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Digital technologies for the "Grazia Deledda" Literary Park in Galtellì (NU): the 3D virtual reconstruction of Pontes Castle

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Abstract

This paper aims to present one of the digital outputs of the ongoing project to enhance the Grazia Deledda Literary Park in Galtellì: the virtual reconstruction of the medieval Pontes Castle, located in an impervious and hard-to-reach area. Although it is now difficult to identify the original structure, historical research, graphic reconstructions, surveys, and the restoration and consolidation works provide valuable information about its layout, which can be further expanded and improved thanks to the application of digital technologies.

The 3D digitization of Pontes Castle using Gaussian Splatting introduces a new way of documenting cultural heritage through photorealistic reconstruction without polygonal meshes. This technique enables real-time interactive visualization, reducing processing time compared to traditional photogrammetry while offering a more natural handling of light and details. At the same time, to assess the benefits offered by this technique, the field data will also be processed using well-established software in the field of classical photogrammetry. In this regard, the results obtained with conventional techniques can serve as a ground-truth reference to verify the quality of the 3D-GS point cloud.

CCS Concept

• ***Applied computing*** → *Arts and humanities; Education;* ***Computing methodologies*** → *Computer graphics; Image manipulation; Rendering;* • ***Human-centered computing*** → *Visualization.*

1. Introduction

In the early 1990s, the Literary Park dedicated to Grazia Deledda was established in the town of Galtellì (Sardinia, Province of Nuoro), today incorporated within the *Associazione Parchi Letterari®* [DeM09]. The village, located in the Barbagia region, holds particular importance in Deledda's literary production: the Nobel Prize laureate in Literature (1926) drew extensively upon its landscapes and traditions, notably setting *Canne al vento* (*Reeds in the Wind*) – one of her most renowned and critically acclaimed novels – within its confines, alongside various short stories [Del96].

Among the literary sites in the Galtellì area, the Pontes Castle occupies a prominent position. It figures not only in Deledda's fictional works but also in her *Leggende sarde* (*Sardinian Legends*), where she recounts popular beliefs regarding the castle's history. Chief among these legends is the notion that the spirit of the last Baron, a member of the Guiso family, continues to guard the site and its concealed treasures [Del99].

Owing to its historical and literary significance, the Pontes Castle has been selected as one of the principal nodes for the enhancement of cultural itineraries within the research group *Spoke 4* (*Virtual technologies for museums and art Collections*) of the PNRR CHANGES project – Cultural Heritage Active Innovation for Sustainable Society [Mur23]. Indeed, the project aims to foster the preservation, dissemination, and accessibility of the tangible and intangible heritage associated with various types of museum, such as the Literary Park of Galtellì.

Particular emphasis is placed on the application of innovative digital technologies, which are especially relevant in the case of the Castle due to its limited physical accessibility. Indeed, the site's elevated and precipitous position – built on a steep, rocky slope and surrounded by dense vegetation – underscores the importance of alternative forms of engagement.

Through the combination of 3D modelling technologies, it is possible to produce a detailed reconstruction of the site, making it understandable and explorable even remotely.

The case of the Castle of Pontes exemplifies how heritage sites, even those with challenging physical conditions, can be preserved and reactivated through strategic use of technological tools, encouraging at the same time new visits and new studies.

2. The ruins of Pontes Castle

The Castle of Pontes is located approximately 2 km northeast of the town of Galtellì, on a hill from which it takes its name. It is a medieval military fortification, typical of the *Giudicato* period, during which frontier castles were built in strategic locations across Sardinia to control the surrounding territory and commercial routes.

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What we know today about the castle is largely based on a series of studies conducted from the second half of the 20th century onward and compiled by Anna Rita Lai. According to these studies, the castle was built between the 11th and 12th centuries, likely on the site of a former Roman settlement, which itself may have been preceded by a Nuragic one. The structure remained inhabited for a long period and was further reinforced during the Aragonese period, specifically between 1352 and 1354. It was eventually abandoned around the mid-16th century and gradually fell into ruin, so that today only scant traces of the ancient walls and the interior spaces remain [Lai09].

Particularly important were the initial investigations conducted by the scholar Antonio Cambedda, which revealed that the fortification was organized into three concentric lines of walls positioned at different elevations. Several architectural features can still be clearly identified, including the cistern, the oven, a stone staircase, various rooms and defensive/residential posts, and the so-called *Mastio*, located at the highest point [Cam95].

The research drew upon a variety of historical and diplomatic sources, most notably documents preserved in the *Archivio General de la Corona de Aragón* in Barcelona, which include letters and testimonies from castle inhabitants, such as servants and castellans.

Finally, new insights were provided by the 2006 excavation carried out by the Superintendence for Archaeological Heritage of the Province of Nuoro, undertaken as part of a project to consolidate and restore the structure.

The Castle is still a culturally and symbolically significant site for the local community of Galtellì, and is frequently included in guided tours and literary itineraries curated by local experts. However, its conditions limit the access for a broad segment of potential visitors, particularly those with reduced mobility, thus underscoring the need for alternative means of engagement, such as digital reconstruction and remote exploration tools.

3. Methods and results

During the 3D reconstruction process of the site, a comparison between two different techniques was carried out: classical photogrammetry and Gaussian Splatting. Applying Gaussian Splatting to Pontes Castle highlights the potential of this technology in improving the experience of cultural heritage objects through easy and immersive access directly from browsers and mobile devices, without the constraints of traditional meshes. At the same time, Sfm-MVS reconstruction methods are still more reliable in terms of geometric accuracy.

Other key aspects of Cultural Heritage communication have been evaluated, such as the realism of the final 3D renderings, the management of potential informational gaps, and the complexity of the operations required. To facilitate the comparison, datasets have been acquired using the same equipment.

The acquisition campaign was carried out in collaboration with the company Risviel Srl (https://risviel.com/it).

3.1. Acquisition and processing using classical photogrammetry

Pontes Castle is situated on a rocky promontory at a height of about 117 meters above the surrounding terrain [Mel10], and covers an area of about 7,500 m². According to available literature, the only surviving elements consist of fragments of the defensive walls, two cisterns and a corner tower [Foi92].

Although the original structure is difficult to recognize today, as is often the case at similar sites, some portions of the ancient masonry remain visible, particularly on the upper level, where the keep was probably located [Cam95, OM21]. The lower sections reveal traces of the outermost enclosure, built directly on the rocky outcrop and now largely obscured by dense vegetation.

This configuration results in a very intricate spatial distribution, characterized by some still well-preserved and vertically developed wall segments and others where only the perimeter foundation walls remain. While the lack of homogeneity of the structure makes the acquisition of the remains rather complex, the relatively isolated location of the castle allows for surveying operations without significant spatial constraints from nearby structures; as such, it is possible to capture each side of the structure while maintaining a constant distance [WSLH25].

Considering the elevated location of the castle, an Unmanned Aircraft System (UAS) was selected for the photogrammetric acquisition, enabling the rapid surveying of the entire structure and the capture of a dense, closely spaced network of images, useful to reinforce the geometry for the subsequent alignment phase [MHG22, ES20, OM21]. For the survey planning, the applications DJIFlightPlanner and Litchi were initially employed, creating two types of missions: a nadir mission based on a parallel-axis imaging system, with the camera axis set at -90° and side and forward overlaps of 70%, and a spiral mission, in which the camera remains oriented toward a focal point while capturing the object of interest at various heights [AEAA22, LL23]; A distance of approximately 30 meters was therefore set for both nadir and circular flights, achieving a uniform image acquisition scheme and avoiding potential collisions during orbital captures [FSQK17, WSLH25].

The EVO II Pro RTK, a UAS from the enterprise series, was selected to carry out the flights. This device features a GNSS positioning system capable of achieving centimeter-level accuracy even at distances exceeding 1 km and offers good wind resistance (level 8 on the Beaufort scale). Its omnidirectional sensor system further enhances operational safety by detecting obstacles in all directions—an important feature for operations in complex environments such as the castle remains. The surveys were conducted over two days (April 9–10, 2025). Although the initial goal was to complete most of the flights on the first day, worsening weather conditions prevented the planned missions from continuing, and flights around the castle had to be postponed until the following day. Since the missions created in Litchi appeared to significantly slow down the performance of the flight software (Autel Enterprise), a new mission was created directly within the proprietary application, replicating the parameters originally set in DJIFP and Litchi. A total of six flights were carried out: the first was a nadir flight, while the remaining five followed a circular scheme based on waypoints oriented toward the point of interest (POI). . The subsequent five flights were conducted at an approximate altitude of 10 meters AGL (Above Ground Level) for each mission.

A preliminary flight was first conducted to verify that the drone's trajectory was correct and to avoid any risk of collision with the rocky walls [WSLH25]. The following flights were performed by taking off from lower altitudes; since the base of the castle and the promontory broaden at lower elevations, it was necessary to adapt the flight pattern to the external perimeter, thereby maintaining a consistent distance from the nearest surfaces.

The final dataset, composed of 463 images, was processed using Metashape Pro software (v. 2.1.3), following the standard photogrammetric reconstruction workflow, divided into four phases: Align Photos (internal and external orientation), Build Dense Cloud, Build Mesh, and Build Texture [DDG*20]. The dataset was imported by organizing the images according to the different missions performed. For each processing phase, a high-quality setting was selected, resulting in a dense cloud of 97,800,829 points with a ground resolution of approximately 1.36 cm/px.

3.2. Processing with 3DGS

The reconstruction of Castello Pontes using the Gaussian Splatting technique [KKL*23] aimed to produce a visually realistic, lightweight, and web-accessible 3d model to be easily available to the public. This 3d processing methodology, based on real-time neural rendering techniques, proved to be ideal for the digital enhancement of cultural heritage [OB25].

Gaussian Splatting modelling distinguishes itself from other techniques due to its simplicity and speed in obtaining the final model, avoiding the complexity of traditional mesh reconstruction and texture mapping [KKL*23].

The first phase was pre-processing and photogrammetric alignment: in this phase the set of images collected during the mission in the municipality of Galtellì (NU) underwent a preliminary analysis to exclude unusable shots (motion blur, glare, incorrect exposure), especially those with poor overlap. Once this filtering step was completed, the dataset was processed using COLMAP, a well-established tool in the field of Structure-from-Motion (SfM), for automatic image alignment and sparse point cloud reconstruction [SF16].

COLMAP was preferred for its reliability, its compatibility with various neural frameworks, and its ability to directly export data in formats compatible with neural rendering pipelines [WWM*23].

After completing the processing with COLMAP there was the dataset preparation for the Gaussian Splatting pipeline were the images, poses, and intrinsic parameters were converted into a format compatible with the Postshot framework for Gaussian Splatting, an intuitive and robust German platform for both Neural Radiance Fields and 3d Gaussian Splatting. Postshot's preparation utility allowed the structural data to be quickly organised according to the standard directory layout required by the pipeline (https://www.jawset.com/).

The system implemented by Postshot adopts an optimised volumetric splatting technique based on Gaussian primitives, thus simplifying the 3d production process compared to traditional methods requiring mesh, texture, or UV mapping. This approach proves particularly suitable for heritage-oriented scenarios, where achieving good visual quality combined with efficient and lightweight distribution of models is essential [OB25].

Finally, the neural network was trained using the calibrated images and poses through an iterative optimisation process [WWM*23]. The goal was to adapt the position, orientation, size, and colour of the Gaussian primitives to reproduce the real-world views accurately.

We adopted photometric loss functions, in particular L2 (Mean Squared Error) and SSIM (Structural Similarity Index) to optimize the parameters of the Gaussian Splatting model. The goal was to ensure a visual correspondence between the synthesized and real images, preserving the structural details of the castle. L2 penalizes pixel-by-pixel differences, while SSIM measures the structural similarity in terms of luminance, contrast and shape, improving the perceived yield.

The training, carried out on an NVIDIA RTX 3090 GPU, required about 2 hours in total. The result was an interactive 3d model, manipulable, rotatable, and navigable in real time, without the need for mesh-based reconstructions [WWM*23].

The Gaussian Splatting technique proved particularly suitable for representing cases like the Castello Pontes, enabling a visually accurate, lightweight, and immediately accessible reconstruction [WWM*23], while significantly reducing production times and promoting an efficient and replicable workflow.

4. Publication and user interaction phase

For the model's publication phase, a WebGL viewer based on Three.js was used, extended to support real-time rendering of Gaussian primitives.

This solution enables immediate access from any device equipped with a modern browser, facilitating the dissemination of cultural content also in educational or public outreach contexts.

The 3D model will be integrated into an interactive platform tailored for end-users, as part of a cultural and narrative itinerary specifically designed for the Literary Park. This integration will enable users to explore the castle virtually, alongside other multimedia content such as videos, panoramic images, and podcasts, accessible via a dedicated website, interactive totems located on-site, and QR codes positioned along the visitor route. The virtual visit will offer a unique opportunity to deepen the understanding of local history, narrating events related to the castle's changes in ownership and its historical inhabitants. Furthermore, considering that the actual site is privately owned and difficult to access due to limited entry, the virtual model will serve as a valuable support tool for the park's guides. They will be able to accompany students and visitors in discovering the castle, using the digital replica to provide detailed and interactive explanations.

The user experience could be further enhanced by integrating informative hotspots and contextual annotations, thus enriching the experience and making it more coherent with the site's cultural valorisation objectives [OB25].

Additionally, the two models represent a foundational resource for further research and future activities. Beyond enabling historical research and remote analyses, the produced 3D models could serve as a basis for planning more detailed survey campaigns, as well as for the virtual reconstruction of the castle in different historical periods, thus illustrating the site's evolution over the centuries. Moreover, these 3D models could be effectively utilized in developing interactive and gaming applications, particularly leveraging the efficiency and high visual quality offered by the Gaussian Splatting model. This will open new avenues for participatory and immersive experiences aimed at a broader and more diverse audience.

5. Conclusions

Wanting to make a rough comparative analysis between the two 3D reconstruction approaches in this context we can say that both the classic photogrammetric modeling with mesh and texture and the Gaussian Splatting one can be considered complementary and both with specific advantages and limitations, to be evaluated based on the context in which they are to be applied.

The traditional photogrammetric technique, based on Structure-from-Motion (SfM), with mesh generation and texturing, offers high geometric precision and is widely consolidated in the scientific and professional fields [CNAC24]. The workflow, applied with the use of Metashape, allowed the generation of a detailed 3D model, also thanks to accurate flight planning and the use of high-resolution RTK images (Figures 1,3).

On the other hand, this methodology requires high computational resources and long calculation times in the mesh and texture generation phase, which can be complex in contexts with irregular geometries or low visual coherence as in the case of the vegetated ruin of Pontes Castle.

On the contrary, the Gaussian Splatting technique has allowed a much faster and more streamlined workflow. The neural rendering method completely avoids the need to generate meshes and textures since it represents the scene using volumetric Gaussian primitives. The resulting model is lightweight and is obtained in a short time, it is visually realistic and immediately usable in web-based environments (Figures 2, 4). Unfortunately, since this approach is relatively new, it has limitations in terms of metric accuracy and poor interoperability with widely adopted workflows such as GIS and BIM.

Ultimately, classic photogrammetry guarantees greater geometric precision and operational flexibility, proving more suitable for technical documentation, conservation and integration in geospatial environments. Gaussian Splatting, on the other hand, stands out for its speed and visual rendering, proving ideal for public communication, interactive dissemination and cultural valorisation.

Taking these aspects into account, the choice between the two techniques must be guided by the specific needs of the project, which means that if we want to obtain good metric precision and formal documentation, then the classic pipeline is more convenient. If instead we want an immersive, accessible, fast fruition that still maintains a good definition of the modeled objects, then Gaussian Splatting is definitely the most recommended solution (Figures 5-6).

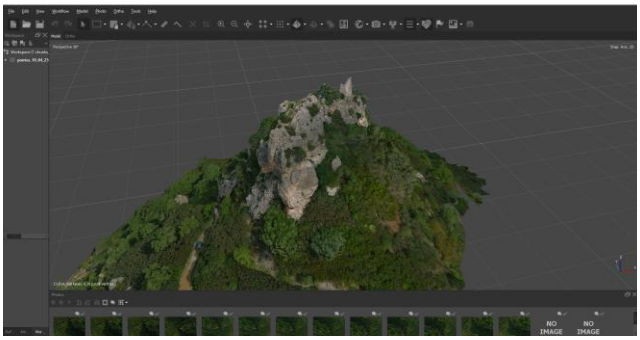

Figure 1: *Model obtained in Metashape, south side*

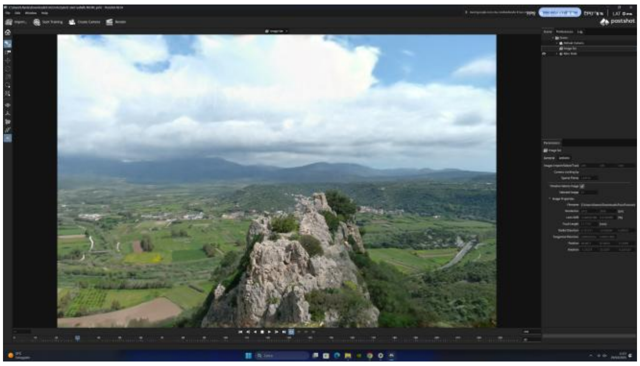

Figure 2: *Model obtained in Postshot, south side*

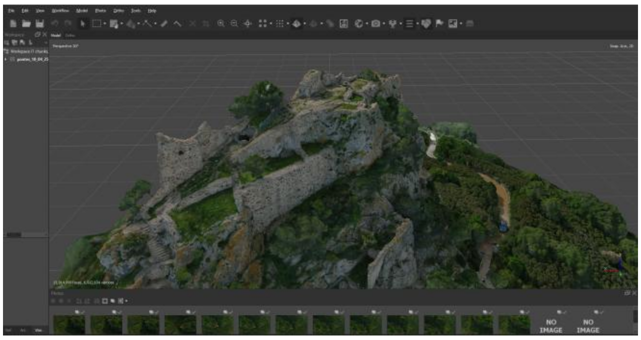

Figure 3: *Model obtained in Metashape, north side*

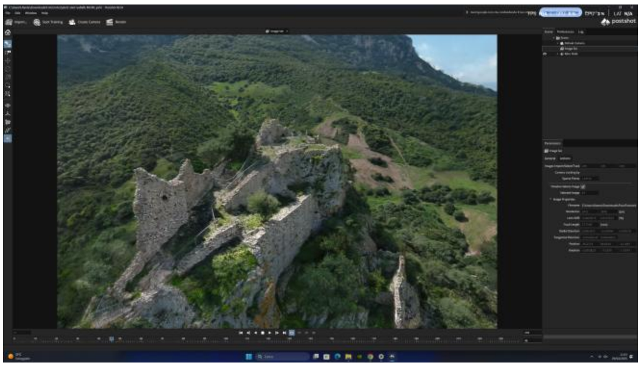

Figure 4: *Model obtained in Postshot, north side*

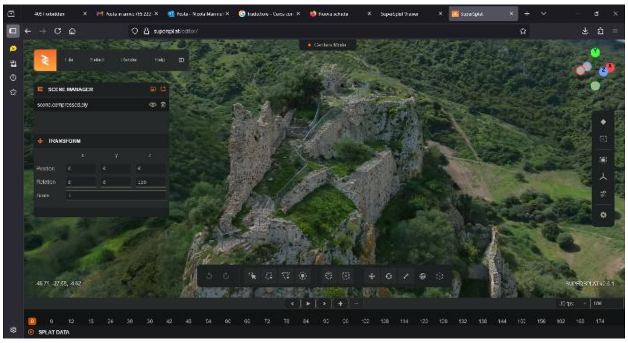

Figure 5: *Gaussian Splatting Model visualized in Supersplat, north side*

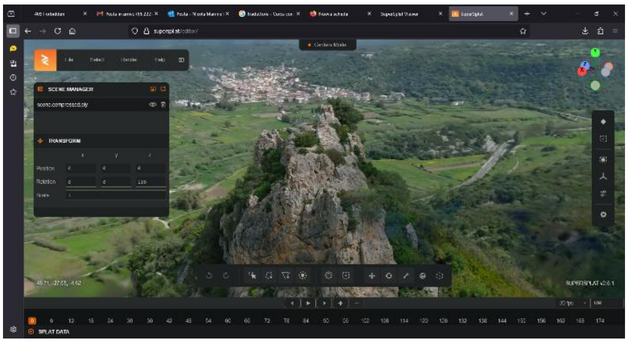

Figure 6: *Gaussian Splatting Model visualized in Supersplat, south side*

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