Research Article

Stefano Bertoldi*

C.A.P.I. Project in the Making: 3D Applications at Poggio Imperiale Between Materiality and Virtual Reality (Poggibonsi, IT)

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Abstract: The archaeological project on the hill of Poggio Imperiale began in 1992. From the beginning this project was characterized by intense experimentation with a range of IT applications. During 2014, the University of Siena began a new project focused on the valorisation of archaeological data with the creation of an Open-Air Museum of the Carolingian village, one of the archaeological phases of the settlement. Over the last several years, the use of three-dimensional (3D) data in archaeology has increased exponentially due to the application of photogrammetry to record every stratigraphic unit. This ever-increasing amount of data fostered the development of the C.A.P.I. project (Collina Accessibile di Poggio Imperiale – Accessibility of the Hill of Poggio Imperiale), which involved the construction of a 3D model of the archaeological area of Poggio Imperiale. The project modeled the three main life stages of the hill using 3D computer graphics. Virtual tours can be experienced through PCs, tablets, smartphones, and even virtual reality headsets, offering users a fully immersive experience. However, virtual reality will not be a replacement for the materiality of the archaeological site. On the contrary, it will provide an additional tool to make the site accessible and inclusive to any potential visitor, regardless of physical distance, physical ability, or time zone.

Keywords: virtual reality, technologies applied to cultural heritage, virtual reconstruction, computer science and archaeology

1 Introduction

The C.A.P.I. framework (acronym for Collina Accessibile di Poggio Imperiale – Making Accessible the Poggio Imperiale Hill) is directed by Prof. M. Valenti of the University of Siena. The goal of the project is to virtually enhance all aspects of the historical heritage of the archaeological excavations of Poggibonsi. In our case, the final purpose of digital information is to democratize history and archaeology by breaking down linguistic, cultural, and economic borders as well as removing the existing limits to people with motor and cognitive diversities (Opitz, 2016, Tringham & Lopez, 2001).

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* **Corresponding author: Stefano Bertoldi**, Dipartimento di Scienze Storiche e dei Beni Culturali, Università degli Studi di Siena, Siena, 53100, Italy, e-mail: stefano.bertoldi@unisi.it

Since inception, archaeological research in Poggibonsi has promoted two major lines of inquiry directed toward the disclosure of archaeological information and the systematic use of information technology to catalogue, analyze, and publish stratigraphic data (Valenti, 1996). During the 1990s itself, several IT solutions were tested during the excavation of Poggibonsi: GIS applications to manage geographic data of the excavation and the wider territory (Nardini, 2000), databases for cataloguing alphanumeric data such as finds and stratigraphic units (Fronza, 2000), and three-dimensional (3D) reconstructions and multimedia (Salvadori, 2009).

During the last 20 years, the LIAAM (acronym for Laboratorio di Informatica Applicata all'Archeologia Medievale – Laboratory of Computer Science Applied to Medieval Archaeology) team has worked at the archaeological excavation of Miranduolo (Chiusdino, Siena). This project continued to experiment with different IT solutions and, in parallel, to enhance the archaeological park of Poggibonsi.

At Miranduolo, experiments were carried out regarding the application of a laser scanner (Peripimeno, 2008) and photogrammetry (Bertoldi, 2018). Moreover, all archaeological activities were documented every day and shared in real time through multiple posts, photos, and/or videos on the Facebook page “Miranduolo in Alta Val di Merse – Il progetto” (facebook.com/miranduolo/). The goal of this documentation was to stimulate the public's participation, debate, and discussion, as well as to ensure complete transparency of the excavation.

The archaeological activities at Poggibonsi have increased during the last several years with the roll out of the Open-Air Museum, a project that produced a full-scale reconstruction of the 17 huts found during the excavation of the village from the Carolingian period (Figure 1).

Since 2003, the local Municipality has carried out a development program focusing on the context of Poggio Imperiale in terms of its cultural heritage, focusing on the 16th century fortress citadel (planned by Giuliano da Sangallo) and on the spaces enclosed by the walls.

Figure 1: The open-air museum of Poggibonsi.

In 2014, a first 1:1 reconstruction of a ninth-century longhouse-manor house was undertaken at Poggibonsi. This was the first step toward constructing the open-air museum, which expanded gradually in the following years to become an important archaeological park (Valenti, 2019).

Initially, the role of the open-air museum was to transform a culturally unknown place, very close to major tourist attractions (e.g. Siena, Florence, San Gimignano) into a new cultural center (Valenti & Salzotti, 2017).

The Facebook page of the Open-Air Museum of Poggibonsi is one of the most important single project pages of archaeology in Italy, with more than 10,000 followers at present. Official data on tourist trends in Poggibonsi show continuous growth: 42,453 tourists visited in 2014, 46,909 in 2015 (+10%), 61,712 in 2016 (+31.56%), 64,828 in 2017 (+5.05%), and 73,849 in 2018 (+13.92%).

After 6 years of activity and although the open-air museum is still in the implementation phase, the process had already reached an advanced stage. However, the communication of the long and complex history of the hill still remained a problem. In fact, the main goal of the project was to illustrate and display the *longue durée* history of the town, beyond its transformation into a *curtis*, although this phase is certainly archaeologically important.

In particular, the problem was the need to describe the period of Poggio Bonizio, which during the course of the thirteenth century had an urban development with an extension of about 7 ha comprising two monumental churches and a market square (*forum Podii Bonizi*), where there must have been a balance to weigh saffron. The success of the settlement during this period was largely due to the route of the Via Francigena and its manufacturing, commercial, and entrepreneurial opportunities (Valenti & Causarano, 2011). Therefore, clearly representing and visualizing such a complex and articulated city remains a challenging undertaking, due to the fact that it is quite impossible to materially reconstruct it on a 1:1 scale.

2 Historical Background

The hill of Poggibonsi was a long-lasting settlement, which developed throughout the course of the Middle Ages. It was founded between the late fifth and sixth centuries CE, when Poggibonsi was just a small village, perhaps part of a larger property of *possessores* (rural élite of Roman or Ostrogothic ethnicity). The site was abandoned during the second half of the sixth century, reoccupied in the Lombard period as a village of huts, and later transformed into a *curtis*¹ in the ninth century.

Following another period of abandonment, in 1155 Count Guido Guerra launched an ambitious project to build new structures on the hill of the city of *Podium Bonizi* – Poggio Bonizio (Figures 2 and 3).

The Count, relying on the support of Emperor Frederick I, managed to ally himself with the city of Siena, which in those years was beginning to expand into the area around *Podium Bonizi*.

The presence of highly skilled craftsmen working at this time in Poggio Bonizio testified to the huge investment Guido Guerra undertook in planning the urban development of the town. It was an unusual construction for that time, given that its size and architecture made it look more like a city than a castle.

Following the death of Guido Guerra, the city continued its development. In 1185, under the patronage of the Emperor, Poggibonsi became a municipality with political officials (consuls and mayor-podestà).

Archaeological excavation on the hilltop identified two urban churches that historical sources indicate were dedicated to S. Agostino and S. Agnese, 12 houses, and other evidence related to the settlements (e.g. the principal road and the water well).

¹ The Curtense system was introduced in Italy by the Carolingian invasion, and was a model of rural property management that tended to be self-sufficient. The Curtense system transformed the Lombard way of managing the countryside, making it more efficient and profitable. This system divided villages into a *pars dominica* (owned by the elite and the location of warehouses) and a *pars rustica* (where the peasants lived). For further information about *curtis* and Curtense system see Andreolli and Montanari (1983, pp. 177–200), Francovich (2008), Francovich and Hodges (2003), and Toubert (1983, 1995, p. 188).

Figure 2: Graphic reconstruction of *Podium Bonizi* (Ink Link Studio – Cultural Heritage Communication & University of Siena).

The development of the settlement was encouraged by the passage of the Via Francigena, and the identified material culture shows wide-ranging business contacts. In particular, this evidence comes from the excavation of many coins, 75% of which date between the eleventh and twelfth centuries. This collection contains the “denari” of Pisa naming Frederick I (coined after 1181), and Sienese coins minted from the end of the twelfth century to the second half of the thirteenth century.

There are 12 coins minted in Verona in the thirteenth century which were used for small daily transactions. The commercial role of the city, improved by its excellent position between several major roads, is also documented by the presence of coins from areas outside Tuscany and Italy. Identified coins come from within Italy (Ancona, Pavia, Ravenna and Brindisi), and also further afield (in Toledo, Salamanca, Orange, Navarre, Normandy, Carinthia).

Excavations also brought to light a “dinar” minted in Murcia (Spain) by King Abdallah Ibn Iyad (or Ayad) in 1146. The coin contains verse 85 of surah three of the Koran and the words “There is no God except the God Mohammed, the envoy of God the Emir Abdallah ibn Iyad”; on the reverse it is written “In the name of God, gracious and merciful, this dinar was coined in Medina Múrcia in the year 40 and 500” and “Imam Abd-Allah Emir of the religious people” (Causarano, Cicali, Sbrana, & Tixier, 2009).

In the beginning of the thirteenth century, *Podium Bonizi* was a settlement characterized by constant growth in economic prosperity and a marked entrepreneurial initiative with many manufacturing and trading activities. In 1270, Guido di Monfort besieged Poggio Bonizio and the city was completely destroyed. Roughly 40 years later, in 1313, Emperor Arrigo VII chose the site of the old Poggio Bonizio to build a new city, called Monte Imperiale, which was to be a fortress of imperial power in Tuscany. But the adventure of Monte Imperiale was short-lived, and its end coincided with the death of Arrigo in Val d’Era. Florentine troops attacked the hill and destroyed the settlement again (Francovich & Valenti, 2007). During the sixteenth century, Lorenzo De’ Medici and the architect Giuliano da Sangallo planned to build a fortress upon the hill, but the walls were never completed. The hilltop site was completely abandoned and the development of the modern city of Poggibonsi began in the valley.

Figure 3: Graphic reconstruction of a neighborhood of *Podium Bonizi* (Ink Link Studio – Cultural Heritage Communication & University of Siena).

3 Theoretical Framework

Virtual tours and virtual reality (VR) can be extraordinary tools for communicating complex information: users can immerse themselves in a different world, without the mediation of a computer, projector, or even a mobile phone (in standalone version). The enveloping field of view offered by VR headsets creates a shield from their real-world sensory surroundings, isolating the user in a new reality formed by visual and sound experiences.

From a theoretical point of view, when discussing these applications in an archaeological setting, it is necessary to elaborate on the definition of the concepts “reality” and “virtuality.”

The concept of “reality” means “the state of things as they are, rather than as they are imagined to be” (Cambridge Dictionaries online, 2013). However, this definition is different from “the state of things as they are, rather than as they are imagined to have been.”

Bondi (2019) states that a VR must be understood as a real dream, almost completely realized by the construction of a non-material reality; this is exclusively formal and created by the people, that is a representation of the will.

Bondi, in this conception, starts from the definition of “Nature” (which must be understood as a synonym of reality), and applies this term to what is independent of the intervention of a human being.

Following this approach, the difference between a wooden statue and a tree must be analyzed according to Aristotle; in the first case nature is exclusively wood (i.e. matter and not form), while in the second case nature is both matter and form.

But by projecting the wooden statue back in time, we can observe that it was originally pure matter, when it was a tree.

In the same way, an archaeological excavation is real in its physicality, but it can be real (if reliable, philological and carried out with an analytical approach) also in its 3D reconstruction. The excavation represents “what it was” and not “what is imagined.”

While the concept of VR implies imagination, illusion, and unreality, I argue instead that it is more accurate to speak of it as “another reality.” By applying this idea of another reality in the past, we can introduce the value of time.

But this real-virtual dualism has not yet been fully accepted by archaeological researchers in Italy. Some years ago, virtual reconstructions of Rome and other virtual archaeological applications were superficially dismissed by a cultural heritage professional as “lacking the aura of real” (Niccolucci, 2007).

The model that inspired this study is the one done by the Metropolitan Museum of Art in New York, where they created a map of the museum that depicts the different levels and the dislocation of characteristics of the space that can be considered critical (such as light, crowds, or noise). In this way it is possible to know the potential sources of disturbance and to get more familiar with certain museum rooms.

Getting acquainted with the museum space is one of the main guidelines given by the MAC “Museum Access Consortium”²; additional guidelines outline how to deepen the cultural themes of the museum with online brochures. The good quality and design of the specific content of a website is another step toward a good reception of museum material by the public.

Given these guidelines, from our point of view, digital resources could become a support element in some cases and a substitute element in others. Virtualization of content could be a way of allowing a sort of “preventive” visit to the Poggio Imperiale hill.

The C.A.P.I. program is first of all a technical project, but it also works toward the social goals of Public Archaeology,³ in which technology is available to the entirety of the community. Ultimately, the aim is to offer a truly global level of accessibility to Cultural Heritage.

4 Methods

The proposed working hypothesis is therefore to display the archaeological phases (and in particular those inherent to the medieval city) in 3D graphics. Where possible, these are based on stratigraphic data, and in areas outside the excavation sectors it will be based on remote sensing and crop-marks (Valenti, 2000).

The workflow, which will be described in detail below, is essentially based on three fundamental steps: a 3D survey (A), modeling in 3D graphics (B), and the creation of the virtual tour (C).

The goal of the photogrammetric survey of the excavation areas is to obtain the correct position of archaeological evidence and structures (Figures 4 and 5).

This approach is used to create a 3D model of a monument as it appears in an archaeological excavation, based on a survey of what remains (i.e., reality based). This method is opposed to creating a model using a computer graphics approach only, which is intended to be hypothetical. The possible compromise for a scientifically accurate 3D model would be to elaborate a source-based model by using a reconstruction process such as source blending (Demetrescu, 2015).

Photogrammetry is the technology used to create a photographic survey defined as “structure from motion”; the first step of the operation is to create a grid of marker points and measure these points to define the distance between them. In the case of Poggibonsi we used the marker points of the excavation sectors.⁴ In the C.A.P.I. project we used the photogrammetric software Agisoft Metashape.

² Making Content Usable for People with Cognitive and Learning Disabilities, Working Group Note 29 April 2021: <https://www.w3.org/TR/coga-usable/>.

³ For the application of Public Archaeology in Poggibonsi, see Valenti (2020). For a general definition of Public Archaeology, see Moshenska (2017).

⁴ It is important to elaborate a local (or absolute) system of coordinates of marker points defined by longitude, latitude, and elevation; every marker point must have X, Y, and Z coordinates (Zoni, 2020).

Figure 4: Photogrammetric survey of the open-air museum.

After measuring the distance between a marker point and the absolute height of each one, the second step is to take photos around the specific object to survey it. In general, 35–40 photos are enough, but it depends on the morphology, walls, stones, the geometric complexity of the object as well as the desired level of graphic resolution.

The photogrammetric software elaborates photos and creates a dense cloud of 3D points: a mesh and a 3D photographic texture. The main advantages of photogrammetry are the speed of data survey in the field, the production of a huge quantity of spatial data, as well as metric and photographic details. The photogrammetric software simulates the operation of the human brain (Fussel, 1982, p. 157). The analysis of photos of the same object taken from different positions generates a 3D model. Archaeology has developed several applications for the utilization of photogrammetry in both excavation and terrestrial surveys. Within excavation surveys, the 3D model can also be used to form 3D reconstructions of monuments for virtual archaeology (Figure 6).

Our workflow continued by exporting the 3D model in an obj file (with a very high resolution⁵), which was then imported into a 3D graphics project using the open-source software Blender. This environment facilitates modeling the structures of the city, based on the photogrammetric survey, the excavation data, and on the graphic reconstructions made by InkLink.⁶

Given the enormous number of geometries, the structure of the dataset has been divided over several projects. The files of the individual reconstructions are subsequently connected through the blender link function within the executive project.

For the graphic rendering, we combined photographic textures of the excavation with other open source assets (models and textures) downloaded from the main 3D sharing websites.

In this first phase, the 3D modeling exclusively concerns the architecture, but subsequent stages of the project also include the interior design of the houses, churches, artisan shops, the medieval population of *Podium Bonizi*, and artifacts.⁷

⁵ In the export properties of Agisoft Metashape, we use a local coordinates system, a jpeg export texture, and a precision value of 100. The model has 200 thousand faces (data from the Agisoft report).

⁶ For an overview on Inklink, see <https://www.inklink.it/>, Bartolini, Tronti, and Valenti (2005, pp. 56–61).

⁷ For the workflow that will be used, see Neamțu, Comes, and Popescu (2016).

Figure 5: Photogrammetric survey of the archaeological area.

At the end of the first phase of the reconstruction of a city neighbourhood, the renderings will be made by simulating a 360° photograph, with the same shooting characteristics of an Insta360 One X⁸ (Figures 7 and 8).

Subsequently, the panoramic renderings will be transferred to a virtual tour software (which specifically is 3dVista). The final result will be a “historical” journey of the neighborhood, in which the user can freely move between the medieval buildings.

The intention is to create a virtual space similar (albeit with different software tools) to the one proposed for Çatalhöyük (Forte, 2014).

The operation of the virtual tour is not really a new technology: QTVR (QuickTime Virtual Reality) technology was invented over 20 years ago (Forte & Beltrami, 2000). It was a 360° panorama that came from the result of a sum of many images taken and stitched together, which could be viewed using the Quick Time software. The 360° panorama could then be connected to others, creating a sort of virtual path.

Even if this technology had not advanced greatly in the following years, the original idea has been revisited many times, in some cases with great success. A common example is the global mapping available

⁸ Exporting with the same characteristics of the Insta360 One X allows one to obtain spherical images and to overlap produces renders with pictures taken with the same 360° camera.

Figure 6: 3D rendering of a neighborhood of *Podium Bonizi* in Blender.

through Google Street View, which offers an exceptional web interaction between Google maps and 360° panoramic photos. In subsequent years, Facebook itself introduced the possibility of uploading spherical photographs.

It was precisely the introduction of these technologies in the world wide web. While the technique was a good starting point it did not succeed in having a wide diffusion and “mass” application.

In fact, still in 2004, during the design phases of any web content, it was necessary to think about the relationship between the quality and weight of a page, to prevent slowing down the connection too much (Francovich & Isabella, 2004).

In Italy, there have been numerous VR applications.⁹ As in many other parts of the world, the multiplication of VR techniques testifies to the usefulness and success of these tools.

⁹ Select example are the projects at the Scrovegni Chapel of Padua (Borra, Forte, Pietroni, & Rufa, 2002), the Villa di Livia (Forte, 2008), Nora (Bonetto & Zara, 2017, 2018), and at the Museo delle Origini (De Luca, Conati Barbaro, La Marca, Savino, & Rosati, 2019).

Figure 7: 360° photograph realized with Insta360 One X.

Figure 8: 3D rendering of a neighborhood of *Podium Bonizi* in Blender at the same position as in Figure 7.

But in recent years, the greatest contribution to VR in cultural heritage has been offered by Google with the Arts & Culture project (<https://artsandculture.google.com>).¹⁰

5 Discussion and Preliminary Results

In the period between 2015 and 2019, the archaeological park of Poggibonsi has had a steady growth in tourism. It is now necessary to integrate what is currently available to tourists with new digital solutions in order to allow Poggibonsi to compete with the main cultural sites of Tuscany.

¹⁰ It is necessary to underline that the Google Arts & Culture is a commercial project with issues related to proprietary and copyright aspects. See also Kizhner et al. (2020).

Figure 9: Virtual tour of the open-air museum of Poggibonsi.

The archaeological park of Poggibonsi is one of the most important sites in Tuscany for understanding the transformation of the early medieval rural landscape. Communicating this to the public and enhancing public engagement is an important way to develop the cultural heritage and scientific results of archaeological excavations.

During the Italian lockdown period in response to the COVID-19 pandemic emergency, a first virtual tour of the hill was created that was already available online via PC, tablet, smartphone, and a VR headset.

By clicking on a link (<https://archeodromopoggibonsi.it/VR/Archeodromo/index.htm>) anyone can take a tour of the open-air museum. Therefore, it is possible to move both inside and outside the ninth-century huts, and to obtain information on the structures (from archaeological excavations and the reconstructions). In some cases, visitors can view 360° videos with the re-enactors who work and carry out (historically accurate) daily activities inside the homes (Figure 9).

Figure 10: 360° render of *Podium Bonizi*.

Figure 11: San Galgano project: 3D rendering and VR.

A second version of the virtual tour was released in April 2021; this is a journey inside Poggio Bonizio in 3D graphics (https://archeodromopoggibonsi.it/VR/Poggio_Bonizio/index.htm; Figure 10). The 3D reconstructions are processed from the excavation data, while as regards the information coming from the cropmarks (Valenti, 1993), it was chosen to represent the volume in glass.

Parallel to the project in Poggibonsi, the Department of Historical Sciences and Cultural Heritage of the University of Siena is proceeding with the realization of a virtual tour of the abbey of San Galgano (Chiusdino, Siena). Here, archaeological investigations proceed in tandem with 3D graphic reconstruction (Figure 11).

The goal of the San Galgano project, as was anticipated in the introduction, is mainly to use VR to reconstruct what cannot be physically reconstructed. At the same time, it achieves the social and “democratization” aspects of cultural heritage. Moreover, the online publication of “historical journeys” is a way to break down national borders, distances, as well as linguistic, economic, social, and political barriers.

Ultimately, a virtual museum (Signore, 2007) is also a way to virtually break down architectural barriers that cannot be eliminated in archaeological contexts. In this regard, it is important to note that protection precedes the concept of valorization in Italian jurisprudence. The third article of the Italian Legal Code of Cultural Heritage and Landscape describes the concept of protection, stating that the ultimate goal of cultural heritage is public enjoyment; this therefore implies an inseparable link between the two key concepts.

At the same time, however, Italian law establishes a real order of priority between the protection and development of cultural heritage. Following the duty of protection and the guaranteed safety of people and things, the mission is to make cultural heritage accessible (Ministerial Decree, May 10, 2001).

Virtual museums also help to overcome cognitive barriers, especially for people with autism spectrum disorders, allowing them to visit the museum directly from home and learn about the environment of the open-air museum and the archaeological park.

6 Future Research

The virtual reconstruction of *Podium Bonizi* mixes photogrammetry and 3D computer graphics. It has been tested on eight houses, two churches (S. Agostino and S. Agnese), the water well, the square in front of the church of S. Agostino, and the Via Francigena. Additional 3D models need to be constructed in order to

refine the framework, workflow, and graphical details as well as to test the hardware and software stresses of working with very large data sets (e.g. multiple houses, palaces, urban walls, trees, tools, people).

At the same time, the project includes the launch of a VR webapp using spherical rendering and 3dVista software to configure and manage the tour.

The last step will be experimentation with the Unity Real-Time Development Platform, not only to develop a user interface for exploring the 3D topographic map (Laksono & Aditya, 2019), but to build an interactive videogame for children. For this goal to be possible it is necessary to compose story lines that walk users through a historically accurate adventure.

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