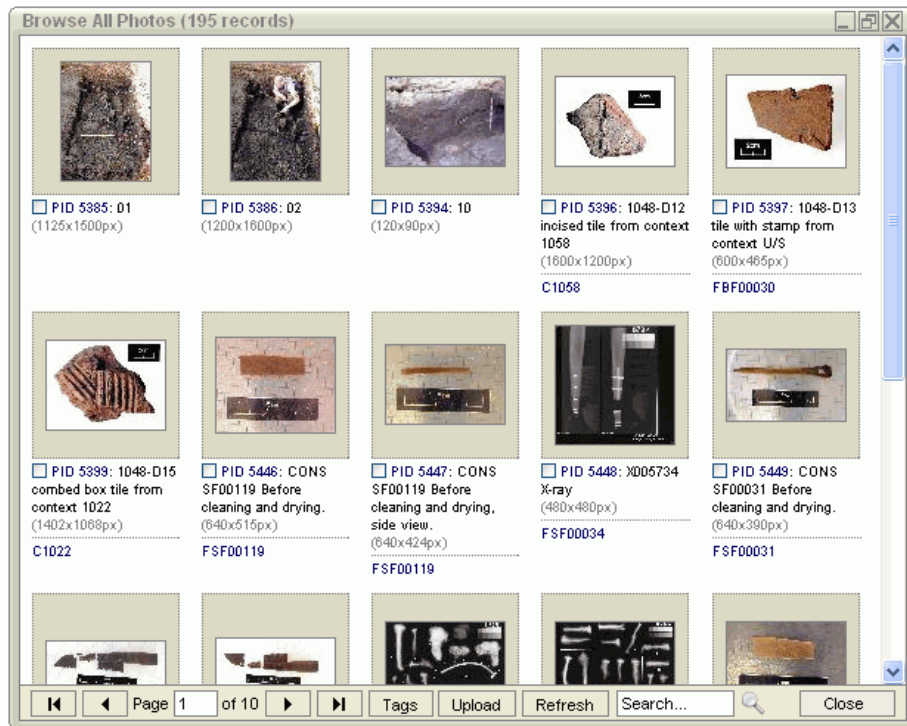
IADB can be found at the following link: http://www.iadb.org.uk/

Site Recorder 4

Site Recorder 4 is a system designed to integrate GIS and information management for use specifically in underwater archaeology. It has support for real-time data collection, publication, migration of data from other systems, and data archiving. This system is designed for collecting and displaying data as well as on-site data collection. This system has features for recording artifacts as well as site features such as trenches, areas, and sectors. It also allows for tracking of divers and boats in the area, and allows archaeologists to upload photos, drawings, and site documents. It allows for some data linking based on location. The system also allows archaeologists to complete site drawings in-application and publish data using the system. However, this system is designed only for use with underwater archaeology and requires a computer running older versions of Windows (Vista and older) to use. It also requires payment to use. Below is a screenshot of the system showing a map of site artifacts for a wreck, including cannons and an anchor.
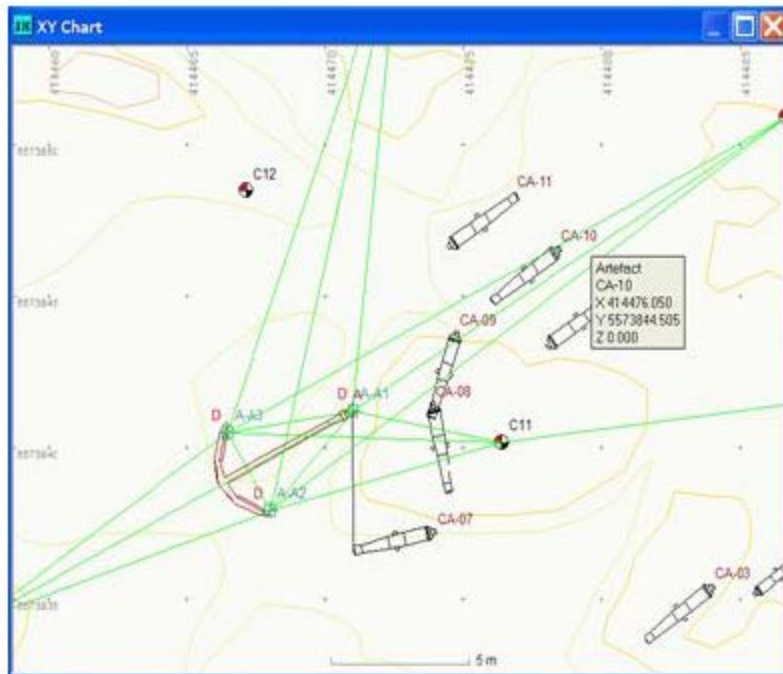
More information on Site Recorder 4 can be found at the following link:
http://www.3hconsulting.com/ProductsRecorderMain.htm

Comparative Archaeology Database

The Comparative Archaeology Database, created by the University of Pittsburgh, supports archaeological efforts to preserve and publish archaeological data. This system provides numerous datasets specifically revolving around Latin American archaeology. The system aims to provide a more efficient and more user-friendly method for preserving large amounts of archaeological data. Below is an example of the system's map-based interface:

Click on a location to access its dataset
To zoom in, click and drag a box (or click on an individual country).
Powered by DIY Map

More information on the Comparative Archaeology Database can be found at the following link: http://www.cadb.pitt.edu/

tDAR

The Digital Archaeological Record, or tDAR, is a database for digital archaeological records. It assists with data management and organization, as well as with sharing archaeological research and publishing data. This system is not aimed at data analysis or correlation, but rather at data management. It is aimed primarily at United States archaeologists and is proprietary, requiring a login to access. Therefore, it was difficult to obtain much information on the system itself. More information on tDAR can be found at the following link: https://www.tdar.org/

QGIS

QGIS is an open source Geographic Information System, or GIS. It allows for location-based analysis of finds. It is not a tool unique to archaeology but has proven highly useful for archaeological analysis. Several other systems discussed in this appendix interface with qGIS to use location data. QGIS is free to use.
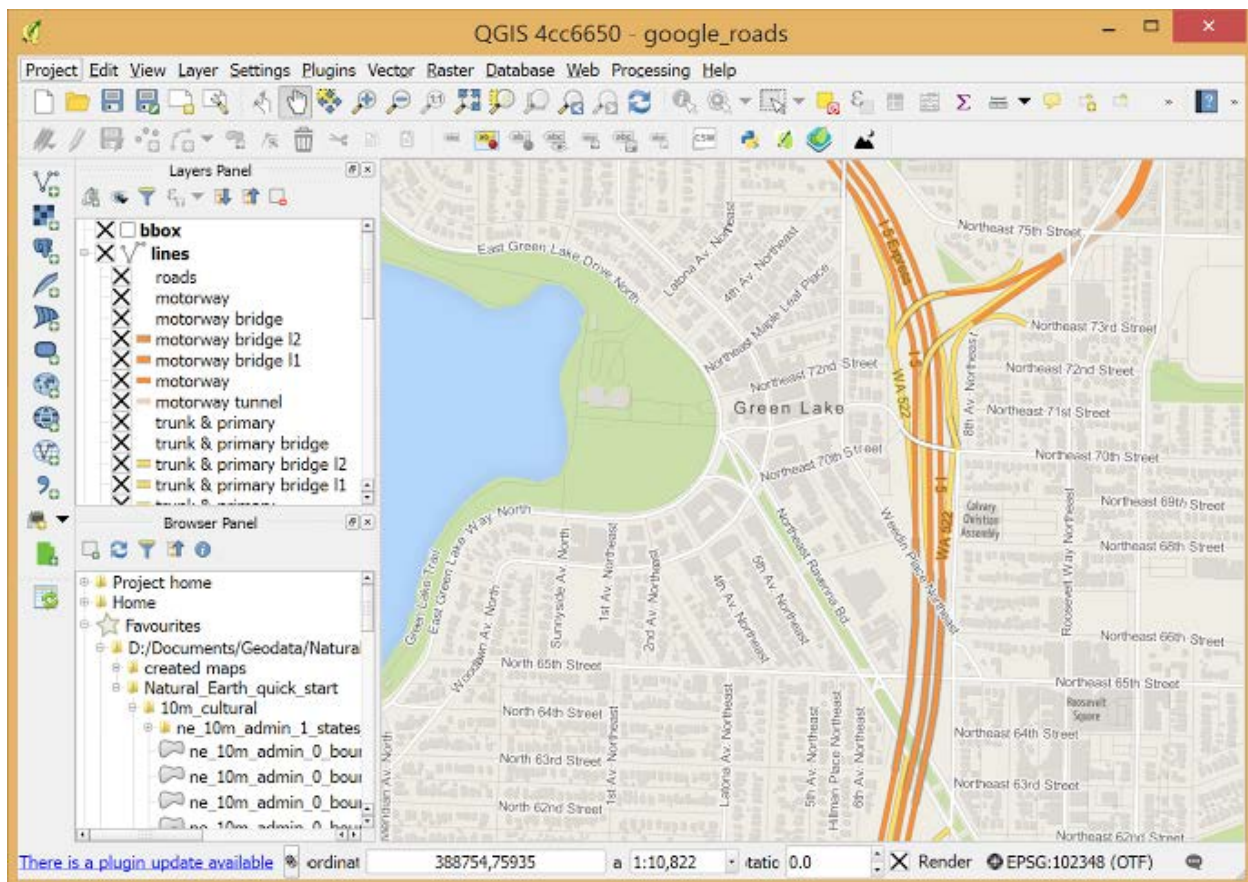
More information on QGIS can be found at the following link: http://www.qgis.org/en/site/

Kobo Tool

   KoBoToolbox is comprised of a set of tools for use in data collection. It allows researchers to collect data through use of mobile forms. It also allows researchers to modify and create new forms, as well as to analyze data gathered through the mobile system using Excel or other data analysis systems. This is useful to archaeologists when collecting data from archaeological sites, as it allows for real-time data collection. Although it is free for use by humanitarian organizations, it has data restrictions for non-humanitarian users, and limits submissions to less than 10,000 and data uploads to less than 5 GB per month. Therefore, this system is too limited for use in our current project.

More information on Kobo Tool can be found at the following link:
http://www.kobotoolbox.org/

ExeGesIs/HBSMR

HBSMR is a GIS platform for data management, analysis, and publication. It was created for use by English archaeologists in data management. It allows users to record monuments, finds, landscapes, casework, events, sources, designations, and data synthesis. It integrates GIS into its data management system for the display of locations and finds on map interfaces. It also provides support for admins and is customizable. This system is not free to use, and requires registration.
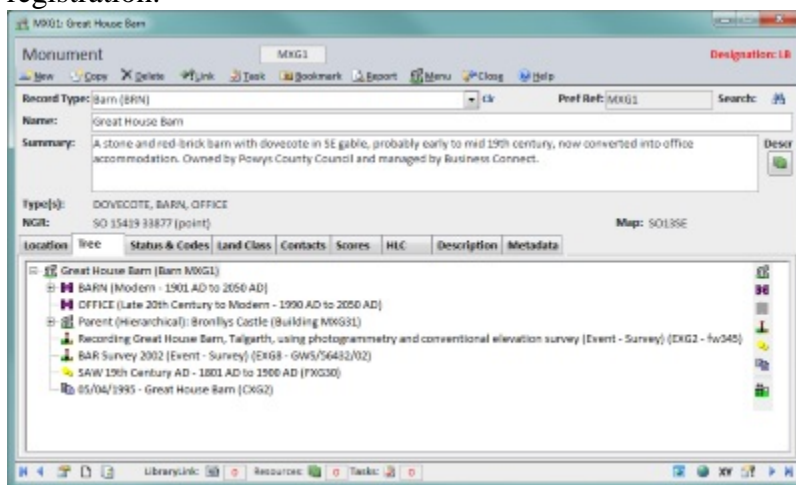
More information on ExeGesIS - HBSMR can be found at the following link:
https://www.esdm.co.uk/hbsmr-historic-environment

SHARD

SHARD, or the Sonoma Historic Artifact Research Database, is a system designed by Sonoma State University for cataloging of artifacts and archaeological sites. It also provides support for creation of data tables for cross-site data correlation. It is free to use with registration, but requires MS Office Access 2003 to run. It has not been updated since 2009.
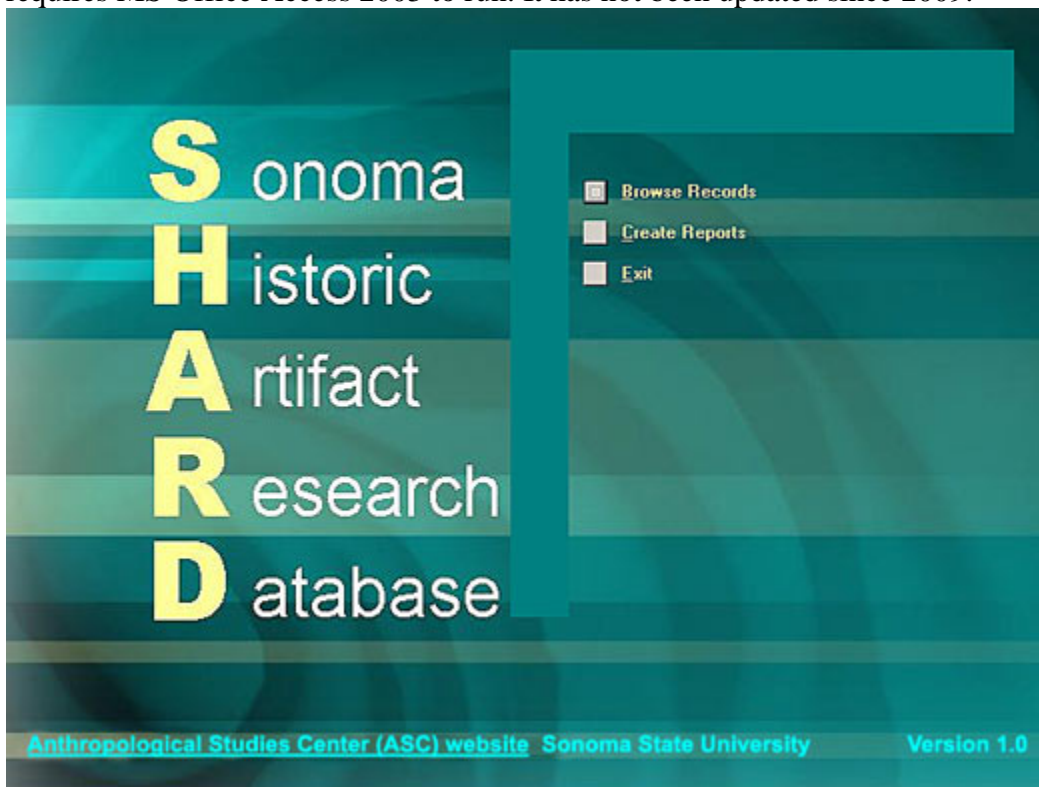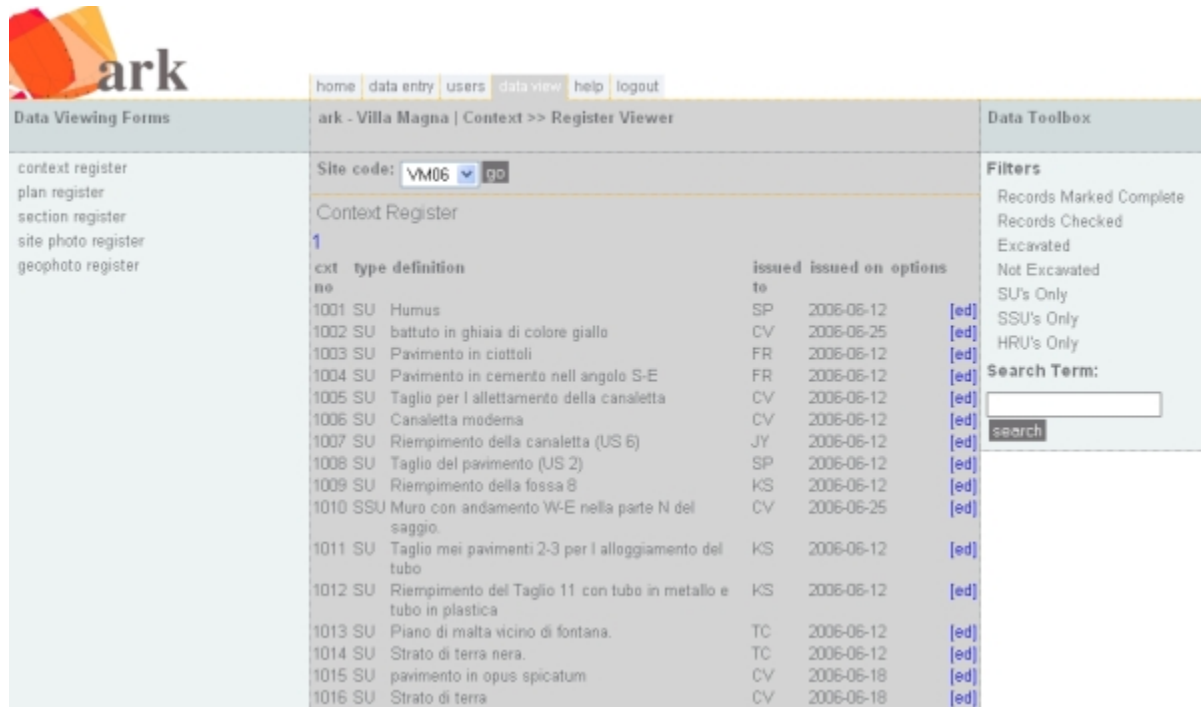
More information on SHARD can be found at the following link:
http://www.sonoma.edu/asc/shard/

ARK- The Archaeological Recording Kit

ARK is a system for archaeological data management. It allows archaeologists to collect data and edit, view and share the collected data. It allows archaeologists to customize data entry for their sites and finds, and is fully open-source. ARK is web-based and requires no additional software to run. It is also free to install and use.

More information on Ark can be found at the following link: http://ark.lparchaeology.com/

Intrasis

Intrasis is a GIS aimed specifically at archaeological data management. It allows archaeologists to combine all data related to a single site in order to better analyze and record site data. It was developed by a Swedish archaeological department, and is widely used in Swedish archaeology. The system itself is aimed at archaeological documentation on-site and is comprised of two separate products, Intrasis Explorer and Intrasis Analysis. Explorer allows for data importation and administration. Analysis uses GIS analysis to help organize and make sense of data. The system is object oriented. It is not free or open source and requires a key to activate.

More information on Intrasis can be found at the following link:
http://www.intrasis.com/engelska/index_eng.htm

Nabonidus

Nabonidus is a web-based application used for data management and analysis. It allows archaeologists to store excavation data in-field using an internet-capable laptop. Data is stored privately and securely and the system analyzes entered data using statistical models in real-time. Nabonidus also allows archaeologists to cross-reference finds across sites using a search engine. The system itself is up-to-date and is free to "any excavation run by a university, charitable or not-for-profit organisation." Future versions will allow for use of PPCs, or Pocket PCs in-field as well as excavation management.

Context6	Wall Context	Brief Description	Last Modified	Complete	View as PDF	View as HTML	Edit	Delete
100001	No		14/01/2015 8:12:33 AM	No				
1001	No	fill of pit	13/09/2016 4:39:18 AM	No				
New Context	No		2/07/2015 3:25:36 PM	No				
New Context	No		2/07/2015 3:26:29 PM	No				
New Context	No		2/07/2015 4:20:13 PM	No				
New Context	No		7/08/2015 7:13:15 PM	No				
New Context	No		7/01/2016 5:34:16 AM	No				
New Context	No		5/08/2016 5:21:12 AM	No				
New Context	No		17/01/2015 4:45:46 AM	No				
New Context	No		14/01/2015 3:15:26 AM	No				
New Context	No		28/12/2011 12:22:45 AM	No				
New Context	No		23/02/2012 10:08:48 PM	No				
New Context	No		6/07/2012 5:38:15 PM	No				
New Context	No		30/04/2013 3:55:22 PM	No				
New Context	No		3/12/2013 1:02:07 AM	No				
New Context	No		5/12/2008 2:12:30 AM	No				
New Context	No		23/08/2009 8:34:41 PM	No				
New Context	No		3/12/2009 10:00:10 AM	No				
New Context	No		22/03/2010 1:54:58 AM	No				
New Context	No		27/10/2010 10:19:10 PM	No				

Show 20 ▼ results on a page (total records 66)   1 2 3 4 next

More information on Nabonidus can be found at the following link: http://www.nabonidus.org/

SingulArch-Pocket

SingulArch-Pocket is an application for PPCs, or Pocket PCs. It allows archaolgists to collect a wide variety of data during archaeological excavations. It also has applications for geological and biological investigation. SingulArch also allows users to store coordinates and interpret GPS data. There are two versions, the full and the light version, which offer differing levels of functionality. The light version only allows use of CAD tools, coordinates, and GPS. The full version allows use of all of the features of the light version plus databasing capabilities. The full version also includes tools to synch PPCs with desktops. However, this tool has not been updated since 2007 and is likely defunct.
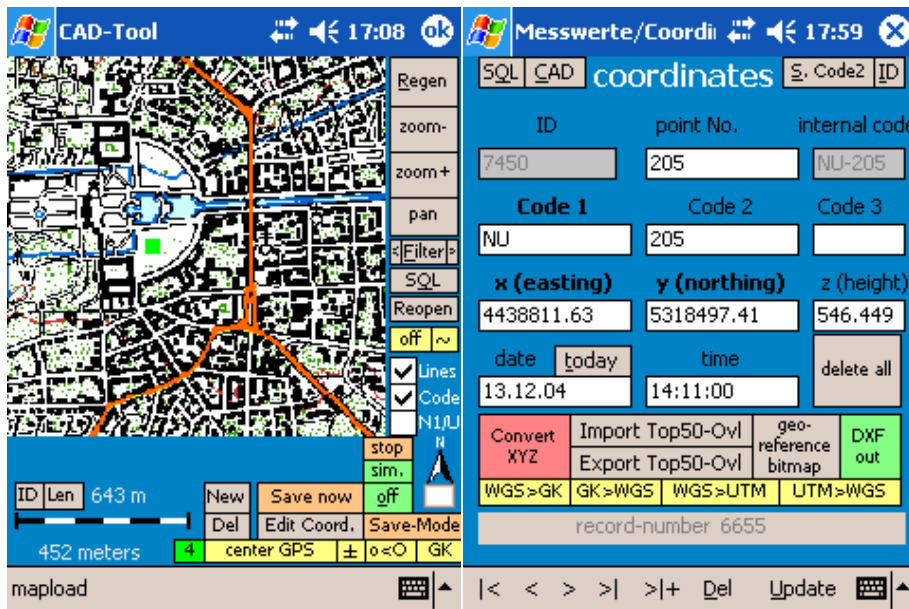
More information on SingulArch-Pocket can be found at the following link:
http://www.singularch.de/pocket_e.htm

BASP Posthole

BASP Posthole is a program used to dectect rectangular structures in site drawings. It uses algorithms to detect structures in scanned excavation plans for use by archaeologists in excavation and site searching. No screenshots were found on the website, but it is free-to-use and distribute. It is aimed specifically at archaeologists.

More information on BASP Posthole can be found at the following link: http://www.uni-koeln.de/~al001/posthole.html

Bcal

BCal is a radiocarbon dating tool used to organize radiocarbon dating data. It is hosted by the School of Mathematics and Statistics at the University of Sheffield. BCal is a tool designed for experienced researchers to use when organizing, analyzing, and publishing radiocarbon data.

More information on BCal Posthole can be found at the following link: http://bcal.shef.ac.uk/

Appendix B: Data Recording Forms

This appendix contains full forms used for Objective 1 and data entry.

General Information

Information for Archaeological Site

Date of Excavation

Your answer

Lead Archaeologist

Your answer

Science Management

Your answer

Catalogue Number (Replace periods with "-")

Your answer

Sopr. Archeo

○ Soprintendenza archeologica per il veneto

○ Other : _____

Center

○ Cannaregio

○ San Polo

○ Santa Croce

○ San Marco

○ Castello

○ Other :

NEXT

Never submit passwords through Google Forms.

General Information

Geographic Information

Will be obtained using an app?

GPS Latitude

Your answer

GPS Longitude

Your answer

BACK   NEXT

Never submit passwords through Google Forms.

General Information

Specific Information

Site types

Site type (Urban vs. Non-urban)
○ Urban
○ Non-Urban

Site type (Level of Water)
○ Underwater
○ Wet
○ Dry

Object Finds?
○ Yes
○ No

Analysis?
○ Yes
○ No

Draw Maps?
○ Yes
○ No

Vertical Draw Section?

○ Yes

○ No

Photos/Film?

○ Yes

○ No

Digital Photos?

○ Yes

○ No

Finds

☐ Structures

☐ Layers

☐ Find objects

☐ Other: _____

[BACK] [NEXT]

Never submit passwords through Google Forms.

General Information

Dating

Dating information

Epoch (most important)

Choose ▼

Century - From

Your answer

Century - To

Your answer

Interpretation

Your answer

[BACK] [**SUBMIT**]

Never submit passwords through Google Forms.

Form Screenshots from App

General information

Location:

Get location

Site code

Year

Archaeologist

Science Management

Intervention Type

☐ Excavation
✓ Samples
☐ Tomb
☐ Anomalies
✓ Core Sampling

Specific Information

Site information

● Urban ○ Non-Urban

○ Wet ○ Dry ● Underwater

Object Finds

● Yes ○ No

Draw Maps

● Yes ○ No

Vertical Draw Section

○ Yes ● No

Photos/Film

● Yes ○ No

Digital Photos

○ Yes ● No

Finds

✓ Structure
✓ Layers
☐ Object

16% 9:50 PM

US	Description	Edit info	Edit finds	Remove
100	Floor tiles	Edit	Edit	Remove
101	Concrete	Edit	Edit	Remove
102	Sand and rubble	Edit	Edit	Remove
103	Sand and rubble	Edit	Edit	Remove
104	Wall structure	Edit	Edit	Remove
105	Gravel and sand	Edit	Edit	Remove
106	Grey sand	Edit	Edit	Remove
107	North Foundation	Edit	Edit	Remove

14% 10:53 PM

Organic/Inorganic find

Ministry for Cultural Assets and Activities

Archaeologist

Locality

Form

Initials

Appendix C: Archaeological Forms

Site form provided by Studio Zandinella

US matrix form provided by Studio Zandinella

Site Forms provided by Studio Zandinella

Front and back pictures of the USM form provided by Studio Zandinella

ID foto	DATA	INQUADRAMENTO	SOGGETTO	RIPRESA	AUTORE	NOTE
			VE16CST1212			
ft001	2016-02-14				dott. Alberto Zandinella	
ft002						
ft003						
ft004						
ft005						
ft006						
ft007						
ft008						
ft009						
ft010						
ft011						
ft012						

US Site Layers Index provided by Studio Zandinella

The anthropological forms provided by Studio Zandinella