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AUGMENTED REALITY RECONSTRUCTION OF DETERIORATED ART

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ABSTRACT

ARRDA (Augmented Reality Reconstruction of Deteriorated Art) is a mobile app that leverages AR to revitalize the rural cultural heritage. The pilot, deployed for the Romanesque San Miguel church in Soria/Spain, allows the user to visualize the digital reconstructions of centuries-old, faded graffiti. Developed with Unity and ARFoundation, it enhances the visitor experience and gathers data related to the behavior and number of users. ARRDA seeks to preserve the cultural heritage and revitalize areas affected by the "España Vaciada" demographic challenge, fostering a cultural and emotional connection with forgotten cultural environments and our past.

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1. Introduction

Augmented reality (AR) has gained an unprecedented popularity over the last decade as a technology with a very high potential to transform the way in which people interact with their environment. AR came to the public with the massive success of the Pokemon Go mobile game, which allowed players to interact and see their Pokemons integrated in the environment. Its capacity to overlay digital information over the physical world opens new possibilities in fields like education, tourism, medicine or cultural heritage. In this context, this project appears with a clear goal: use augmented reality to highlight the value of the deteriorated cultural heritage and, as a result, contribute to the revitalization of rural communities in risk of depopulation.

1.1. Project Context

Spain is facing now one of the biggest demographic challenges in modern era, this challenge is popularly known as the *España Vaciada*. This expression has recently gained prominence to describe the persistent depopulation affecting Spain's interior regions, (Pazos-Vidal, 2022). This phenomenon is characterized by an increasingly aging population, disappearance of basic services and the neglect of the cultural heritage in a substantial percentage of the interior of Spain.

As a result, there is an increasing divide between major urban areas, constantly expanding and saturated and the small rural communities, that cannot help but watch as their economic and social fabric deteriorates over time. One of the most visible consequences and often one of the most neglected is the decay of the rural cultural heritage. In many towns and villages, the art, architecture and traditions that have defined the identity of Spain for centuries are at risk of disappearing. The toll of time, lack of resources devoted to preservation and the lack of technological means for its promotion have resulted in most of this heritage to be forgotten and deteriorated. Without a proper intervention, the knowledge of this legacy is at risk of being lost for future generations as well as the communities that safeguard it.

With this reality on sight, it becomes increasingly urgent to understand what are the means and techniques that can be used to preserve and leverage the cultural heritage of these communities in the 21st century. Beyond the aesthetic and historical value, this heritage can be turned into a strategic asset in regards of tourism. Cultural heritage can work as a powerful tourism magnet when it is properly presented and made easily accessible to visitors, turning these assets in an invaluable resource to help with the demographic challenge and the revitalization of these rural areas. Such strategies have been explored academically like in the case of Tàrbena, where village heritage was transformed into a cultural-tourism asset to address rural depopulation (Signes-Pont et al., 2022). The integration of new technologies, such as augmented reality, allows not only to protect these assets without a physical intervention on them, but also to reinterpret them, to make them accessible to new kinds of visitors and exploit their value as a local development tool. The opportunity lies in turning oversight into experience and neglect into a meaningful connection with the past.

1.2. San Esteban de Gormaz and San Miguel church

San Esteban de Gormaz (SedG) is a town located in the province of Soria, one of the most affected by the demographic challenge of the interior of Spain. With a population of a little over 3000 people, this town has had a key role in Spain's history. The focus of this work is on the church of San Miguel and the secrets that it holds within its walls. This temple was built between 1060 and 1081, making it the first Porticoed Romanesque church ever built (Arribas, 2024).

Figure 1 shows the church as of today. It remains as a standard-bearing of Christendom and the Spanish Reconquista. In addition to this, and as mentioned before, the portico is one of the most relevant elements in the church. Its importance lies in the fact that this type of gallery appears to date back to the Spanish Romanesque period, first appearing in the churches of San Esteban de Gormaz, and is evidence of the influence of Eastern art on the Peninsula. For some authors such as Gaya Nuño (Pantoja, 2012), porticoed galleries in the Romanesque period first arrived through the peaceful coexistence between Christians and Umayyads in Syria during the Islamic invasion of the latter and with the subsequent settlement of the Umayyads in Spain. Soria was an area with a strong Umayyad presence and, later, a Mudejar presence after the Reconquista. This portico served as a meeting point for all the villages under the proximity of San Esteban de Gormaz, who was the county seat (*Cabeza de comarca*). These meetings were performed weekly and had a representative of each village reach an agreement on how to manage resources correctly.

The church is surrounded by corbels (*canecillos)*, which are essentially the early predecessors of what nowadays is now known as gargoyles. In Figure 2, there is a particular corbel holding an open book which reads: "*IVLIANUS MAGISTER FECIT ERA MCXVIIII*", which in English means: "Master Julianus made me in the era 1119" and the era 1119 is the year 1081 of our calendar. This provides irrefutable evidence that this was the first porticoed romanesque church in history.

Figure 1. San Miguel church

Source: Iglesia de San Miguel, 2016.

Figure 2. Julianus's corbel

Source: Iglesia de San Miguel, 2016.

The San Miguel church has undergone several interventions throughout its history, some of them were not successful and resulted in a partial loss of the murals and graffiti. However, between 2007 and 2012, in-depth research on San Miguel was performed by the *Soria Románica* initiative. This research revealed exceptional discoveries underneath the layers of dust and dirt on the walls. Several graffiti were found, which were dated between the XI and XIII centuries. These varied sketches depict different figures such as soldiers, latin inscriptions and a once-unknown perimeter tribune.

These graffiti are shown in detail later in the document, but the north wall of the church can be seen in Figure 3, showing most of the graffiti highlighted in white. San Miguel's walls contain several hundreds of different medieval graffiti and markings. Some of those graffiti are visible with the bare eye, however, a substantial majority of these markings cannot be appreciated by visitors, therefore a cultural connection between the visitor and the cultural heritage remains impossible.

Figure 3. San Miguel's north wall.

Source: Sadia, J.M. (2019)

1.3. Goals and Scope

The main objective of the present work is the design and development of a technological solution that addresses the preservation and innovative communication of the deteriorated mural heritage of the San Miguel church through an immersive experience using AR. The proposed approach is providing a mobile app that leverages on the use of AR to superimpose the digital reconstructions of the medieval graffiti directly over the original walls, allowing the visitor to discover the sketches and markings that are not visible to the unaided eye. Similar approaches have been used to visualize graffiti through AR in heritage environments such as Temple of Debod (Gutierrez et al., 2015). This can help to improve display richness, to provide more vivid information and also enhances the heritage experience (Wang & Zhu, 2022). This proposal does not only seek to enrich the cultural experience but also to provides a tool for the local authorities to manage and analyze the behavior of the visitors, thus facilitating informed decision-making regarding tourism, conservation and development.

This project adopts a dual approach. On the one hand, it is conceived as a cultural intervention with social impact by making visible and revalorizing endangered heritage, on the other hand, it is a technological innovation endeavor that explores the possibilities of AR in rural environments with challenging technical and logistic conditions. On a functional level, the application allows for the scanning of specific areas in the temple, the visualization of the digital reconstruction and the interaction with them by the user, as well as the gathering of usage metrics such as number of users, average time per session, ratio of completed scans, etc.

The scope of this work entails the development of the mentioned application as well as the coordination of the different stakeholders that have been crucial for the development of ARRDA such as the authorities of SEdG and the researchers of *Soria Románica*. The app also provides a modular and scalable architecture ensuring its applicability to other different cultural heritage environments. Ultimately, this work aspires to be a demonstrative model of how technology can serve the rural areas of Spain and other countries in similar conditions, generating cultural, social and economic value in a demographic challenging context.

2. Previous Research and State of the Art

The use of technological alternatives for art reconstruction in cultural heritage has been on the rise for the last few years. This is due to several reasons such as the improvement of XR (Extended Reality) which involves VR or AR, and the recent advancements in generative AI. Recent studies have identified a trend in the application of AR in cultural heritage, including reconstruction, education and tourism as presented by (Boboc et al., 2022).

2.1. AR as cultural revitalization tool

This work focuses on AR and how to leverage it for the demographic challenge in Spain, as it has emerged as one of the key technologies in the context of artistic heritage dissemination and the reactivation and dynamization of cultural spaces. Its ability to superimpose layers of digital information such as reconstructions, narratives or pieces of information over physical spaces allow for the reinterpretation and interaction with the cultural and artistic heritage without altering the physical artistic assets. In the case of rural heritage, where several artistic manifestations remain forgotten or abandoned, AR provides an effective method for giving back the visibility and meaning to these environments and generating at the same time new ways of connecting and interacting with the heritage.

Different studies have proven that the use of AR can significantly increase the level of visitor engagement, retention and comprehension, particularly in historical environments. For instance, (Bekele et al., 2018) highlight how AR can improve the interpretation of the heritage when offering visualization in real time that engages the user and allows for real time experimentation. Similarly, (tom Dieck & Jung, 2017) examine their application in the context of heritage tourism and conclude that AR does not only improve the level of immersion and enjoyment of the user, but it also contributes to fostering greater visitor loyalty and broader promotion of the visited location.

In the context of the *España Vaciada*, where most of the cultural assets lack the necessary resources for restoration, preservation or digitalization, AR emerges as a sustainable and scalable alternative. Its deployment does not rely on physical infrastructures, nor does it alter or degrade cultural assets, fostering innovation and preservation for future generations. At the same time, by offering immersive and interactive experiences, AR can generate a significant interest for these spaces, attracting new visitor profiles and contributing to the economic and social revitalization of these areas.

2.2. Similar works

The use of immersive technologies dedicated to the cultural heritage has created a growing number of works that seek to enhance the preservation, accessibility, or interpretation of the past of these different assets. A review of representative studies is presented below.

The work from (Tukhboeva, 2023) presents a digital reconstruction system for medieval cultural heritage, more specifically, for the Amir Timur palace in Uzbekistan. This system relies on the use of AR and VR to recreate the original structure of the palace, and its aim is to provide an enjoyable and interactive experience to the visitors. In this case, the work is widely based on 3D reconstruction of the temple, providing a fully recreated model of the original palace. Although the aim of this work is the same as the one in this document, the scopes widely differ.

The study from (Shih & Kung, 2024) presents a system that allows users to create, share and store virtual graffiti. This allows for creating a thriving graffiti culture without damaging infrastructure. It is also based on AR technology, and the graffiti can also be tridimensional. While

the goal of this work is different from the one presented in this document, it shares the same spirit of allowing people to see and understand the creativity of other people through their phones.

Digital twins (Ćosović & Maksimović, n.d.) are exact virtual representations of a real object; they hold the same information and parameters for further study. By using technologies such as HBIM (Heritage Building Information Modelling), IoT and data analysis it is possible to create a perfect replica of a cultural asset. This would be one of the most precise and effective ways to tackle our project, however, it may also mean that the application might not be as lightweight as the project may require, therefore tourists might consider it an inconvenience when visiting the church.

AR might not only be useful for end users such as visitors or tourists but can also be beneficial for professionals such as art restorers. This is precisely what ARTworks does (Brondi & Carrozzino, 2015). It allows restoration professionals to overlap crucial information such as UV images or X-rays over the piece of art to be restored. Although having a different goal than ARRDA, the foundation is very similar due to it having a "target image" and its respective information to be projected upon the target.

Narralive (Vrettakis et al., 2019) introduces the Narrative Storyboard Editor (NSE), a tool designed to facilitate the creation and investigation of mobile digital narratives in regards of the cultural heritage. This system empowers independent and multidisciplinary authors for generating immersive experiences focused on the historical value of the assets. AR is not quite integrated, although it is presented as a possible next step, however, this work is truly relevant for this proposal, as it holds the idea of storytelling at the core, facilitating the understanding of the heritage and making it more attractive for future visitors.

2.3. Differential Value Proposition

While some of these solutions bear resemblance to this study, the presented work provides a unique approach and value that no other offers. These are some of the most relevant features:

Local and rural approach: One of the main objectives of this project is to foster tourism and activity of all sorts in the *España Vaciada*. To achieve it, the solution must offer a better experience for current and future visitors. A modernized and interactive approach to make the idea of visiting and staying in villages such as this more attractive.

In-situ image targets: Visitors should not have to look for QR codes or similar solutions. In the current proposal, the aim is to provide a seamless experience so that only by pointing a mobile phone at the wall, the graffiti pop up, allowing visitors to locate them accurately in the walls of the church.

Cross-disciplinary approach: While developing an application like this, several disciplines must be involved. Firstly, technical development, which is based upon computer vision, mobile development and AR, however, there is a strong component of cultural heritage studies and digital humanities. The reason for this is the strong reliance on projects such as *Soria Románica* for an accurate reconstruction of the different graffiti and the collaboration of the culture ministry of San Esteban de Gormaz. Lastly, this app is aimed to be used as a support for the local guide, so it also involves the people at San Esteban de Gormaz's culture department.

Modularity and Scalability: The proposed solution has been created with ease of scaling in mind. The logic of the app does not need to be altered to use the application in other cultural heritage environments. The only elements that will have to be added are the new target images for detections and the overlays of the reconstructions that will be displayed over the target references.

3. Methodology and System Design

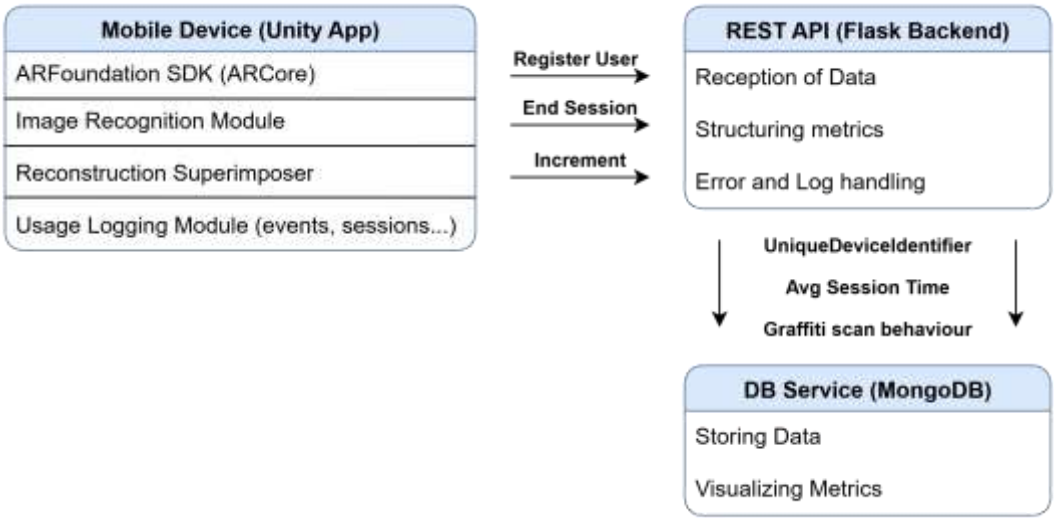
This section presents the discussion of the methodology and decisions that guided the development of ARRDA. This work uses an iterative approach, based on validation cycles and continuous improvement with a clear goal: create an accessible, non-invasive tool and contextualized within the cultural heritage of the *España Vaciada.*

3.1. Architecture Design

The ARRDA system is composed by a modular 3-tier architecture: A mobile app, which is the frontend, a light backend for managing the data and a database storing key metrics of the application. This structure allows for presenting a responsive and fluid experience to the end user, while also facilitating the maintenance and creating the possibility for future scalability for new cultural heritage environments.

The application itself is developed under Unity 6, leveraging the ARFoundation resources focused on the creation of AR multiplatform experiences through ARCore and ARKit. This tool was chosen due to the possibility of target image recognition in real time, physical space anchoring and real time rendering of 2D and 3D models. Unity's ARFoundation is a highly modular system that provides a common interface to platform-specific AR functionality for both ARCore (Android) and ARKit (iOS) and it is used in similar projects (Putro & Setyowati, 2022). ARRDA is designed to detect specific patches of the walls inside San Miguel and superimpose the associated digital reconstruction for that patch. The backend relies on a REST API, enabling the application to gather and manage the different data and metrics from the behavior of the visitors. This intermediate layer facilitates the separation between the frontend and the logic side of the application while maintaining a client-server architecture. Lastly, the data is stored in MongoDB, a modern database management system (DBMS) widely used for data-intensive project such as AI or machine learning. In this case, there are not substantial amounts of data for processing, but its JSON structure provides a particularly useful level of flexibility to the project and the data to be stored. Figure 4 shows a detailed overview of the application's architecture and modules.

Figure 4. System Architecture.



Source: Own elaboration, 2025.

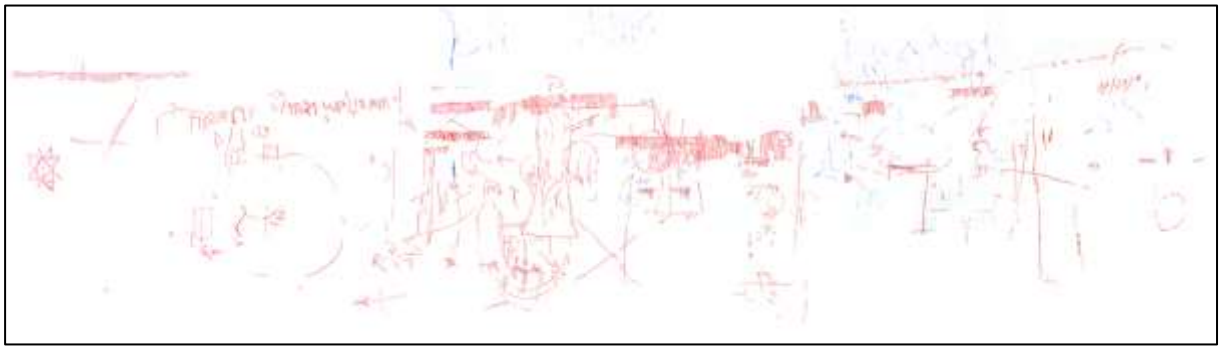
3.2. Cultural and Digital Resources

ARRDA relies heavily on the different resources that it needs to provide a meaningful and smooth experience for the visitors of San Miguel. The first type of resources is composed from the different graffiti clusters that will be superimposed over the walls of the temple. The second type gathers are the multiple target reference images that the prototype uses to detect when a user is looking at a particular cluster, and afterwards, superimpose the associated graffiti cluster to that section of the wall.

Two church walls were selected for the selection of the graffiti clusters included in the application, due to historical relevance and graffiti proximity: the north wall and the west wall (*Hastial),* obtaining the digital reconstruction of their graffiti. These reconstructions are presented in Figures 5 and 6.

Figure 5 shows the digital reconstruction of the different graffiti and markings present in the west wall of San Miguel. These figures are located between 4 to 5 meters above the ground and faded beyond recognition. The reconstruction reveals different information. Starting from left to right, two symbols that repeat all over the wall. The first one is a Star of David, and above it, a line of primitive markings can be appreciated. These markings were likely used for accounting purposes such as keeping track of different assets like cattle or agricultural goods. The most important element is a pointing monk located at the center, which is the most prominent figure in the west side of San Miguel. Going further right, the symbols mentioned before such as the accounting markings repeat along with some other unrecognizable markings.

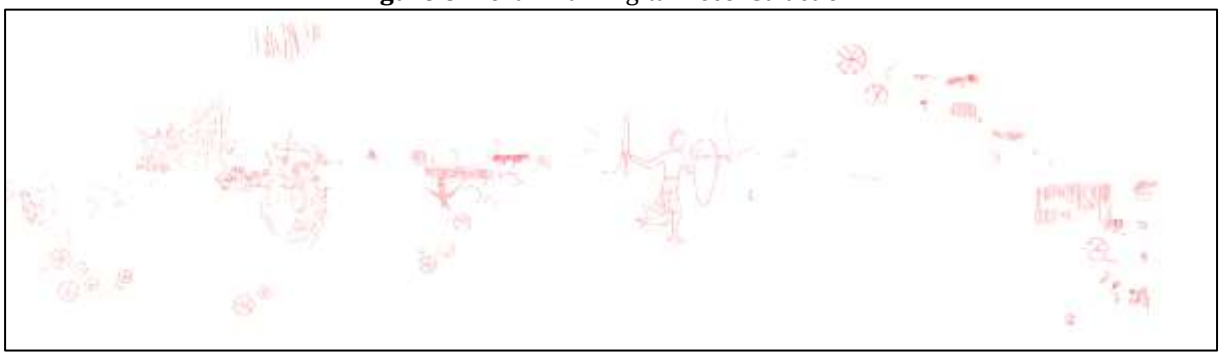
Figure 5. West Wall Digital Reconstruction.



Source: Virtual reconstructions of the West Wall of San Miguel by Soria Románica Initiative, 2009.

The second wall selected was the north wall, arguably the biggest and most graffiti-dense surface in the temple. Figure 6 presents the digital reconstruction of the graffiti in the north side of the church. This wall is much bigger than the west one and it bears two out of the three graffiti clusters selected for the prototype. In this case, there are some graffiti of same kind as the ones in the west wall, such as David Stars and markings to keep track of cattle or agricultural assets. Once again, the main elements are located at the center of the wall. The first one is a gothic inscription along with a figure with its arms wide open. The last one is the most relevant and the biggest figure in San Miguel, it resembles a soldier in a fighting stance, wielding a sword and a shield.

Figure 6. North Wall Digital Reconstruction.



Source: Virtual reconstructions of the North Wall of San Miguel by Soria Románica Initiative, 2009.

The second step was to gather as many materials and resources from the walls of San Miguel as possible. Figure 7 shows a portion of the resources taken for this purpose. In this case, the structure portrayed is the North Wall, the one that holds most of the artistic expressions in the church. Once the councilor for culture had conveyed the most significant wall patches of the church, the documentation process focused on capturing those specific areas with the highest detail possible. Dozens of photographs and videos were taken from multiple angles, lightings and distances. This modus operandi was systematically repeated for each of the major walls inside the church. Although in this case due to the limited graffiti clusters photographs have been taken with a mobile device, the original materials extracted from the *Soria Románica* initiative used advanced digital imaging techniques such as close-range photogrammetry, which has proven highly effective (Georgieva & Seaton, 2022).

Figure 7. Multiple Angles of the North Wall

Source: Multiple angles taken of the north wall on the first visit to San Miguel. Own work (2025).

After careful review of the digital reconstruction resources and discussing the cultural relevance of the different elements, three graffiti clusters were selected for the prototype application. These clusters were selected and extracted from the original reconstructions provided by *Soria Románica* and they were cleaned and formatted afterwards for using them and superimposed images in the walls of San Miguel. Figures 8, 9 and 10 show the selected graffiti clusters. Figure 8 depicts the only cluster from the west wall, which is the pointing monk. Figure 9 shows the leftmost cluster in the north wall, where a small figure with open arms lays below a gothic inscription and accounting markings. The last one, in Figure 10 depicts the soldier, armed with a sword and a shield.

Figure 8. Pointing Monk.

Source: Graffiti cluster from West Wall extracted from the resources of the Soria Románica Initiative, 2009.

Figure 9. Gothic Inscription.

Source: Graffiti cluster from North Wall extracted from the resources of the Soria Románica Initiative, 2009.

Figure 10. Soldier.

Source: Graffiti cluster from North Wall extracted from the resources of the Soria Románica Initiative, 2009.

3.3. Wall-based Image Tracking

The experience that ARRDA provides aims to be as seamless as possible. The reason behind this is to avoid damaging or further deteriorating the graffiti in San Miguel and to avoid any possible distractions that might disrupt the immersion of the user. For this reason, using artificial markers

such as QR codes or ArUco markers is to be avoided. Graffiti are evidently faded away and with no real perceptible texture, walls are irregular, have no clear marking or references for the application to discern where it is pointing at, the height at which the graffiti are located and the varying conditions of lighting throughout the day.

For the purpose of dealing with these issues, an extensive photographic documentation was performed on the different selected graffiti clusters inside the temple, allowing ARRDA to have a robust backlog of reference images to be able to perform under the changing conditions of the church. In figures 11 and 12, both walls to be used in ARRDA can be seen as well as the locations where the graffiti clusters selected are present but cannot be seen without aid anymore.

Figure 11. *North Wall Clusters.*

Source: Own elaboration, 2025.

Figure 12. *West Wall Cluster.*

Source: Own elaboration, 2025.

After configuring the *XRReferenceImageLibrary* with this collection, the application proved to have the ability to detect and track the target images in real time, validating also the blurry and zoomed-out targets. A smooth and responsive experience is key (Akçayır & Akçayır, 2017) if the intention is to create a connection between the user and the cultural heritage.

A crucial technical challenge is avoiding the simultaneous overlap of the different digital reconstructions. This is caused by the several different target images of the same graffiti cluster, as there is more than one target image for each reconstruction due to having different angles and lighting. To address this, a dynamic grouping image pool is configured. Each pool groups the images with changing perspectives and lighting of a wall patch and the system dynamically chooses only one active image per group. This is done through the use of a dictionary (*activePoolImages*), where, in each frame, the last detected image is kept and after that, the system verifies if there is an active overlay for that group. If there is, the image is discarded, if not, the overlay associated with that patch is displayed.

After the verification of the suitability of the San Miguel's wall patches as target images, the next step is to increase the level of immersion and interactivity of the app. The goal is to make the visitors feel like they can really manipulate and feel the graffiti reconstructions, giving the user the ability to anchor and zoom into the graffiti cluster that they decide. This was necessary due to the reconstructions being projected in its actual size might be too small and would not allow for

an adequate appreciation of the cultural heritage of San Miguel and San Esteban de Gormaz. The steps taken to develop this feature are the following:

Capture active overlay: When pressing the zoom-in button, the active visible overlay is identified (if it exists) and then, that overlay is extracted and turned into a fixed object (*fixedOverlay*).

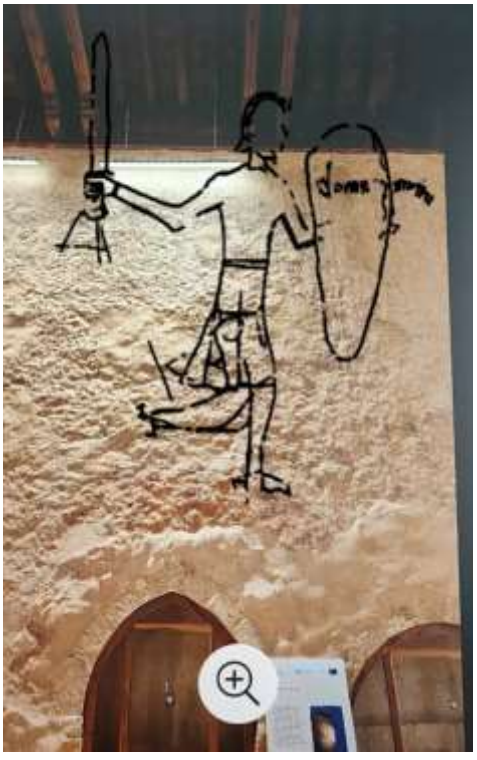
Screen reposition: The center of the user screen is calculated in real-world coordinates with *ScreenToWorldPoint* to a fixed distance from the camera. The overlay is then positioned in that point to ensure maximum visibility. Overlay zoom: The width of the overlay is calculated and then compared with the 90% of the width of the user's screen. This value has been predefined so that the overlay shows maximum visibility without being in contact with the margins of the screen.

Deactivation of overlays: When the user clicks on the zoom-in button, the active overlay that was selected is destroyed so that it does not interfere with the zoomed in one. When the user clicks on the button again, the zoomed in overlay and all other active ones are destroyed and the detection system is reestablished. Figures 13 and 14 illustrate the behavior of the described functionalities, presenting how the app tracks and superimposes the digital reconstruction and, afterwards, the zoom-in to appreciate in detail the focused graffiti:

Figure 13. Soldier Graffiti Scanned in lab environment.

Source: Snapshot taken from the app prototype in the lab environment showing the viability of the image tracking module. Own work (2025).

Figure 14. Soldier Graffiti Zommed-In in lab environment.



Source: Snapshot taken from the app prototype in the lab environment showing the zoom-in functionality. Own work (2025).

3.5. Tracking behavior metrics

The backbone of this work is the creation of a functional prototype that can detect the target images of the wall patches of San Miguel church and superimpose the digital reconstruction of the graffiti over them. In this particular case, the secondary goal of the prototype is to provide the tools to the San Esteban de Gormaz council to extract the data produced by the behavior of the visitors of the church and leverage this information and the insights extracted from it to promote and dynamize the tourism and influx of visitors to San Esteban de Gormaz and Soria. The design of the system architecture is composed by three different modules. The main one is the functional application to detect and superimpose digital reconstructions. The two modules that are left will be the ones needed for this last step of the work.

As previously mentioned, one of the differential elements that this project proposes is the capability of monitoring the data of the AR app regarding the behavior of visitors within the church. The process begins with the development of the second module of the system architecture, this module consists of the creation of a REST API service developed under the lightweight Flask framework, which is particularly suitable for this work due to the low requirements regarding the endpoints needed and the amount of data sent.

For the database, which is the last module of the architecture, the technology choice is MongoDB. This is a service mostly used due to its big data capability and data processing, features that are not needed in this project. However, what it also provides is an extremely flexible structure due to the NoSQL and JSON approach, which is crucial in a dynamic development with several different prototypes and a fuzzy set of requirements that called for a database service that could manage such changes and could efficiently store different types of data such as images or videos. The backend is structured in three different collections:

Users: It contains a unique identifier per device (*deviceUniqueIdentifier*) and a list of the scanned graffiti per unique user. This serves as a way of knowing which percentage of users have scanned all three possible graffiti clusters.

Graffiti: It contains the three graffiti clusters, saving their id, name and the number of times each one of them has been scanned by any user.

Stats: This collection is in charge of calculating all the aggregated metrics of the project. This contains data such as the number of unique users, the number of users that have scanned all three graffiti clusters and the average length of the session (this means keeping the app open) of every visitor.

One of the key functionalities of the API is the possibility of registering in the app the duration of each session, this is, keeping track of the total time that a visitor has been using the app during their stay in the church. This metric allows for an analysis on how much time do visitors invest in investigating the cultural heritage and in that way, assesses how deep and immersive the experience is. Temporal metrics such as session duration and navigation patterns have been successfully used in cultural heritage environments to manage visitor engagement (Yoshimura et al., 2017). This functionality is based upon the component *UserRegister*, in charge of extracting the unique user id provided by Unity, which allows for several different functionalities such as calculating the average time of usage.

When the app is opened, the app checks if the device is new, if it is, the device is registered with its unique device identifier. After this first check-up, the app registers the time at which the app has been opened. When the app is closed, the duration of the session is calculated with the timestamp at which the app was closed, and the request is sent to the API by a POST request.

The backend updates the field *average_session_time* incrementally using an average, which provides a realistic estimate of the average time per session of every visitor. This metric is key for validating the second specific goal related to increasing the average stay of visitors in San Miguel.

Besides the register of the session average, the app also gathers information related to the different graffiti that are over San Miguel's walls and how the visitors interact with the reconstructions and the potential difficulties when scanning, pointing the device or finding the relevant wall patches.

The backbone of this activity is the *SimpleImageIncrementer* component. This script is responsible for recognizing when a particular target reference has been scanned. When that event happens, a POST request is sent to the API service. This request does the following: Increment the total scans of that particular graffiti, adds the ID of the scanned graffiti to the array of that particular user, checks if the array has been completed by all three graffiti IDs, in which case the state of that user turns to completed, this means that the user has scanned all possible graffiti in San Miguel.

With the information that this request provides, ARRDA gets access to the following metrics: How many times has each graffiti been scanned, which could give the San Esteban de Gormaz council insights on which ones are more popular. How many visitors have scanned all possible graffiti, which could reflect the level of engagement of the visitors or reflect possible issues when recognizing wall patches. Lastly, the completion rate of scanned graffiti (*users_completed* / *unique_users*).

4. Evaluation and Results

The prototype testing was performed inside the San Miguel church, in a field trip organized with the support of the culture department of San Esteban de Gormaz. The environment, as mentioned before, presents multiple challenges for the detection of the target images such as the varying lighting throughout the day, irregular surfaces, deteriorated target images and the height at which these targets are located. Below, figures 15, 16 and 17 show a screen recording of the mobile device in which the prototype was tested can be seen. These figures show the three different graffiti clusters that the application can superimpose over the walls of San Miguel, proving that the wall patches of the church can be used as reference targets for AR application such as the one created in this work.

Figure 15. *Gothic Inscription Graffiti inside San Miguel.*

Note: Snapshot taken from the app inside the church of San Miguel superimposing the gothic inscription cluster. Own work (2025).

Figure 16. *Pointing Monk Graffiti inside San Miguel.*

Note: Snapshot taken from the app inside the church of San Miguel superimposing the pointing monk cluster. Own work (2025).

Figure 17. *Zoomed-In Soldier Graffiti inside San Miguel.*

Note: Snapshot taken from the app inside the church of San Miguel superimposing the zoomed-in soldier cluster. Own work (2025).

To ensure a satisfactory and accessible experience, the testing was done in two different devices of different capabilities and price ranges. The devices are the following: Xiaomi MI 11 lite (Low/Mid-tier): Represents an end-user profile that uses an economic device with limited processing and graphic resources. Samsung Galaxy s25 (High-tier): Represents an end-user profile with a recent device, optimized for resource-intensive activities such as AR.

Table 1 shows the average performance of the different devices, with the low-end device having a drop in performance and a slightly slower detection time. However, both devices performed adequately as the figures of the low end are within an acceptable and user range that allows for a satisfactory experience in both tiers. If the aim of initiatives such as this one is to democratize the access to culture and the heritage of a past that belongs to all of humanity, such access must be as easy to reach as possible. For this reason, having an optimized performance in different device quality tiers is crucial for allowing all visitors to equally connect with this heritage.

Table 1. *Average device Performance in live tests*

	Detection time	Tracking stability	Performance
Xiaomi mi11	Between 1 to 2 seconds	Stable	~30 FPS
Samsung s25	Under 1 second	Stable	~60 FPS

Source: Own elaboration, 2025.

The development of the project ARRDA has the ultimate goal of proving the technical feasibility and the real impact of a solution based on AR technology to revitalize the rural communities in Spain. This proposal aims to unlock the potential of the cultural heritage as a catalyst for tourism and economic activity. Through the use of a mobile AR app developed in unity and connected with a Flask and MongoDB backend, this project has achieved the creation of an immersive experience that allows the visitor to discover and appreciate the hidden graffiti of the historic San Miguel church in San Esteban de Gormaz, which are mostly faded and cannot be seen by the naked eye. This solution is built and refined through an iterative prototyping method, in-situ validation and feedback from the councilor for culture.

It is important to take into account that the results are obtained in an environment where the conditions are not the most suitable for an AR app to recognize target images due to the suboptimal lighting of San Miguel, the irregular surfaces and severe deterioration of the original graffiti. Additionally, the logistics that were necessary for the resource gathering and the final testing were severely restricted due to the limited availability of the church and the local experts. Nevertheless, the results prove that the technical approach is not only feasible, but also scalable and effective.

5. Discussion and Conclusions

After the analysis of the results obtained, this section focuses on the interpretation of the different findings and assessment of the work on a broader scale. Beyond the technical feasibility, different aspects such as how this solution positions itself as a strategic tool for cultural heritage appreciation and the revitalization of rural communities in risk of depopulation. Constraints tied to the work are also examined and lastly, an assessment of the potential of this tool for future investigation works is provided.

5.1. Technical and Logistic Constraints

One of the main technical constraints is the complexity of the physical environment. The graffiti are located in irregular walls, faded over time, edges and silhouettes are not defined and all graffiti clusters are located more than 4 meters above the ground, which proved to be a significant barrier. This obstacle highlights one of the most common difficulties when dealing with AR based on markers and vision: the need of a precise target and correspondence between the physical world and the digital information. This concept was initially demonstrated in small AR workspaces with high precision through real-time mobile tracking(Klein & Murray, 2007). As some studies in this field point out, the lighting variation throughout the day and irregular textures negatively affect the tracking stability and therefore, the user experience (Noh et al., 2009).

Beyond the technical challenges related with the environment and the physical condition of the San Miguel's walls, the logistic constraints have also played a significant role in the development of this work. The access to the church was limited and depended on the coordination with the culture department of San Esteban de Gormaz. This affected the availability of the different tests and resource gathering within the church. This dependency on third parties and

the lack of a reliable and easy access to the church are factors that are often overseen but can be critical for the success of a development. These kinds of barriers can impact the ability of creating quick iterations of the prototype and to gather enough resources for a robust target detection system. During the development of this work, San Esteban de Gormaz suffered heavy rain which caused a partial collapse of the most direct communication road between Madrid and San Esteban de Gormaz. This is an example of an unforeseen obstacle, totally outside ARRDA itself, and highlights the importance of the flexibility and planification in works related with cultural heritage.

These constraints, both technical, associated with the physical characteristics of the heritage and the logistic constraints, limiting and hindering the different visits to San Miguel that are instrumental for ARRDA prove that a work with similar characteristics does not only depend on the technical innovation, but also on a deep and profound understanding and connection with the heritage, the town and its people.

5.2. Replicable Model for Heritage Preservation and Rural Revitalization

This work transcends its first case study to consolidate itself as a high replicability methodological and technical model, with a significant potential for the preservation of the cultural heritage and the social and economic revitalization of depopulated rural areas. The viability of the model resides on its modular approach, which unties the technology from the particularities of the heritage in San Esteban de Gormaz, therefore allowing its application to a wide range of environmental contexts not just in the rural areas of Spain suffering from the *España Vaciada* problem, but also other contexts outside of Spain that are victims of the same circumstances.

The ARRDA model is based in the integration of low-cost technologies tied with rigorous historical documentation. The ability of leveraging the 3D scanning to capture and accurately digitalize the heritage, independently of its observation state, is a crucial foundation for replicability. This study proves that technology can overcome constraints inherent to cultural heritage contexts such as erosion or accessibility, which are key for the preservation of the heritage on the long term. By associating the digital reconstructions of each graffiti cluster, ARRDA ensures the preservation of these centuries old graffiti and gives the opportunity to democratize the access to these resources, that would otherwise be buried under layers of bureaucracy. Furthermore, it opens new lines of interpretation for these drawings, as new and fresh perspectives from visitors may arise and shade light into the meaning and worldview of these markings. This model is aligned with the increasing research in digital humanities, which underlines the importance of 3D and AR models for the creation of new immersive cultural experiences that complement traditional visits.

In addition to its technical versatility, the replicable value of ARRDA is found in its ability to act as a catalyst for local development. Depopulation and the lack of resources and economic opportunities are chronic challenges in several Spanish regions. This model proposes an innovative solution by transforming an underappreciated cultural asset such as the graffiti of San Miguel into a magnet for new visitors of the church and San Esteban de Gormaz. By offering a unique and interactive cultural experience through the use of AR, this model fosters a sustainable and responsible tourism as the heritage is preserved due to not physically interacting with the graffiti. This work will attract visitors interested in the cultural assets of San Miguel and also in the innovative approach of ARRDA. This strategy does not only create an influx of new visitors, but it can also stimulate the local economy due to the tourist increase and therefore, the creation of new businesses and service to accommodate such increase. Numerous studies highlight the role of digitalization in the development of tourism and the promotion of less-know areas as new cultural heritage destinations as a tool for the economic and social revitalization of rural communities (Jiang & Phoong, 2023).

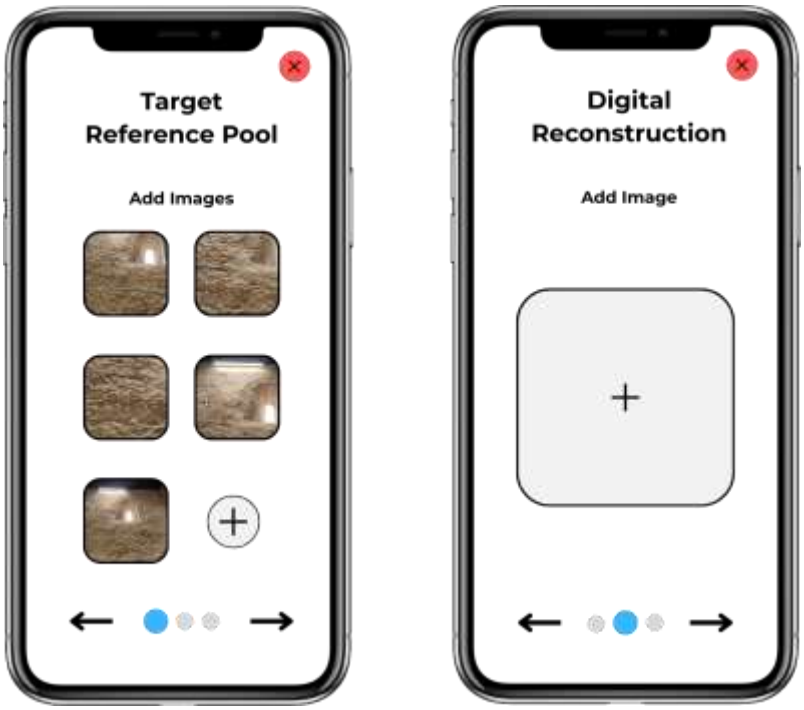
5.3. Future Development and Research

This work is a successful development of a prototype that sets the foundation for a future development and further research in both the technical and historical aspects. The next steps are focused on expanding the capabilities of the application and exploring new ways of cultural heritage preservation and dissemination.

One of the most key areas for future improvement is the upgrade of the user experience and the integration of emerging technologies. As of today, the prototype is based on AR through mobile devices, but because of all the historical load that this graffiti contains, the integration of technologies such as generative AI can substantially improve the user experience. Generative AI can create personalized narratives and dynamics that answer to the particular interests of each visitor. Another technology to be implemented are the augmented reality goggles. These devices can deliver a much more immersive and hands-free experience to the user, allowing for a much deeper connection with the heritage.

ARRDA aims to be a modular, scalable and easy to use application for rural cultural heritage environments such as San Esteban de Gormaz. For this very reason, the application must accommodate the addition of new and personalized target images and their respective digital reconstructions or associated information. The prototype in its current state does not have any possible way of adding these new images, as they must be added by a developer adding the targets in the *XRReferenceImageLibrary*. The process is very simple; however, it still could not be done by the respective councilor for culture or cultural guide. For this reason, the next improvement for ARRDA should be adding a user-friendly section to create and update new target images and associated digital information modules such as the one seen in Figure 18.

Figure 18. Custom Target Image and Digital Reconstruction Screen



Source: Wireframe created for further app development. This figures shows a user-friendly procedure to upload new reference targets and virtual reconstructions associated to them. Own elaboration (2025).

From a broader perspective, this work opens-up new important lines of interdisciplinary research. A critical field is the sustainability and long-term preservation of the digital heritage. It is crucial to research on standardized methodologies for storage, usability and access to 3D data

ensuring that these resources do not turn obsolete and can be used in the future for research and conservation purposes. Besides this, this work can act as a steppingstone for future studies regarding the real and measurable socioeconomic impact of the role of technology in rural tourism. Future research may assess how the use of applications such as ARRDA affects the visitor influx, the local economy and the perception of the cultural heritage form both tourist and local people. This can help to prove the viability of technology as a lure for tourism and as a tool for a responsible and sustainable tourism.

All in all, this prototype is the first step towards a much longer road that includes a technical expansion, the integration of new interaction systems as well as personalized experiences and thorough research on the best possible use of technology to help preserve, disseminate and revitalize the cultural heritage in the *España Vaciada* and in other regions with similar characteristics.

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