On Stage in Antiquity, On Screen in the Digital Age: Two Thousand Years of urban presence and integration of the Theatre in Priene

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The theatre of Priene, among the best-preserved in Asia Minor, represents an exemplary case study for testing integrated methods of digital surveying, procedural modeling, and virtual reality applied to archaeology.

ANCIENT PRIENE AND ITS THEATRE

Priene was founded in the Caria region of the western part of Anatolia, the present Turkey, the settlement is situated on the southern slope of Mount Mykale, overlooking what in antiquity was a gulf opening into the Aegean Sea. From the Archaic period to the Hellenistic age, however, the silting of the Maeander river, once entering the sea at the East of Priene, had gradually pushed the coastline westward, detaching Priene from the seashore that had once defined its economy and strategic importance. The city was architecturally realised in the IV century BCE, providing a model environment for the implementation of a rational, orthogonal urban plan, organized in a series of large terraces, the sloppy topography imposed constraints that required a specific architectural attention, producing one of the

Fig. 01 - View of the theatre, July 2022; View of the archaeological site of the theatre. Panorama taken during the photographic survey phase.

clearest surviving examples of Hellenistic city planning. Priene is a paradigmatic example of urban planning of that time (Wycherley,1945). Its street grid, in which It Is possible to recognize the Hippodamian principles, organises the city into regular sectors aligned to the cardinal directions, though subtly adapted to the mountain slope. Public buildings at Priene, including the Agora, the Bouleuterion, the Prytaneion, and the Theatre, participate in a coherent architectural vocabulary, presenting specific solutions, but remaining coherent to the city layout.

The Theatre of Priene is situated on the third urban terrace of the ancient city, in an intermediate position between the agora and the sanctuary of Athena Polias. The building, exploits the terrain and cliff slope and has most of the additional parts and all the external elements constructed in marble blocks. It exhibits the canonical articulation of Greek theatres (Lawrence, Tomlinson, 1996): cavea, proedria, orchestra, proskenion, stage building, and parodoi. The cavea is organized into five radial sectors, separated by six stairways approximately 0.92–0.96 metres wide. The lower rows are carved directly into the rock, while the upper ones rest on an artificial foundation made of regular stone blocks; only part of these upper rows survives today, while many of the benches have been lost. The seats consist of superimposed slabs with an average height between 39 and 40 centimetres, calibrated to the natural slope of the hillside.

The curved layout of the benches, reconstructible thanks to historical surveys and comparison with photogrammetry, shows slight irregularities suggesting the use of arcs with non-coincident centers. This aspect, apparently secondary, becomes relevant in digital modeling because it requires avoiding geometric simplifications that are too rigid and would misrepresent the original construction logic.

Between the cavea and the orchestra lies the proedria, arranged as a paved band of stone blocks that hosted the row of honorary seats. In this area, five marble thrones and a central altar are still preserved, elements likely added during a later phase compared to the original configuration. The thrones feature articulated bases, lion-paw legs, ivy motifs, and curved backs with Ionic-volute armrests; the quality of the carving and attention to detail confirm the representative function of this zone, reserved for civic and religious authorities.

The orchestra measures 18.65 m in diameter and corresponds almost exactly to the length of the proskenion. The latter represents one of the distinguishing features of the Theatre of Priene, as it preserves twelve frontal pillars and several lateral ones still standing. The Doric entablature, now fragmentary, originally displayed rich polychromy: triglyphs outlined in purple, metopes alternating in black and white, red cornices and fillets, blue architraves. These painted traces, documented by Wiegand and Schrader, were adopted as references for defining materials in the digital reconstruction (Wiegand, Schrader, 1895-1898). From the proskenion façade, stone beams project toward the rear, connecting the scene front to the back wall and supporting the wooden floor of the upper level. The stage rooms, now completely lost, were accessible through five doors whose positions are reconstructible thanks to historical drawings.

The stage building, particularly its vertical development and its relationship with the proskenion, was reconstructed following the hypothesis proposed by Armin von Gerkan, which integrates the Priene data with typological comparisons to other theatres (Gerkan, 1921). The parodoi, located on the sides of the scene, still preserve their masonry access structures and constitute an additional point of comparison between the existing state and the reconstruction.

Overall, the Theatre of Priene stands out for the exceptional amount of preserved lower architectural elements and for the quality of the historical documentation available. This dual condition makes it possible to produce a digital reconstruction that does not merely offer a formal restitution but explicitly clarifies the relationship between what is preserved, what can be reconstructed with reasonable certainty, and what remains hypothetical.

THE PHOTOGRAMMETRIC SURVEY

The definition of the current state was carried out through a photogrammetric survey that combined ground-based and drone-based imagery. A total of 824 images were acquired: 795 ground shots taken with a SONY ILCE-6000 mirrorless camera and, for the detailed recording of the proedria, with a Nikon D800e equipped with a macro lens; and 29 aerial images, produced using a DJI Spark drone flying at low altitude above the orchestra and the cavea. The ground shots followed a radial path along the cavea and a linear path along the proskenion, with multiple fan-shaped captures to ensure redundant coverage of shaded areas.

Processing was performed in RealityCapture. The initial alignment of the images generated several separate components due to the presence of vegetation, visual discontinuities, and scale differences between aerial and terrestrial shots. To bring the model into a single reference system, shared Control Points were identified across the various components, placed on clearly recognizable elements (slab edges, throne bases, joint intersections). Introducing at least three common points made it possible to merge all components into a single macro-model.

DIGITAL MODELLING

The goal of the digital modeling process was not to produce a single static model, but

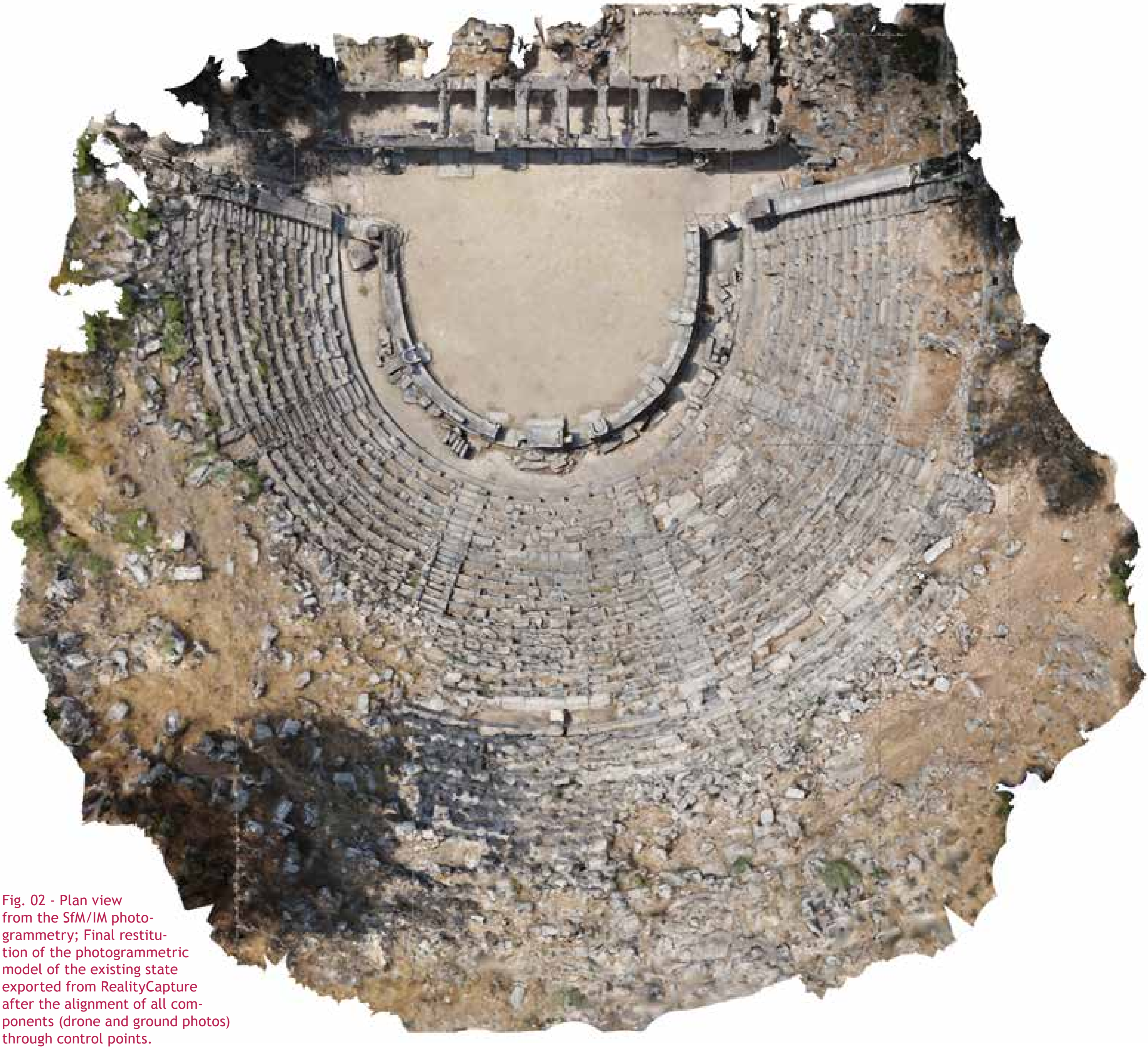

Fig. 02 - Plan view from the SfM/IM photogrammetry; Final restitution of the photogrammetric model of the existing state exported from RealityCapture after the alignment of all components (drone and ground photos) through control points.

Fig. 03 - Digital reconstruction of the theatre; Final phase of the modelling process in Blender, after importing the construction details through metadata via a Python script. The resulting model was obtained by refining the construction details through sculpting and texturing using OpenShadingLanguage.

to construct an information structure capable of explicitly describing the geometric and typological functioning of the theatre. To this end, the work was carried out in Rhinoceros 7 with the support of Grasshopper, organizing the complexity of the monument into a network of objects, instances, and metadata.

Deconstruction and macro-structure

The theatre was divided into five macro-groups: cavea, proedria, orchestra, proskenion and stage building, and parodoi. Each group includes sets of recurring elements: steps, benches, bases, backs, thrones, columns, pillars, beams, slabs. For each typology, a single reference object was modeled, conceived as a simple geometric "prototype." The repetition of elements within the theatre occurs exclusively through instances, generated and controlled parametrically.

This choice makes it possible to drastically reduce the computational weight of the model, simplify updates, and make the relationship between typology and occurrence explicit. Any modification to the reference object automatically propagates to all its instances, maintaining the overall coherence of the system.

Generative elements

Generative elements are abstract geometries that define the spatial arrangement of the components. Linear elements rely on points and vectors, curved ones on oriented curves, and complex joints on reference planes or surfaces. The curves were extracted from the photogrammetric model by projecting the outlines of the cavea, the proedria, and the proskenion onto plan view and removing local irregularities.

These curves were parametrized within the 0–1 interval, assigning each parametric value a point in space and a local reference system (a triad of axes). On these planes, the transformations required to place the instances, translation, rotation, and, where necessary, slight scaling, were calculated. This ensures that the repetition of seats or proskenion blocks follows the real curvature of the theatre, including small deviations from an ideal geometry.

In areas where the original blocks are no longer present, particularly in the upper part of the cavea, the arrangement was reconstructed by interpolating the available data: the average distance between slabs, the apparent radius of preserved sectors, and the alignment with the retaining walls. The geometric assumptions adopted were explicitly marked in later stages through metadata categorization (Rosone, Verdiani, 2024).

The resulting mesh was densified and subsequently simplified, maintaining high definition in key areas (proedria, proskenion, orchestra) and reducing detail in peripheral zones. A set of high-resolution textures preserved the chromatic and material information necessary for the reconstruction phase. Metric verification was carried out by comparing the model with the measurements recorded by Wiegand and Schrader: the deviations observed fall within an acceptable margin for an indirect survey, making the model suitable for the subsequent phase of procedural modeling.

Objects, instances, and deformations

The objects were modeled in Rhinoceros as low-complexity meshes, sufficient to clearly describe the basic form of each element. The instances are generated in Grasshopper, which calculates for each one the full set of transformations derived from the generative elements. This procedure produced thousands of components with complete control over their positioning.

For curved elements or those adapted to non-planar surfaces, such as the backs of the proedria or certain slabs of the cavea, the process continued in Blender using CurveDeform and similar modifiers. In practice, the linear object is “wrapped” along a reference curve while maintaining consistent proportions and detail. Here as well, the deformation is described within the metadata, ensuring that the relationship between object, curve, and instance remains fully traceable.

XML metadata

The informational structure of the model is defined through a metadata system exported in XML format (Erik T. Ray, 2001). Each object and each instance corresponds to a node within the XML tree and is described through:

- the name of the typological object;
- the path to the reference mesh file;
- any associated generative curve or surface;
- position, rotation, and scale coordinates;
- the assigned morphological variant;
- the reliability category (existing state, confirmed reconstruction, hypothesis).

This structure allows the model to be reloaded and regenerated across different environments without loss of information. The XML file therefore does not simply list objects: it describes the procedural logic that determined their spatial arrangement, enabling the entire process to be reconstructed directly from the data.

Once the procedural model was generated, it was imported back into Rhinoceros and overlaid onto the photogrammetric mesh. Verification concerned both geometric coherence and the relationships between parts (alignments, symmetries, distances between key elements). To express the degree of reliability across different portions, a chromatic classification system was adopted: green for elements matching the surveyed existing state; yellow for parts

reconstructed with strong support from historical sources; red for hypothetical elements, especially in the upper portions of the stage and the higher levels of the proskenion.
This visual distinction, combined with the categories stored within the metadata, allows anyone using the model to immediately recognize the nature of each element, avoiding the misconception of a unified reconstruction when in reality it is based on very different levels of certainty.

DIGITAL RENDERING AND PHOTOREALISM

The transition from procedural modeling to graphical rendering

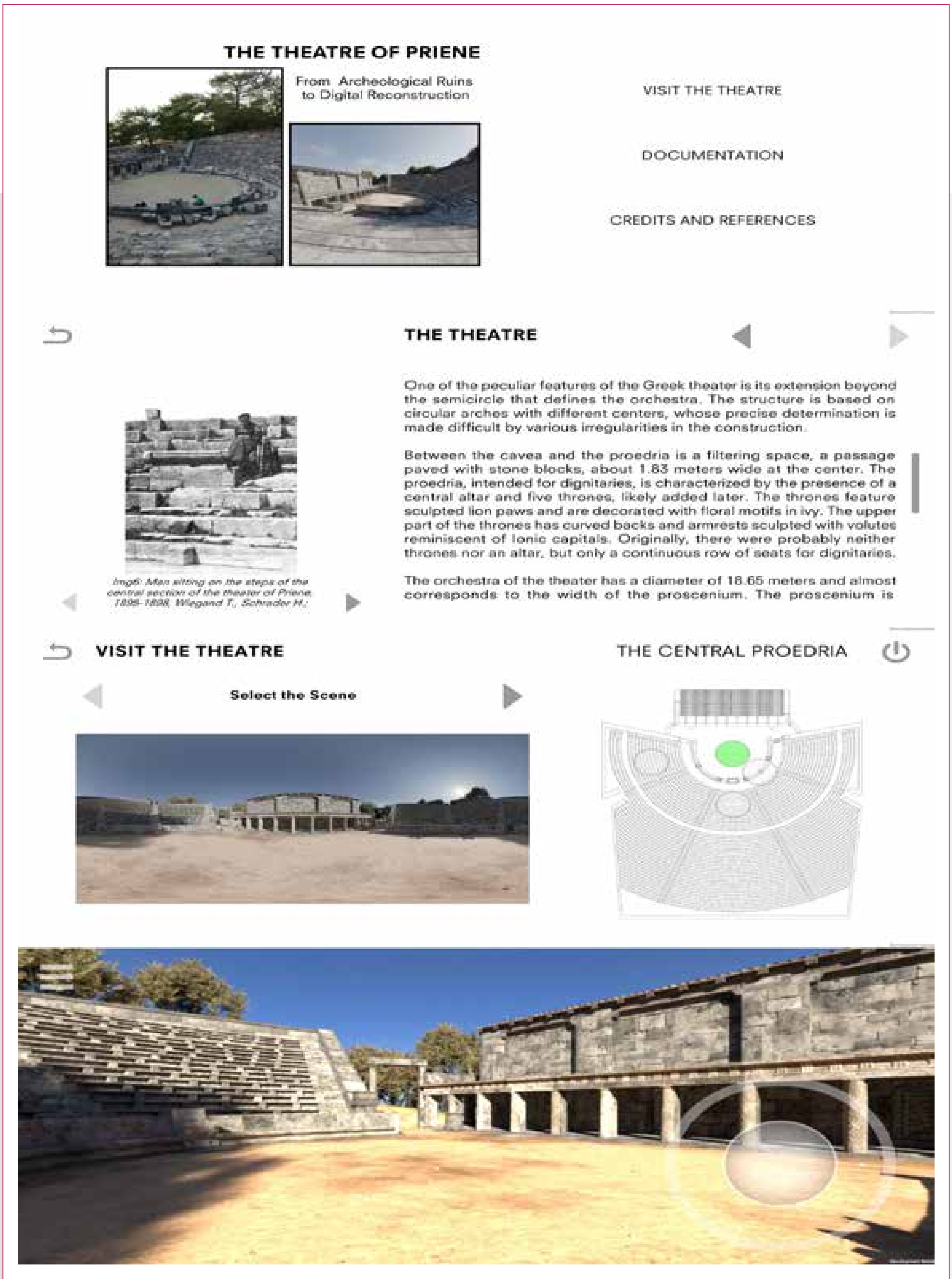

Fig.04 - The APP for the virtual visit, screenshot from the 3D and contents; Through the app, created with Unity, it was possible to select viewpoints exported from the final model as HDRI panoramas for the exploration of the reconstructed site according to the archaeological hypotheses.

took place in Blender, where the model was imported together with its XML metadata. The goal was not merely to obtain a convincing image, but to construct a scene consistent with the historical period chosen for the reconstruction, corresponding to the Doric phase documented by Wiegand, Schrader, and Gerkan, while excluding later additions from the advanced Hellenistic and Roman periods.

Sculpting and morphological variants

Although typological objects had been modeled correctly, they initially appeared too “perfect” when compared to the real appearance of stone blocks. For this reason, each object underwent a sculpting process (Xury Greer, 2022), which involved temporarily increasing polygon density in order to add micro-irregularities such as chipped edges, abrasions, small fractures, and depressions. The work was carried out using a graphics tablet, treating the elements as proper digital sculptures.

From each base object, several variants were then produced, differing in the intensity of imperfections and fracture patterns. During scene generation, these variants were assigned to instances through a controlled randomization system, avoiding visual repetition and restoring the natural heterogeneity of the materials.

Procedural materials

In parallel with geometric work, material definition was developed. Based on the photographic dataset from the survey, reference textures were created and integrated with procedural maps in Blender’s Shader Editor. Normal, roughness, and displacement maps were combined to reproduce the grain of the stone, surface absorption variations, and ageing effects.

The procedural component, managed also through Open Shading Language (Larry Gritz, 2020), introduced microscopic random variations in color and roughness without requiring an excessive number of distinct textures. Here too, the link between material and instance is stored within the metadata, enabling controlled regeneration of the model in different environments.

Environment and context

The theatre was placed within a simplified environment reproducing the current landscape of the site, without reconstructing the entire ancient city to keep computational costs and complexity under control. The main slope, selected vegetation masses, and an HDRI-based lighting setup were modeled and calibrated to simulate neutral daylight. This configuration allows for a clear reading of the theatre’s volumetry, cast shadows, and the overall visual effect of the scene reconstructed according to Gerkan’s hypothesis.

VIRTUAL REALITY

The model, once prepared, was exported into Unity for the creation of an immersive environment (J. G. Bond, 2017). The goal was to offer a virtual visit experience useful for comparing the current state with the proposed reconstruction.

Importing and optimization in Unity

Within the game engine, several panoramic camera positions were created, corresponding to significant viewpoints: the orchestra, the proedria, the lateral sectors of the cavea, and the lowered viewpoint at stage level. Each position was transformed into a 360° panorama, allowing the user to explore the surroundings through gyroscopic sensors or standard joystick-based controls.

Interface and interpretative functions

The navigation interface features a simplified map of the theatre, with buttons enabling rapid selection of the desired viewpoint.

The application was developed for Android devices and desktop computers, with the possibility of use both through VR headsets and in “flat-screen” mode. This dual configuration makes it suitable for exhibition and museum contexts as well as for educational and research scenarios.

CONCLUSIONS

The work carried out on the Theatre of Priene shows how the integration of historical sources, photogrammetric survey, procedural modeling, and virtual reality can generate a digital model that is not merely a three-dimensional replica, but an actual tool of knowledge. The centrality attributed to Armin von Gerkan’s reconstruction hypotheses for the scene, verified and integrated in light of the survey and the documentation of Wiegand and Schrader, demonstrates how digitalization does not replace archaeological judgment, but makes it more readable, verifiable, and communicable.

The decomposition of the theatre into typological objects and instances, described through XML metadata, enabled the construction of a scalable, updatable, and interoperable information model across different software environments. The rendering phase in Blender transformed this abstract model into a photorealistic scene able to convey the material quality of the marble, the imperfections accumulated over time, and the spatial articulation of the complex. The implementation in Unity finally made the theatre an explorable environment.

In this sense, the Theatre of Priene becomes a laboratory for defining procedures that can be transferred to other contexts of archaeological heritage: a method that starts from historical documentation, compares it with digital surveying, builds a transparent procedural model, and returns it in accessible an d immersive forms. The scene, which in antiquity hosted theatrical performance, became today a space for the representation of knowledge, no longer only a place of spectacle, but an interface between data, interpretations, and contemporary audiences.

From a methodological point of view, one of the most significant outcomes is the possibility of keeping three levels separate yet in continuous dialogue: the measured data, its geometric abstraction, and its immersive translation. The transition from the survey to the VR scene does not occur in leaps, but through a chain of traceable transformations, each of which leaves a “signature” within the metadata. This makes the model not only reusable but also open to critical revision: a hypothesis can be replaced, a parameter updated, an entire section regenerated without having to start again from scratch. In a context where technologies evolve rapidly, this capacity for adaptation becomes a fundamental requirement for any digital archaeology project that aims to endure over time.

Abstract

The Theatre of Priene is a well-preserved example of Greek theatrical architecture, offering an exceptional case study for the integration of historical documentation and digital methodologies. The theatre dates to the late Classical and early Hellenistic period and preserves cavea, orchestra, proedria, and proskenion. It was the subject of extensive documentation during late 19th-century excavations, which provides a solid foundation for interpretative reconstruction. This study presents a comprehensive digital workflow combining photogrammetric survey, parametric modelling, and virtual reality visualisation. UAV and terrestrial photogrammetry allowed producing a metrically reliable 3D model, subsequently refined through data cleaning and validation against historical sources. The model was then transposed into typological elements governed by generative rules, enabling the creation of a metadata-based system. The integration of detailed modelling and material rendering further enhanced the legibility of architectural forms and surface characteristics. Finally, the digital model was implemented within a virtual environment to support immersive exploration and comparative analysis between the current state and reconstructed hypotheses, demonstrating how the convergence of archaeological evidence, digital survey techniques, and advanced visualisation tools can produce a coherent and accessible narrative for both scholarly investigation and public dissemination.

Keywords

Architecture; Archaeology; 3D model; UAV ; Drone; photogrammetry; mesh; texture; Virtual Reality, APP; digital reconstruction;

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