International Symposium on the Conservation of Monuments in the Mediterranean Basin

(2024)

Proceedings of the 11th MONUBASIN (2024)

Contribution of 3D Bedrock Formation to the Restoration of the Ancient Theater of Dodoni, Greece

Dimitrios Makris, Petros Katsoudas

doi: 10.12681/monubasin.8179

Contribution of 3D Bedrock Formation to the Restoration of the Ancient Theater of Dodoni, Greece

Dimitrios Makris, University of West Attica, Campus I, Ag. Spyridonos Street, Egaleo 122 43, Athens, Greece
demak@uniwa.gr
Petros Katsoudas, Ephorate of Antiquities of Ioannina, Ioannina, Greece
pkatsoudas@culture.gr

Abstract. The study focuses on developing and implementing a methodology for restoring and reconstructing the ancient theater in Dodoni, Greece, using advanced digital technologies. The research employed photogrammetry to create detailed three-dimensional documentation and diagnosis of the conservation status of two kerkides at the theater. The Dodoni Theater, a significant historical monument, faces numerous preservation challenges, including the need for extensive documentation of its architectural members. The project aimed to preserve cultural heritage by producing a detailed digital 3D replica of the theater's bedrock, which supports both the accuracy of restoration efforts and the understanding of the monument's original construction logic. The study included creating 3D models of kerkis 9A before restoration, revealing essential geometrical and structural details. These models were crucial for the accurate repositioning and identification of displaced members of the theater. The study's framework enhanced research efficiency by integrating digital repositioning and identification techniques, thereby minimizing errors during the restoration process. The overall methodology proposed in the study significantly improves the restoration quality and process efficiency for monumental architectural heritage like the Dodoni Theater. The digital models and workflow processes developed are intended to assist future conservation efforts, providing a foundation for precise restoration and preservation of similar historical sites.

Keywords: Digital Reposition, 3D Digitization, Building Analysis, Ancient Theatre, Close-Range Photogrammetry, 3D Model, Digital Cultural Heritage

1 Introduction – The theatre of Dodoni – challenges and open issues

The Dodoni Theatre is a monumental structure associated with the reign of Pyrrhus. The orchestra forms a complete circle, with the thymele positioned at the center. The koilon has a capacity of approximately 15,000 spectators and is divided into nine kerkis (**Fig. 1**). Two concentric pathways, known as diazomes, vertically divide the koilon into three sections. The configuration of the ancient theater, as it appeared until 2009, is the result of restoration work completed in a relatively short period during the 1960s [1] (**Fig. 2**). This restoration enabled the theater to host performances of ancient drama in the summer of 1960. The projects completed in 1960 were executed in a short timeframe without the necessary documentation. This lack of documentation led to improper placement of architectural elements, geometric deviations, and the loss of components due to wear, as well as limited information regarding the monument's original condition. Furthermore, the pathology of the stone material, combined with environmental conditions, has contributed to the dissolution and loss of material, alterations due to wear, and misinterpretations. Consequently, an additional challenge to the quest for authenticity has emerged for contemporary scholars.

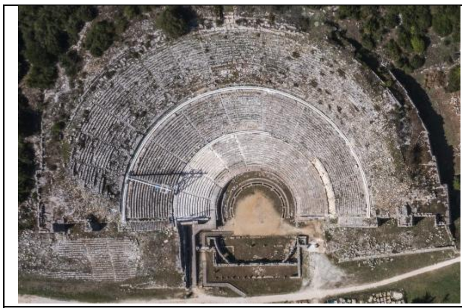


Fig. 1. Location of the archaeological site (Ephorate of Antiquities of Ioannina).

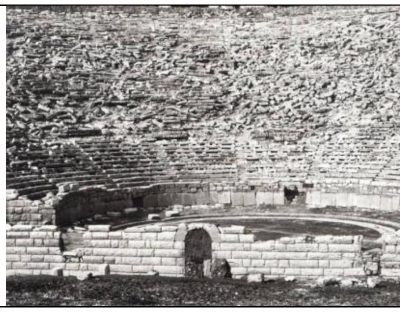


Fig. 2. Restoration works 1960's (Ephorate of Antiquities of Ioannina).

In the 2000s, an important multidisciplinary study was conducted on the topography and architecture of the koilon, the static analysis of the retaining walls, and the conservation of materials. This research culminated in an examination of the two eastern lower kerkis and their corresponding retaining wall [2, 3]. The use of a point cloud during this phase of the study greatly enhanced the estimation of the koilon's geometry and the restoration of the two eastern kerkis.

The restoration of the lower zone seven kerkis was completed in 2022 through a staged development process, which included the approval and implementation of studies for each stand. Over the past decade, the studies conducted by the Ephorate of Archaeology of Ioannina have focused on preserving the material, recovering lost authenticity, and achieving the morphological restoration of the monument.

For this purpose, the potential of digital technology was harnessed through a combination of methodological tools, with a primary focus on authentic members related to the time period of the monument prior to 1960. [4, 5].

Among the major challenges in documentation are: a) the issue of original geometry, b) the positioning of original members, c) the authenticity of fittings for neighboring members, and d) the identification of fragmented parts belonging to the same member. The restoration methodology begins with an on-site investigation of the architectural members in their original location, followed by their removal and transport to the construction site, where comprehensive measurements are conducted prior to maintenance work. Field testing and the development of final restoration plans are subsequently carried out. This process demands significant effort and meticulous organization to safely transport a large number of members, each averaging approximately 1,000 kg. During the cleaning of kerkis 9A, stepped rock was uncovered (**Fig. 3**). Its surface exhibits vertical and horizontal formations, indicating direct contact with the architectural members of the koilon (footstools, steps, edolia).

Fig. 3. The bedrock of kerkis 9A (Authors)

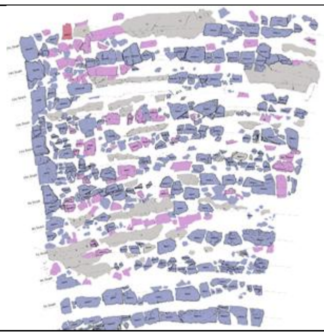


Fig. 4. Bedrock in gray color. Pathway plates in blue color (6)

These formations provide essential information for the construction logic of the monument, and their study is a fundamental requirement for the accurate geometric restoration of the koilon (**Fig. 3**). From the restoration work conducted thus far, a significant number of members in the lower zone, particularly those in kerkis 9, are constructed on formed bedrock [6] (**Fig. 4**). The bedrock remained clean and visible for only six months, which facilitated a comprehensive application of three-dimensional (3D) documentation techniques.

1.1 Research Aims – Objectives

The Dodoni Theater presents significant restoration challenges, primarily due to the complex and detailed documentation required for its architectural members. Among these challenges is the need to accurately determine and reposition the original placement of the edolia (seats and footrests), which is crucial for preserving the theater's historical integrity. To address these challenges, we propose a comprehensive methodological framework that employs advanced 3D digital acquisition and modeling technologies specifically tailored to the theater's unique architectural features.

The primary objective of this framework is to digitally support the restoration of the kerkis by employing advanced 3D documentation techniques. By revealing and meticulously documenting the exposed rock relief in three dimensions, we aim to enhance ongoing efforts to document and restore the theater's architectural members. This digital approach provides a detailed and accurate record of the state of the kerkis 9A, which is vital for guiding future restoration work. The second objective is to accurately document the positions of the edolia and to plan their precise repositioning in a more efficient and systematic manner. To achieve this, we developed a methodology that combines the digital study of the rock surfaces with an analysis of their relationship to the architectural members, such as the edolia. This approach involves integrating close-range photogrammetric capture, creating detailed 3D models, and applying digital assessments to match and verify authentic joints between components. This enhanced workflow serves as an essential tool for the restoration team, providing the capability to explore various digital repositioning scenarios and make informed decisions throughout the restoration process. By offering a reliable and precise digital reference, this methodology significantly improves the efficiency and accuracy of restoration planning. Overall, the proposed framework not only addresses the immediate challenges of restoration but also establishes a new standard for the use of digital tools in the preservation of complex cultural heritage monuments.

2 Relevant Approaches

Numerous studies focus on the application of laser scanning, 3D imaging, and modeling methodologies, which are essential for documenting and reconstructing archaeological monuments, particularly ancient theaters [7, 8]. Concurrently, 3D digitization through photogrammetry significantly enhances our understanding of these structures by ensuring the accurate restoration of both surface and volumetric features, thereby aiding in the visualization and highlighting of many ancient theaters [9, 10, 11]. The digital capture of architectural and decorative elements facilitates a comprehensive understanding and precise reconstruction of replicas, which is vital for completing restorations [12, 13]. However, to our knowledge, the existing literature does not include comprehensive 3D surveys of the kerkis' bedrock. Examining the rock relief and conducting a detailed study could provide valuable documentation regarding the original formation of the kerkis structure and, consequently, its theater. In the Dodoni theater, we have a unique opportunity to digitally survey the rock relief in detail.

3 Data Acquisition – Processing – Editing

In the context of the restoration of the koilon, significant emphasis was placed on the acquisition and documentation of the exposed bedrock. The carvings in the natural rock of the slope provided valuable insights into the geometry of the theater. However, they also raised questions regarding the initial placement of the edolia and the necessity for their precise repositioning. This section focuses on the digital capture, processing, and creation of 3D models of the bedrock of K9A kerkis, as well as other members within the same kerkis of the ancient theater of Dodoni. Close-range photogrammetry was employed as the primary tool for documentation due to its rapid image acquisition and high accuracy. A photogrammetric methodology was developed, and three-dimensional models of Kerkis 9A were created prior to any restoration work (**Fig. 5**) in collaboration with the staff of the archaeological site of Dodoni. The process involved photographing the bedrock surface and three consecutive steps: B9A07, B9A08, and B9A09, along with an edolion, K9A18 (**Fig. 6**), which is in contact with the middle step B9A08 on its left side.

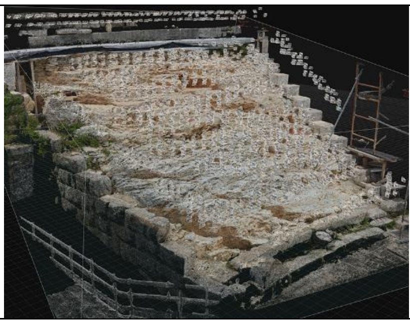


Fig. 5. Parallel lines on the rock, photos (Authors)

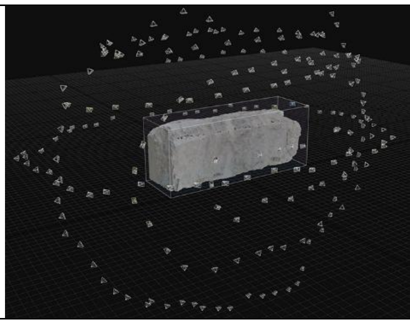


Fig. 6. Edolion photos (Authors)

The entire bedrock was documented in its full magnitude through perimeter photography, utilizing parallel lines that followed the slope levels of the rock wherever the slope relief permitted. All sides of the steps and edolion were photographed to facilitate a comprehensive photogrammetric reconstruction (material collection-processing by M. Tenechtsi, graduate student, Department of Conservation of Antiquities and Works of Art, University of West Attica). The data were then processed using two different software programs ContextCapture© (archaeological site of Dodoni) and RealityCapture© (academic license), for creating the 3D reconstructions. Open-source software, Meshlab, was subsequently employed for post-processing and exporting the final product, which includes individual 3D renderings of each object. The resulting models were further processed to extract the final output, which encompasses the 3D geometry and color information of each object separately.

Fig. 7. K9A Orthographic view (Authors)

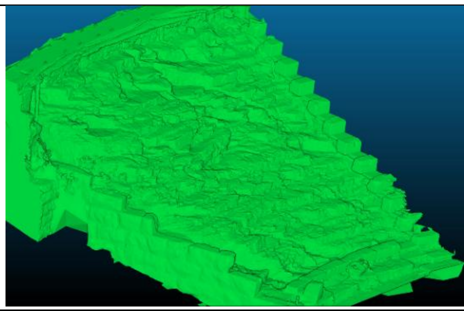
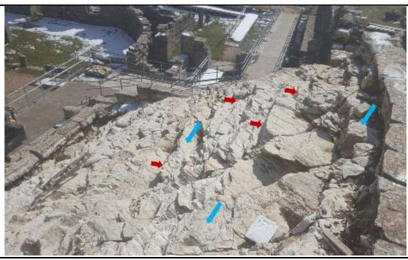


Fig. 8. K9A Isometric view (Authors)

A georeferenced 3D drawing was created for editing and aligning with other footprints to accurately orient and scale 3D models to their real-world dimensions (**Fig. 7**, **Fig. 8**).

4 Digital Repositioning Processes - Results

During the cleaning of the bedrock at kerkis 9A, a stepped rock formation was uncovered. The carvings in the natural rock of the slope, which emerged for the first time, provided valuable insights into the geometry and natural drainage of the theater. However, they also raised questions regarding the initial placement of the edolia and the necessity for their precise repositioning. The ancient formations on the surface of the natural rock revealed significant details about the original geometry of the theater and the edolia. Analyzing the surface of the rock, we observe that it features both horizontal and vertical formations, which were designed to accommodate the main members of the theater, including footstools, edolia, and steps (**Fig. 9**; **Fig. 10**).



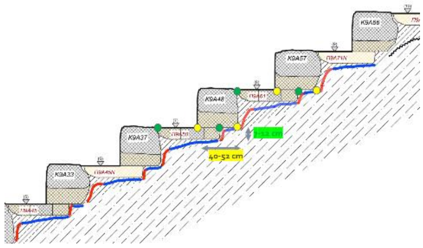
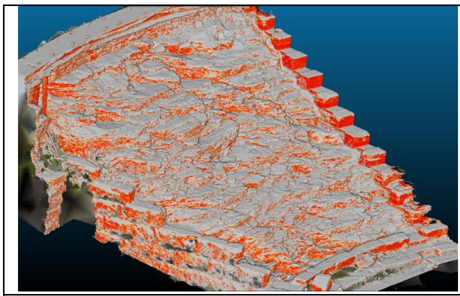


Fig. 9. Areas of carvings – vertical / horizontal (Authors)

Fig. 10. rock section Horizontal-vertical formations (blue-red). Edolion bearing lines (yellow) (Authors) (6)

The digital analysis of 3D data, utilizing point cloud analysis tools in CloudCompare (an open-source software), enables the identification of areas exhibiting both vertical (**Fig. 11**) and horizontal (**Fig. 12**) formations within the bedrock volume. Specifically, the horizontal carvings were primarily created to facilitate the direct seating of slabs during the construction of the corridors and the steps in the stair areas. The vertical carvings are associated with the backs of the slabs as well as the edolia. The specific mode of rock formation provides compelling evidence for the constructional logic of the theater and serves as a fundamental basis for the accurate geometrical restoration of the koilon.



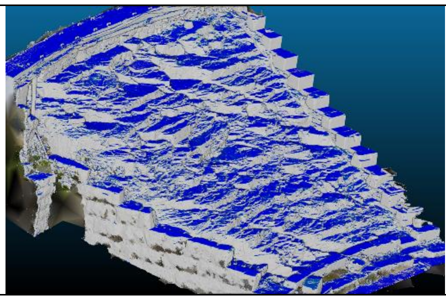
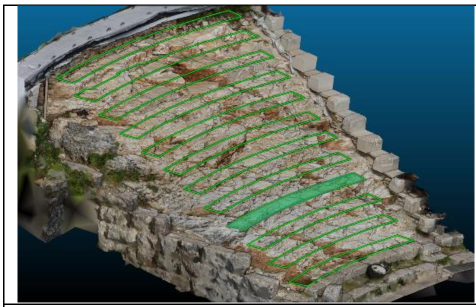


Fig. 11. Areas with vertical formations (Authors)

Fig. 12. Areas with horizontal formations (Authors)

A previous study conducted to update data and compare it with the quasi-original geometry of the monument [14] provides georeferenced 3D elevation planes, which are associated with the estimated end levels of the corridors situated above the 3D relief. Each closed line represents the estimated elevation of the corridors, which corresponds to the seating level of the edolion (**Fig.** ***13***). The elevations were derived from the geometric study of the koilon, specifically from the front line (plate edge) to the estimated width of the back line. The estimation of the heights, as well as the curvature of each level, resulted from the koilon's geometric analysis [14]. The inner curve toward the orchestra aligns with the front edge of the slabs, while the width of each level corresponds to the average width of the corridor slabs following their detailed mapping. Consequently, the georeferenced edolion levels for each edolia row are represented on the 3D relief model (**Fig. 14**). Each closed line indicates the elevation of the corridor plane, which also corresponds to the seating level of the edolion in the respective row. The internal curve toward the orchestra is identical to the front surface of the edolia, while the width of each level corresponds to the average width of the edolia after their thorough documentation.



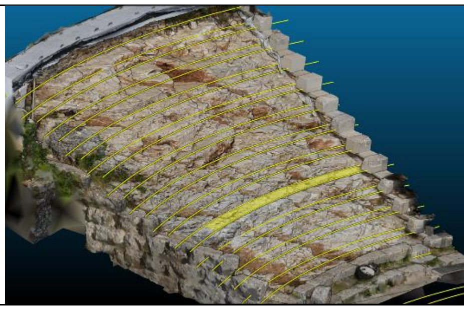


Fig. 13. Corridors levels. Front line: plate edge. Back line width estimate. (Authors)

Fig. 14. Edolia lines. Front line: Edolion edge Back line width estimate. (Authors)

The next step involves comparing the levels of upper georeferenced slabs and assessing the relationship between the edolia and the bedrock relief across the bearing area for each kerkis row. We analyze the data for the 7th row of edolia in kerkis 9A (**Fig. 15**). The estimated absolute elevation of the upper surface of the corridor is 632.29 m. The thickness of the corridor slabs, as determined by precise measurements of the stripped slabs, ranges from 7 to 12 cm. We delineate in the 3D relief the area with elevations ranging from 632.22 m (corresponding to -7 cm) to 632.17 m (corresponding to -12 cm). This area represents the direct bearing surface for the plates' various thicknesses of the plates. Utilizing the scalar field feature of CloudCompare software, we illustrate the elevation differences from 632.22 m (at -7 cm) to 632.17 m (at -12 cm). Areas depicted in red are closer to the reference level of the corridor surface, while areas shown in blue are further away (**Fig. 16**).

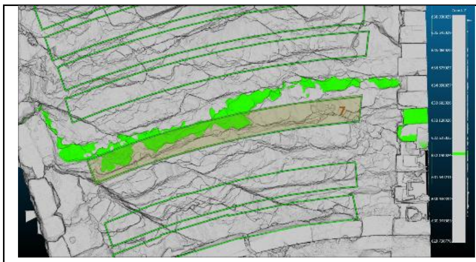


Fig. 15. Area delineation. Elevations from -7cm to -12cm. (Authors)

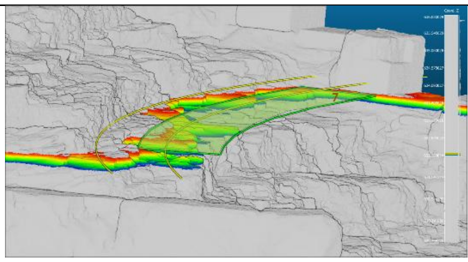


Fig. 16. Elevation's color gradation -7cm to -12 cm. (Authors)

In this manner, we visualize the topography of the rock in the vicinity of the reference plane. Subsequently, we correlate the rock topography with the width of the reference plane, which represents the average width of the corridor slabs.

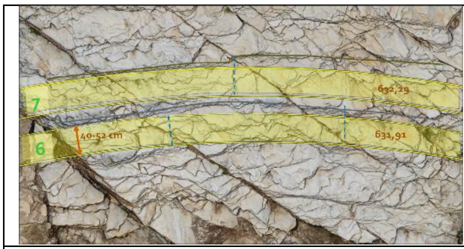


Fig. 17. Edolia bearing rows 6th and 7th. (Authors)

Fig. 18. Edolion bearing lines row 5th (yellow lines). (Authors)

In this manner, we have established the following confirmed facts: a) the level estimation of each row is validated with high confidence; b) minor corrections are implemented in the event of deviations from the initial estimate; c) misplaced runway slabs are managed more effectively based on their thickness and the contour of their bottom surface; d) misplaced corridor slabs are managed more effectively according to their width (ranging from 40 to 55 cm); e) joints between adjacent plates are identified (indicating changes in level and width); f) an accurate assessment is conducted regarding the preparation of the substrate for the repositioning of the slabs. Subsequently, we perform a similar workflow for the edolia of each row. (**Fig. 18**).

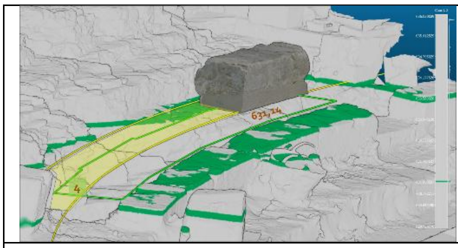


Fig. 19. 3D reconstructed edolion's digitally reposition to its estimated position in the 3D relief. (Authors)

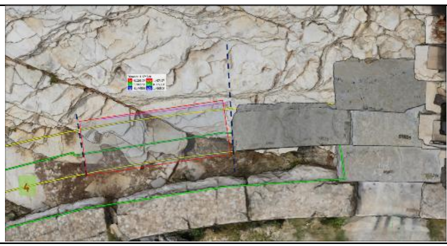


Fig. 20. plan view of edolion placement K9a18, with adjacent member boundary (Authors)

In the case of the 4th row of edolia, we place the georeferenced edolion plane—estimated to have an elevation of 631.14 m and a width corresponding to the mean edolion width—onto the 3D relief (**Fig. 19**). We then delineate the area with elevations ranging from +0 cm (632.14 m) to -5 cm (632.09 m) to identify points where the edolion directly interacts with the rock relief. Subsequently, we correlate the vertical carvings in the bedrock with the width of the reference plane, which represents the average width of the rows of edolia. This approach allows for better management of misplaced edolia by associating the features of the rock relief with their geometric characteristics. Additionally, we can digitally reposition the 3D reconstructed edolion to its estimated location within the 3D relief (**Fig. 19**). The guide for the placement of the edolion is based on the specific row edolion level (**Fig. 20**). Consequently, we can define precise sections that validate both the accuracy of the placement and the geometry of the edolion in relation to its proximity to the bedrock (**Fig. 21**). This method helps to prevent errors during the restoration process.

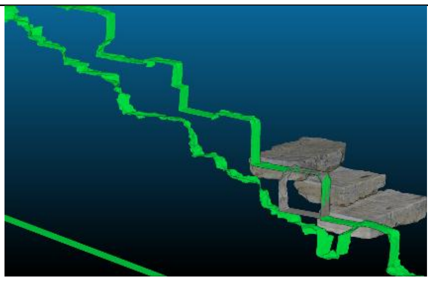


Fig. 21. 3D digital section (Authors)

Fig. 22. Orthographic view ((Ephorate of Antiquities of Ioannina)

Finally, it is possible to digitally position contiguous members (for example, steps B9A07-08-09 and an adjacent edolion, as they were arranged during the restoration of kerkis 9A) (**Fig. 20**; **Fig. 21**). In this instance, in addition to verifying the contact surfaces of the members in relation to the rock, the original contact surfaces between the contacting members are also documented (**Fig. 21**).

5 Discussion – Conclusions

The approaches outlined in this study aim to enhance the capabilities of restoration teams during the restoration study phase, particularly by improving the documentation and identification of the original positions of each architectural component. The primary goals are to maximize efficiency by optimizing the movement of the actual architectural members (e.g., edolia) and to minimize errors during the repositioning and restoration processes. The integration of a 3D digital restoration workflow into the ongoing koilon restoration process significantly enhances the precision of restoration efforts, enabling the accurate reorganization of architectural members by identifying their original positions and authentic connections (**Fig. 22**). This approach not only streamlines research and restoration processes but also establishes a reliable digital reference, which is crucial for preserving the integrity of complex cultural heritage monuments, such as the Dodoni Theater. By setting a new standard for the use of digital tools in restoration, this framework effectively addresses the challenges associated with these intricate projects.

One of the key strengths of the proposed framework is its emphasis on detailed documentation of the theater both before and after the removal of its architectural components. High-quality 3D models are created for each member, capturing their precise condition and geometry, thereby providing an invaluable digital record. This comprehensive documentation extends to areas of the monument that lie below the visible surface, such as foundational rock formations, which are often the most enduring members and offer critical insights into original construction techniques. By incorporating these frequently overlooked elements, the framework ensures a thorough and accurate reference that supports long-term preservation and restoration.

The framework's capability to digitize and document the geometry and topography of the monument provides crucial evidence of the original positions of ancient architectural members in the koilon. This digital record is vital for managing misplaced components, offering precise data that facilitates accurate identification and comparison of members within their intended locations. Consequently, this process enhances the reattachment of displaced components, ultimately improving the accuracy and efficiency of restoration efforts. Furthermore, the digital documentation of the bedrock has enabled more precise application studies in a virtual environment, creating a comprehensive future reference archive of the kerkis. This archive ensures that the data remains accessible for ongoing and future restoration projects, thereby supporting continued research and preservation activities.

Overall, the framework developed in this study not only advances the documentation and restoration of monumental structures, such as the Dodoni Theater but also establishes a new benchmark for the integration of digital tools in cultural heritage preservation. The results demonstrate that a comprehensive digital approach can significantly enhance both the processes and outcomes of restoration efforts, providing a robust and sustainable solution for the preservation of complex historical sites.

Acknowledgements

We are grateful to the Ephorate of Antiquities of Ioannina for providing us with the necessary permissions for publication. The funding for this paper was provided by the University of West Attica.

References

1. Dakaris, S. I.: The Sanctuary of Dodoni. Archeological Bulletin, 16 A΄ Studies, pp. 4-40. (1960) (in Greek).
2. Architecture Ltd Grammatopoulos P.-Panousakis Chr.: Architects, Chatjiantoniou K.: civil engineer, Vozikis E.: Surveyor. (Special Consultants: G. Antoniou-Architect, N. Katsikoudis: Archaeologist, P. Theoulakis: Conservator): Study of consolidation and restoring the ancient theater of Dodoni, Athens, (2007) (unpublished-in Greek).
3. Antoniou, G.: Documentation of the geometry and earlier interventions of the ancient theatre of Dodona. In Proc. of the XXI International Symposium, CIPA 2007 AntiCIPAting the future of the cultural past. Athens, Greece, pp. 73-78, (2007).
4. Katsoudas, P.: Restoration study of the ancient theater of Dodoni: methodology of documenting the monument. Society for Research and Promotion of the Scientific Restoration of Monuments (ΕΤΕΠΑΜ). 4th Panhellenic Restoration Conference, Proceedings Thessaloniki, November 26, 27, 28. (2015) (in Greek).
5. Katsoudas, P.: Documentation of the architectural and geometrical elements of the Dodona theater using new technologies. In: Speira. Proceedings of the scientific meeting in honor of A. Douzougli and K. Zachos, pp 345–356 TAPA, Athens (2017). (in Greek).
6. Katsoudas, P.: Final Study for the Consolidation and Restoration of the 9th Kerkis and the western Retaining Wall in the 1st Diazome of the Ancient Theater of Dodoni. Ministry of Culture, (2020) (unpublished-in Greek).
7. Cuneyt Erenoglu, R.C., Akcay, O. Erenoglu, O.: An UAS-assisted multi-sensor approach for 3D modeling and reconstruction of cultural heritage site. Journal of Cultural Heritage, 26, 79–90 (2017). doi.org/10.1016/j.culher.2017.02.007
8. Bilis, T. Kouimtzoglou, T. Magnisali, M., Tokmakidis, P.: The Use of 3D Scanning and Photogrammetry Techniques in the Case Study of the Roman Theater of Nikopolis. Surveying, Virtual Reconstruction and Restoration Study. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Nafplio, Greece, pp: 97–103, (2017). doi.org/10.5194/isprs-archives-XLII-2-W3-97-2017.
9. Gabellone, F., Ferrari, I. Giuri, F.: The Greek-Roman Theater of Taormina: Towards a Reconstruction Proposal. In Proc. of the 22th International Congress “Cultural Heritage and New Technologies”, CHNT 22, 2017, Vienna, pp. 1-9. (2019).
10. Özer, D.G., Nagakura, T., Vlavianos, N.: Augmented reality (AR) of historic environments: Representation of Parion Theater, Biga, Turkey. A|Z ITU Journal of the Faculty of Architecture, 13(2), pp 185–193, (2016). doi.org/10.5505/itujfa.2016.66376.
11. Gregorio, G., Monteleone, A.: Survey and Representation of the complexity of ancient theaters and amphitheaters. In: "XIII International Forum of Studies ‘Le Vie dei Mercanti’ Heritage and Technology. Mind, Knowledge, Experience pp. 100, Aversa, Capri, (2015).
12. Bartette, T. Rosso, E.: L’apport de l’imagerie numérique à l’étude d’un décor architectural complexe: le mur de scène du théâtre antique d’Orange. In Situ. Revue des patrimoines, (39), pp. 23. (2019). doi.org/10.4000/insitu.21669.
13. Katsoudas, P., Makris, D.: A proposal for the documentation and restoration of the Ancient Theater of Dodoni using digital duplicates. In: Proceedings Conference "Technological know-how and concerns on the occasion of the restoration of the theater of Dodoni" Ephorate of Antiquities of Ioannina, Epirus Region, Dodoni Municipality, (2022) (in press).
14. Katsoudas, P.: Application of the Geometric Model in the Restoration of the Lower Koilon. In: General master plan for the conservation and restoration of the ancient theater of Dodoni. Ephorate of Antiquities of Ioannina, (2023), (unpublished-in Greek).