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Article

# Augmented Reality Methodology for Virtual Georeferenced Reconstruction

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**Abstract:** This paper proposes new methodologies for virtual reconstruction and comprehensive treatment of the resulting historical landscapes: (1) The introduction begins by considering relationship that already exists between heritage, virtual reconstruction and mixed reality; (2) The main aim of this research is to develop a digital methodological tool based on geo-referenced and augmented reality, which allow visualization, analyze and interpret the evolution in the conservation and restoration of cultural heritage; (3) Throughout the process of virtual reconstruction of a trench of the Spanish Civil War, difficulties have arisen that have allowed us to reflect on the effectiveness and usefulness of this type of process in the field of cultural and historical heritage; (4) The methodology and action presented have been designed to offer an innovative tool that can be integrated into previous and subsequent strategies to improve conservation and disseminate heritage.

**Keywords:** cultural heritage; virtual reconstruction; augmented reality; geo-referenced; digital methodologies; historical landscapes

## 1. Introduction

The introduction of information and communication technologies (ICT) has revived the dissemination of historical heritage. Today, it is difficult to imagine visiting to an archaeological site or visiting a museum without a digital tool that allows us to expand and complete the materials on display. Visualization techniques are increasingly better quality and more accessible to visitors, becoming a tourist attraction (Tzanelli, 2013). However, in rare cases these techniques have their application in the field of research or heritage preservation.

Virtual heritage is currently an important asset whose accessibility allows not only to attract visitors, but also to contribute to generating a cultural exchange beyond space and time (Din & Wu, 2014). It is becoming more and more important that virtual reconstructions comply with standards that allow their interoperability by tourists, researchers or entities dedicated to their protection and dissemination (Gavalas, 2020). In practice, this means sharing methodologies for both creation and use.

To carry out this process: First, a scientific basis must be ensured in the archaeological intervention (Rodriguez, 2018). The study must include both field work and proper prior documentation, considering the nature of the materials, their physical location, and their historical origin. Second, it is necessary to contextualize any virtual reconstruction as best as possible. To do this, the physical place in which the intervention is to be proposed must be analyzed, if possible georeferenced any rest from which it starts and try to reproduce the landscape including plants, animals or cultural evidence. Third, the virtual reconstruction itself would be carried out using photogrammetry, 3D modeling or photomontage techniques, depending on the evidence recorded and the capacity for recreation.

Once this virtual reconstruction is completed, different visualization techniques can be used using still images, videos, or 3D objects (Grimshaw, 2014). But all of them require a screen that decontextualizes the reconstructed object from its environment. Therefore, augmented reality technology has proven to be particularly effective in allowing virtual reconstruction to be viewed in its own physical context (Shumaker & Lackey, 2014). This fact adds a special value to virtual heritage, since it makes it not only a tool for dissemination, but also for the preservation of the environment; valuing both the remains present in the site and the landscape that has probably been preserved from the beginning.

When virtual elements are superimposed onto a direct or indirect view of the real world, allowing for the simultaneous visualization of the real environment enriched with virtual data, this is referred to as Augmented Reality (AR). Azuma (1997) adds that this process must occur in real-time. For its operation, in addition to the visualization hardware, a program is required to merge reality with virtual data (Russo, 2021).

Augmented Reality has come a long way to achieve a preferred position in visualization systems known as mixed reality (Milgram & Kishino, 1994). Although in its beginnings this technology required exclusive computers, today these contents can be viewed through any smartphone or tablet (Noh et al., 2009). The imminent appearance of mixed reality glasses and other portable devices with increasing connectivity and processing capacity, suggest that this technology will be more integrated into our daily lives (Dragoni et al., 2019). It is reasonable to consider that, in the future, material and virtual heritage will be part of the same reality that anyone will be able to visualize through time and space (Huggett, 2020). Therefore, it is necessary to collect a series of common practices and propose a joint methodology that facilitates not only the virtual reconstruction of heritage, but also its conservation and accessibility through open display systems with certain information requirements. Only in this way can we ensure the sustainability of virtual heritage and its integration into the possibilities that mixed reality will offer us in the future. Augmented reality in the field of architectural heritage has been predominantly applied to interiors, buildings (Teruggi, 2022a, 2022b), or spaces of similar dimensions (Vilar, 2024). In the context of war heritage, Rodríguez-Gonzálvez et al. (2015) applies augmented reality to underground fortifications of World War II. However, these technologies have significant utility in large open spaces and can even be applied over extensive territorial areas through the creation of Territorial Digital Twins (Bermudez et al., 2023). One of the novel aspects of this research is its area of application: the combination of these visualization advances over a historical space that has not been previously explored—war trenches. These are fortified, semi-buried exterior spaces, which endow them with unique characteristics in comparison to conventional methods of work and georeferencing.

## 2. Methods and Materials

Georeferencing, in its broadest sense, involves determining the absolute location of a dataset (Lippitt, 2020). The scope of georeferencing includes both its informal meaning—related to toponyms commonly used to describe places—and its formal sense, based on latitude and longitude or any other reference system employed in cartography or navigation (Hill, 2006). Assigning a dataset to a global and recognized coordinate system enables the integration of these data with others, either within the same reference system or with another for which a coordinate transformation model is known. This allows for real-time transformations between different coordinate systems. This process is evident when working with spatial information that is georeferenced and positioning data obtained via GNSS, as occurs in augmented reality systems. Positioning is achieved through satellite methods, typically within global coordinate systems such as WGS84, while spatial information may be georeferenced using a different coordinate system, such as ETRS89-UTMH30 in our case.

This project proposes new methodologies for virtual reconstruction and comprehensive treatment of the resulting historical landscapes (Labrador et al., 2018). To do this, we propose combining historical research using traditional methods (Castaño et al., 2018) with the innovative use of new technologies through georeferenced augmented reality (de la Fuente et al., 2017). The project is organized around three approaches:

1. Analysis of the spatial configuration of heritage spaces to identify the landmarks, edges and main axes of their plot following established methods.
2. Critical description of historical buildings, analyzing the singular remains of certain environments, taking into account the dynamics of transformation of the landscape and the conflicts generated by the overlapping and collision of uses in the space.
3. Interpretation of the perceptual units based on the performance of 3D models on which the data obtained with historical research will be applied through Augmented Reality, which will allow for the simulation and analysis by experts of the circumstances and problems to be faced for the improvement of heritage conservation.

The main aim of this research is to develop a digital methodological tool based on georeference and augmented reality, which allow to visualize, analyze and interpret the evolution in the conservation and restoration of cultural heritage (Figure 1). The application of mixed reality in these simulation studies on 3D models greatly facilitates the participation of the end user and the accessibility of decisions, which we understand is one of the added values of this research.

To accomplish this goal the following techniques and methodologies will be used:

- Creation of a 3D model of the space that allows the implementation of an augmented reality environment where virtual reconstructions are showed, that allow for the simulation of scenes. This system will favor the interaction with the possible scenarios, so that promotes expert discussion that can be implemented faster. Also placing value on the historical and cultural heritage, and their relationship with the environment and landscape.
- Establish a data storage based on archives and open-environment applications, and in the future with the implementation of sensors and devices that allow us to know in real time environmental and structural parameters on the conservation of materials.
- Generation of documentation in 2D and 3D plans of cartography and planimetry that analyzes the process of configuration, development and consolidation of these places in their historical development up to the present, which allows the analysis and simulation of future interventions.
- Elaboration of visiting itineraries at various levels, accessible for the transmission of artistic, cultural and landscape heritage and to value this heritage using new technologies.

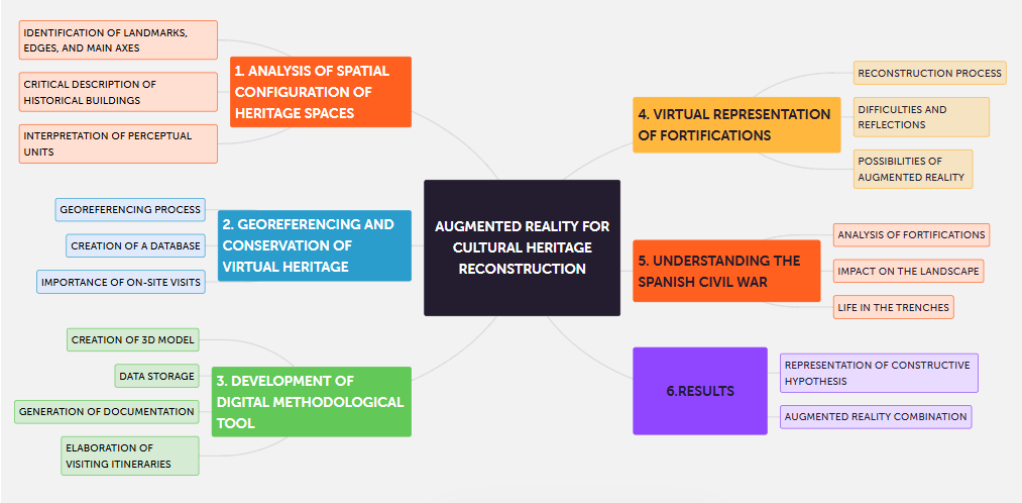


***Figure 1.*** summary of the research process and the main actions taken.

As an example, a case study is approached, such as the *Casas Altas* in Morata de Tajuña (Madrid, Spain) that can be transferred to any other context and confronted with methodologies or actions of national and international scope to verify and formulate hypotheses at the same time.

The *Casas Altas* site corresponds to a Republican fort built during the Battle of Jarama, one of the most tragic episodes of the Spanish Civil War. The fight took place between the mountains and agricultural fields located between the Jarama River and the Tajuña River, southeast of Madrid, in February 1937. The cold and rainy weather that was registered and the conditions of the terrain made the battle one of the tougher battles of the Spanish Civil War with high casualties on both sides.

Today we can know a large part of the facts due to the description of great international authors, since it aroused great interest in other parts of the world due to the high number of International Brigadiers who joined the army of the Spanish Republic. One of these authors was Ernest Hemingway, who through his articles as a correspondent for NANA (North American Newspaper Alliance) today we can learn about the lives of the protagonists of the war and understand how to build and inhabit the trenches.

However, a good part of the vestiges of the conflict are completely destroyed or in danger of disappearing. Despite the abundant historical studies on this conflict (Cobo, 2008; Hughes, 2011) interventions to recover and protect this historical heritage are scarce. Therefore, the application of this methodology to this deposit is more than justified.

The virtual reconstruction process of the *Casas Altas* defensive post began with the preliminary study of the area and the study of different construction manuals for military fortifications on the battlefield. During the Spanish Civil War, many books were published that showed different ways of erecting and building shelters and military posts in the front that could serve as a guide for the commanders and

soldiers who were in the different conflicts spread throughout the Spanish geography.

In these manuals (Capdevila, 1939) there are planimetries represented in plan and section that show basic notions of construction (Figure 2), use of the different materials, approximate dimensions of the defensive elements and the pieces of armament and guidelines for the implementation of these elements in the landscape.

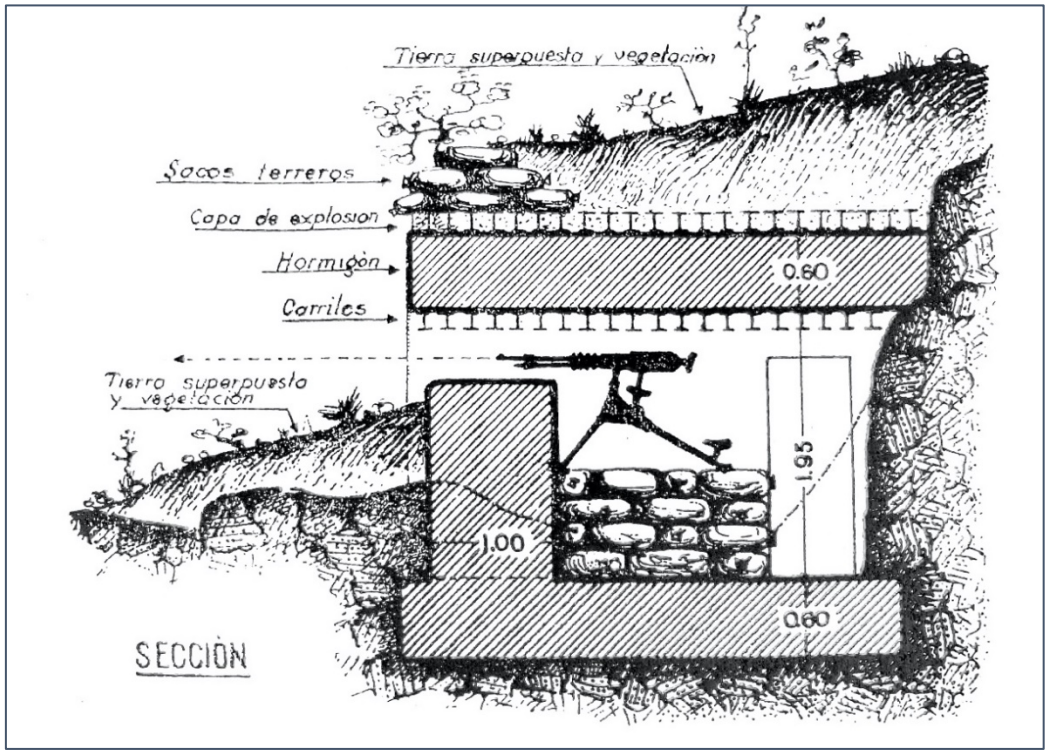


***Figure 2.*** Machine gun nest according to The Campaign Fortification manual. Author: Juan Capdevila.

The field fortification manuals can offer us a first visualization of what the remains that we find in the defensive point of *Casas Altas* could be like, but due to the conditions of the context in which the elements were built, these could vary significantly with the plans edited during the Civil War. This context of war, in which each front had to adapt to the available materials, the capabilities of the soldiers and mainly to the typology of the terrain and orography of the landscape, forces us to take these factors into account and study the environment of the military enclave. For these reasons, other defensive remains from the Civil War that are still preserved in the municipality of Morata de Tajuña were investigated. Among them, a machine gun nest (Figure 3) located at the foot of the M-302 road that connects Morata de Tajuña with Perales de Tajuña and was part of a defensive line further from the front than the *Casas Altas* post.

After the analysis of the documentation and of the fortifications located in the immediate environment, the process of reconstruction of the landscape and the way of digitizing it began. For this, the process was divided into three phases: analysis of the terrain and topography, representation of the current state of the *Casas Altas* enclave and representation of the possible morphology of military constructions.

Regarding the first phase, different works were carried out. On the one hand, the first data collection and analysis of the terrain through photographs of the environment and identification of the different elements and levels of the defensive complex. For this, the study relied on a previous topographic survey (Figure 4) to set the heights of the different levels and to know the distances and size of the elements and their intersection with the terrain using AutoCad software. With the vectorized plans obtained, it was possible to fix the contour lines of the complex and the exact location of each defensive element of *Casas Altas*.

After this analysis, a drone flight was carried out (Figure 5) that allowed obtaining aerial photographs of the complex to better understand the relationship with the environment and the insertion in the landscape of the construction elements. From the set of photographs obtained from the drone flight, a 3D digital survey of the entire study area was obtained, both of the terrain and of the remains of the existing defensive elements.

***Figure 3.*** Photograph of a machine gun nest in its current state in the municipality of Morata de Tajuña. Author: Diego Martín.

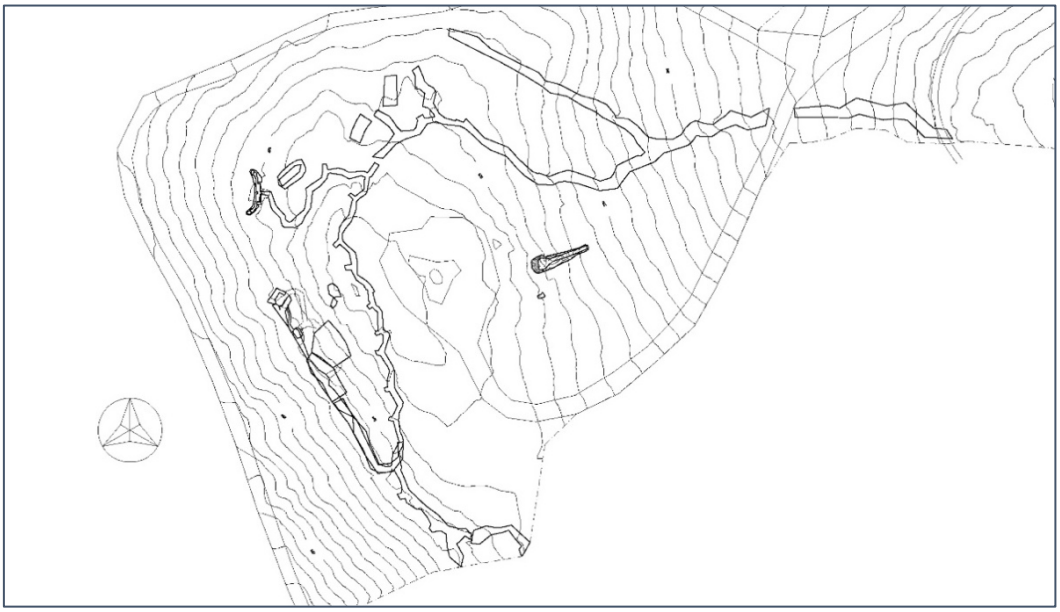

***Figure 4.*** Topographic survey to measure and adjust the heights and defensive elements of *Casas Altas* obtained through AutoCad. Author: Enrique Parra Albarracín.

***Figure 5.*** Aerial photograph of the Casas Altas military post obtained by drone flight. Author: Miguel Fernández.

The drone photographs, georeferenced and with altimetric data, allowed us to know the depth of the defensive elements that were not accessible and that we could not know with the first topographic survey. With the virtual model of the terrain (Figure 6) we were able to know the depth of the trenches dug in zigzag in the rock and of the shelters of great depth with respect to the upper level of the terrain with the 3Dreshaper software and the Adobe Acrobat 3D viewer . With these applications we can navigate through the virtual model and generate sections of terrain to know the relationships of the different defensive elements.

At the *Casas Altas* site there are two types of elements, the defenses that are at ground level and the system of shelters and tunnels that connect them. With the systems for generating topographic plans and 3D models, we can reconstruct the terrain and the remains of defensive elements on the surface, but the covered connection tunnels are obtained through on-site measurement and photographic visualizations.

In the second phase of current representation of the enclave, two different methods were used. The first was the insertion of the 3D model obtained in the Google Earth georeferenced software. In this way, an updated aerial image (Figure 7) of the set of defensive remains was obtained and its visualization in the surroundings of Morata de Tajuña at a higher resolution. This integration also allows anyone to have access to this virtual reconstruction, always maintaining its original context.

***Figure 6.*** Image of the 3D model obtained through aerial photographs. Author: Diego Martín.


***Figure 7.*** Inserting the 3D virtual model in Google Earth.

The next method used was the reconstruction of different sections of the terrain that descriptively showed the levels of trenches and defensive elements in augmented reality. For this, we rely on the set of measurements made in the first phase of the study through georeferenced. The combination of the recognition of the elements in situ, the topographic survey of the terrain and the virtual model in three dimensions of the terrain allowed the definition of the military post.

In the elaboration of the sections, the AutoCad software was used to represent the terrain and the military constructions, since through the vectorized topographic survey it was possible to adjust the heights and measurements of the existing remains.

## 3. Results

Once the terrain sections were obtained, an augmented reality combination was made by means of the Vuforia AR software of these sections in line with the sections extracted from the 3D model in which the terrain textures can be visualized (Figure 8 and Figure 9), adding depth to the representation and reflecting the chromaticism of the terrain and the materials used.

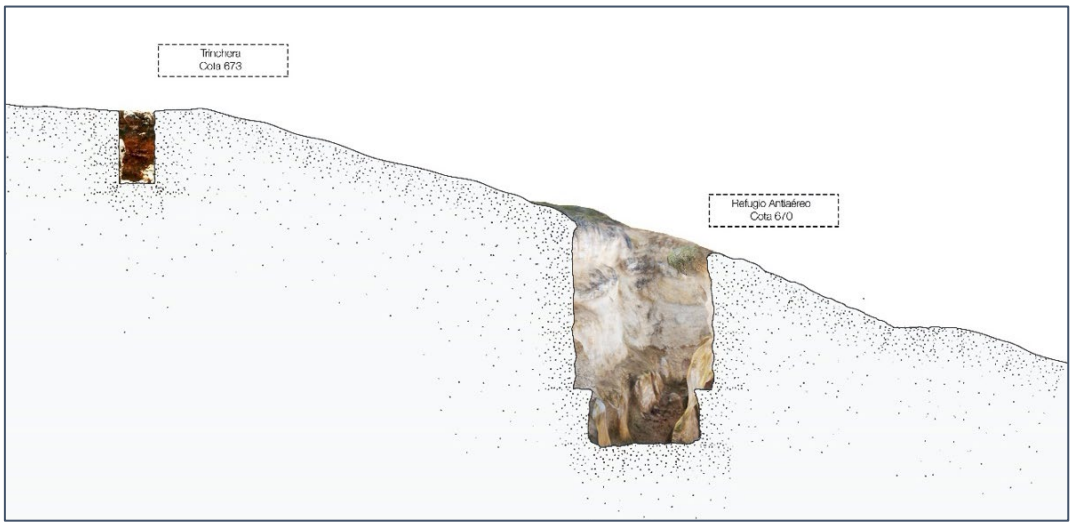


***Figure 8.*** Section of terrain by refuge combined with images of the 3D model showing the different levels of the set. Author: Diego Martín.

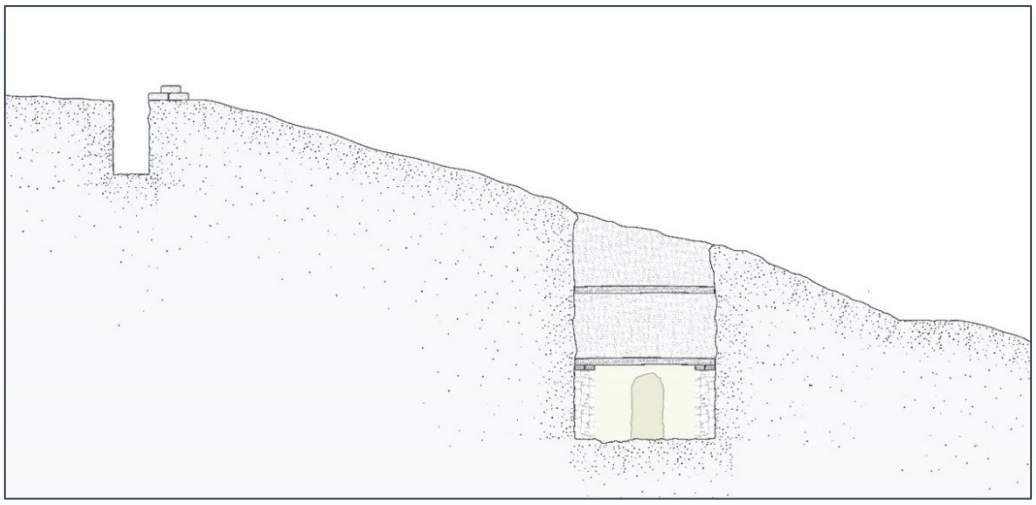

***Figure 9.*** Terrain section per machine gun nest combined with images of the 3D model showing the different levels of the set. Author: Diego Martín.

The final phase of the study consisted of the representation of the constructive hypothesis of the defensive elements (Figure 10 and Figure 11) based on the georeferenced terrain sections made in the second phase. As we have mentioned, it is not possible to recompose military constructions based on the fortification manuals published during the Spanish Civil War since we must consider the data of the context and the situations of the area.

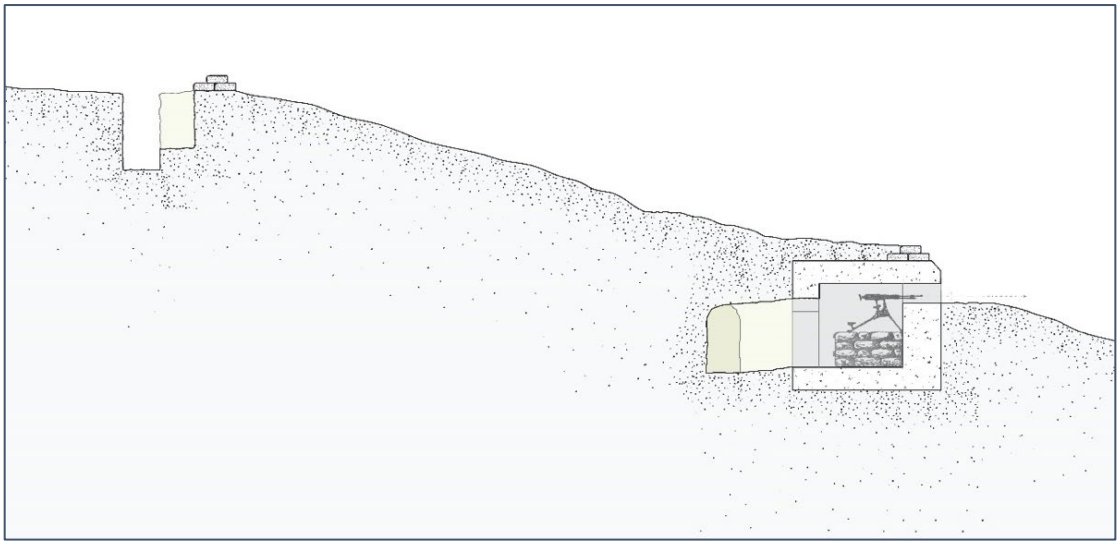

***Figure 10.*** Hypothesis of the construction of the machine gun nest and trenches according to the study of the fortification manuals and the defensive elements of the area. Author: Diego Martín.

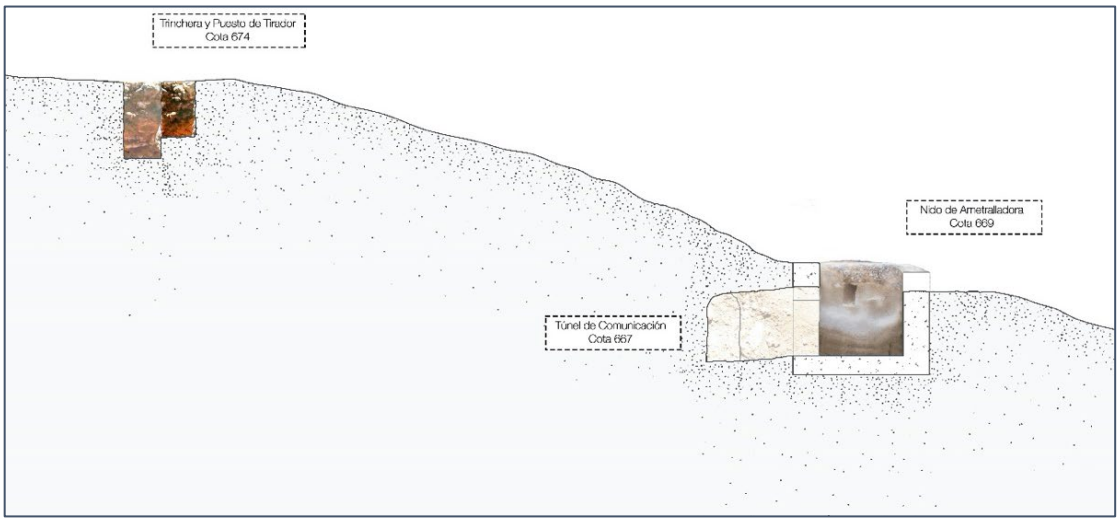


***Figure 11.*** Hypothesis of the construction of shelter and trenches according to the study of the fortification manuals and the defensive elements of the area. Author: Diego Martín.

The main evidence that exists is the dimensions of the elements, obtained both in the topographic survey and in the 3D modeling from the drone flight. We also have evidence that the constructions had been completed, since in the immediate surroundings of the elements, and within them in some cases, we find remains of the fortification roofs. The use of augmented reality makes it possible to compare the elements scattered around the site with the possible constructive use they originally had. In this way, the possibility of discussing its location by the specialist is enabled and generating awareness about its conservation in the case of the visitor.

The result is a virtual representation of the original state of the elements based on the dimensions of their remains, their implantation in the field and the analysis of documentation; as well as other evidence of the environment that may be related, either morphological or of use, with the remains of *Casas Altas*.

## 4. Discussion

Throughout the process of virtual reconstruction of this set of fortifications, difficulties have arisen that have allowed us to reflect on the usefulness of this methodology not only in the field of cultural and historical dissemination, but also in research and heritage protection.

In general, the lack of information that exists on the constructions of the Spanish Civil War or the elimination of many of them after the war, has meant that, in many cases, the only possible intervention

is the inventory of dispersed remains (Ruiz, 2017), the generation of a didactic iconography (Hernàndez-Cardona, 2019) or the virtual reconstruction of isolated remains out of context (López-Tercero et al., 2018).

However, through this methodology we have first demonstrated the possibilities that augmented reality has as a tool to visualize a virtual reconstruction on a real scale (Grimshaw, M. 2014). Which undoubtedly offers an exceptional experience for both the researcher and the visitor, as they can compare the virtual reconstruction with the archaeological remains. In this way, the generation of new hypotheses by researchers is facilitated, but also the awareness of visitors about the correlation between virtual and material heritage.

But we have also achieved that this virtual heritage can be georeferenced and therefore inextricably associated with the landscape in which it was originally located. This work can facilitate the management of virtual heritage conservation but also make it more accessible to researchers and the public. The creation of a georeferenced database of virtual heritage as a metaverse (Capdevila, 1939) would serve to enhance both the disclosure and the conservation and research of these sites.

It is important to remember that virtualization processes should serve to add value and in no case should they replace on-site visits to historic sites, since they show aspects and sensations that are not preserved in digital reconstructions.

In our particular case, the use of this methodology has allowed us not only to analyze the construction of the defensive elements during the Spanish Civil War, but also to understand the modification of the landscape due to the war conflicts and the harshness of the life of the people inside the trenches during the fight.

## 5. Conclusions

The methodology and action presented have been designed to offer an innovative tool that can be integrated into previous and subsequent strategies to improve conservation and disseminate heritage.:

- The technology developed will allow a better planning of excavations and is expected to be transferable to similar deposits of important heritage value.
- The designed system will encourage citizen participation, as it will be a simple tool to bring decision-making closer to stakeholders.
- The content will also serve to redefine the most sustainable tourist itineraries with intensive use, which value the transmission of the artistic, cultural and landscape heritage of these enclaves.
- Graphics and 3D models generated materials, may be used for use as marketing tools and outreach. These contents can be transferred to third parties in addition to sightseeing or cultural use..

In short, this project represents a precedent in the use of georeferenced augmented reality as a planning tool beyond other experiences of dissemination of heritage already carried out.

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