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Three-Dimensional Digital Geospatial Documentation for Cultural Heritage Preservation and Sustainable Management of Tourism Through a Web Platform: The Case Study of the Archaeological Park of Dion, Greece

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Abstract: The sustainable management of heritage tourism sites requires an integrated approach that balances cultural preservation with socio-economic development. Modern methods of documentation include laser scanning, LiDAR sensors, and aerial photogrammetry. This study explores the application of advanced geospatial and digital technologies to the archaeological park of Dion, located in the Olympus region of Pieria, Greece—a site characterized by monuments from various historical periods. Using high-precision methods and high-end software, we produced detailed 3D models and developed a comprehensive digital platform incorporating Web-GIS applications. These outputs extend beyond conventional documentation, offering tools for education, community engagement, and participatory decision making. The originality of this work lies in its interdisciplinary synthesis of digital heritage technologies and land-use planning, contributing to both academic discourse and practical strategies for sustainable tourism development. The platform not only safeguards cultural assets but also promotes inclusive innovation, job creation, and long-term planning models aligned with the sustainable development goals (SDGs). This case study contributes not only to the safeguarding of cultural heritage for future generations but also to reshaping tourism models that prioritize long-term sustainability over rapid economic gain.

Keywords: cultural heritage; preservation; sustainable management; tourism; virtual tourism; 3D documentation; Dion archaeological park

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1. Introduction

Cultural activities in the era of digital communication and globalization protect, preserve, and promote cultural heritage, while fostering contemporary cultural creation. These activities encompass events related to the production of both tangible and intangible cultural goods. When designed with the principles of public interest in mind, cultural

activities contribute to the evolution of cultural processes and play a vital role in shaping cultural policy, as well as enhancing economic, social, and spiritual well-being within a region [1,2].

The successful and sustainable development of cultural activities require innovation, along with modern management and development models. Nowadays, culture evolves dynamically across two interconnected and parallel landscapes—the physical and the digital—both of which contribute to the cultural development. This dual growth helps establish the necessary conditions for fostering local, regional, and global cultural policy networks [3,4].

Cultural heritage is a fundamental and distinctive pillar of Europe's cultural identity. Moreover, it has become crucial issue for sustainable development and tourism policies. With nearly 560 UNESCO world heritage sites in Europe (UNESCO, Statista 2024), the need to balance heritage conservation with increasing tourism demand has led to the proliferation of integrated strategies and policy tools. These include the UN's Sustainable Development Goals (particularly SDG 11.4), the European Framework for Action on Cultural Heritage (2018), and UNESCO's updated recommendations on the safeguarding of digital heritage [5–7].

Carmen Périz Rodríguez (Spanish Ministry of Culture and Sports) in Europeana stories mentions that the modern concept of tourism can be traced back to 17th century when young nobles from West and North Europe embarked on the "Grand Tour"—a journey across Europe, typically including France, Germany, Italy, and Greece. The primary purpose of this journey was to immerse themselves in history, art, and cultural heritage, making it an essential part of their education. By the 18th century, this practice had become widespread among the wealthier classes and eventually extended to other parts of the world, including America. Culture and tourism have always been deeply interconnected. Cultural landmarks, attractions, and events serve as key motivators for travel, while travel itself contributes to cultural exchange and development. However, it is only in recent decades that the relationship between culture and tourism has been more clearly recognized as a distinct form of consumption—cultural tourism [8]. Since the 1990s, the rise in culturally motivated travelers, alongside the overall expansion of cultural heritage tourism, has solidified this sector as a key economic resource and asset [9–11].

Global cultural tourism is expected to grow by 15% in the coming years, making it one of the fastest-growing segments in the tourism industry, currently accounting for approximately 40% of all tourism worldwide. American cultural heritage travelers contribute significantly to the economy, generating an economic impact of USD 123.6 billion. Notably, 30% of adults report that a specific art, cultural, or heritage event influenced their choice of destination on their most recent trip. More recently, research on cultural tourism has focused on achieving a balance between tourism development and the preservation of cultural heritage [12].

The digital turn in cultural heritage is underpinned by several interlinked conceptual frameworks. The notion of cultural sustainability highlights the long-term value of preserving cultural resources for future generations, while ensuring community inclusion and equitable access [13–20]. Closely related is the concept of smart heritage, which integrates digital tools within heritage planning and tourism to enhance decision making and stakeholder participation [21]. In parallel, edutainment—the blending of education and entertainment—has reshaped public engagement, particularly among younger audiences [22]. Emerging research also emphasizes participatory heritage and the co-creation of cultural value through user-generated content, digital storytelling, and citizen science [23,24]. The integration of digital tools not only reshapes how cultural heritage is preserved and shared but also redefines visitor experiences, making cultural organizations

more immersive, engaging, and accessible. Historically, access to museums, historical sites, and cultural artifacts was often restricted by geographical, financial, and social barriers.

Recent advancements in digital documentation have significantly expanded the toolkit available to heritage professionals. Technologies such as TLS (terrestrial laser scanning), LiDAR sensors, and UAV-based photogrammetry allow the precise, non-invasive recording of monuments and landscapes [25–28]. These methods enable the creation of photorealistic 3D models, which serve as both analytical and communicative tools for the scientists and the public.

Furthermore, the integration of these models into Web-GIS platforms and immersive environments (e.g., VR/AR) has transformed the way users interact with heritage content [29,30]. These tools enhance spatial analysis, facilitate virtual access, and support data-driven conservation planning. Scholars have highlighted their potential to democratize access to heritage, particularly for remote audiences and under-served communities [31,32].

Across Europe, a series of projects have advanced the digital transformation of cultural heritage. Europeana, the EU's digital platform for cultural heritage, has aggregated millions of digitized artifacts and multimedia resources from across European institutions [33]. Projects like Inception (Horizon 2020), V-MusT.net, and ARtGlass have combined 3D modeling, semantic web technologies, and immersive storytelling to foster heritage tourism and education [34–36].

Similarly, regional initiatives such as Scan the World, Time Machine Europe, and the Virtual Museums of the Mediterranean have demonstrated the power of open-access 3D repositories, historical reconstructions, and geospatial storytelling.

However, much of the focus remains on well-funded or iconic heritage sites, often excluding lesser-known yet culturally significant areas from the digital mainstream.

Despite growing recognition of digital heritage's potential, challenges persist in embedding these tools within sustainable tourism strategies, particularly in smaller or underrepresented archaeological sites. There is a need for scalable, locally driven digital solutions that not only document heritage but also support participatory planning and inclusive regional development. This gap becomes more evident in countries with rich but underutilized cultural landscapes, such as Greece.

This study addresses this gap through a detailed case analysis of the archaeological park of Dion, located in the Olympus region of Pieria, Greece. This ancient site, marked by architectural remnants from various historical periods, provides a fertile ground for the integration of high-precision digital documentation and community-oriented heritage planning. Our methodology includes terrestrial laser scanning, UAV-based photogrammetry, and LiDAR, leading to the creation of detailed 3D models. These were integrated into a Web-GIS platform, designed not only for heritage visualization, but also as a tool for educational access, participatory decision making, and sustainable tourism management.

In doing so, this research contributes an original, interdisciplinary model that blends advanced digital technologies with sustainable land-use planning. It offers new insights into how lesser-known heritage sites can leverage digital platforms to foster visibility, conservation, and long-term socio-economic benefits aligned with global sustainability goals.

2. Case Study

2.1. Site Identification and History of Research

It was in 1806 that the British military officer and traveler William Martin Leake discovered and identified the ruins of Dion, amid the dense vegetation and rushing waters near Malathria, a small village of farmers and herdsmen. He recognized a theater; a stadium; and, in nearby bushes, the fortified walls of the ancient city. Half a century later,

in 1855, the French Archaeologist Leon Heuzey visited Dion and mapped the perimeter of the city walls, identified some of its towers, and recorded a number of inscriptions from ancient funerary stelae [37] (pp. 19–28).

After the liberation of Macedonia from the Ottoman Empire in 1912, the first Director of Antiquities, G.P. Oikonomos, collected and published all the inscriptions he had found in the vicinity of Dion, which were used as building materials for the houses of the neighboring village.

The first systematic archaeological research was carried out from 1928 to 1931 by Professor Georgios Sotiriadis, the rector of the newly founded University of Thessaloniki, thanks to whom the archaeological site was expropriated and saved, and the first small museum was erected to house the numerous excavation findings. Excavations stopped in 1931 and resumed thirty years later under the direction of Georgios Bakalakis, professor of classical archeology at the University of Thessaloniki. Since then, the excavation has an educational character, in addition to the research, with the participation of students. During the same period, Stylianos Pelecanidis, professor of Byzantine Archeology at the University of Thessaloniki, completed the excavation of the city's Early Christian Basilica [38] (pp. 12–13).

In 1973, Professor Dimitrios Pantermalis assumed direction of the university excavation, inaugurating a new period of systematic excavations, which revealed the history of Dion, in Greece and abroad. Attention was given to the excavation of the sanctuaries and the research of ancient worship, which resulted in the unearthing of the sanctuary of Olympios Zeus, as well as those of Demeter and Kore, Isis, and Zeus Hypsistos. Public buildings, such as the Hellenistic theater, the Roman agora (*forum*), and many Roman bath complexes, as well as private residences, some of which are particularly luxurious, such as the so-called Dionysos mansion, were also uncovered and identified [37] (pp. 19–28). University of Thessaloniki professors A. Mentzos, S. Pingiatoglou, T. Stefanidou-Tiveriou, and G. Karadedos participated in the new excavations, who investigated the ancient city and its walls for many years. Their research was systematically complemented by the University archaeologists K. Vasteli, M. Iatrou, E. Benaki, M. Zampelaki, and I. Vassiliadou.

From 2008 to 2019, the excavation was directed by professor emeritus of the Department of Archaeology, Semeli Pingiatoglou. Since 2020, associate professor of the Department of Archeology, Eleni Papagianni, has been directing the university's research and excavation at Dion.

The current study focuses on four of the monuments of the archaeological park, specifically the Sanctuary of Isis, the Sanctuary of Zeus Hypsistos, the Great Thermae (*public baths*), and the Roman Odeum of the Great Thermae (*concert hall*).

2.2. History of the Site

Dion is situated on the northern foothills of Mount Olympus in an area that ensures control of the narrow coastal passage between Macedonia and Thessaly (Figure 1). It has visual contact with the peaks of Mount Olympus, abode of the Greek gods, and it is characterized by a remarkable natural setting blessed with impressive environmental wealth. The river "Vafyras" flows to the east, and torrent "Ourlias" is to the north.

The location was chosen by the Macedonian kings as the center of the religious life of their Kingdom. It gained importance through the cult of Olympios Zeus, especially after the reorganization of the great festival of Zeus and the Muses by Archelaos, King of Macedon (413–399 BC), who increased its duration to nine days and added athletic and theatrical contests [37] (p. 19), [38] (p. 119). The kings themselves entertained friends and foreign visitors there, held banquets, and hosted lavish meals.

Having served as a place of worship, Dion developed over time into a thriving city. King Kassander, during the late 4th–early 3rd century BC, fortified this city, enclosing an area of 43 hectares, north of the area of the sanctuaries [39] (pp. 26, 41–44, 134).

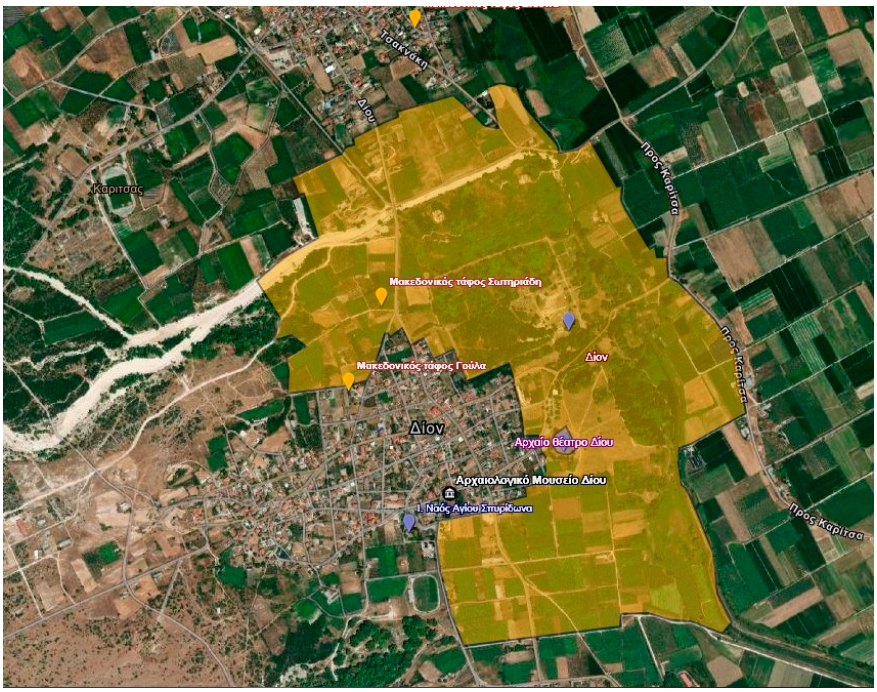


Figure 1. The archaeological park of Dion and its surrounding area (source: Archaeological Cadastre, https://www.arxaiologikoktimatologio.gov.gr/en (accessed on 22 April 2025)).

Following the end of the Hellenistic world, Roman Emperor Octavian designated Dion a colony, exempt of taxes and entitled to self-government. From the 3rd century A.D. onwards, a new period of prosperity and development began in Dion, which can be seen in many of the public and private buildings in the city [37] (p. 19). It is mainly this period of prosperity that is reflected in most of the architectural remains that visitors to the archaeological site can see today.

This prosperity was followed by a period of decline, until the early Christian period (4th century B.C.), when Dion was chosen as the seat of a bishop [40] (pp. 156, 182) and, despite the shrinkage of the city's size, it flourished again [41] (p. 432). The last reference to Dion is found in the "Peri thematon" work of Constantine Porphyrogenitus, dating to the 10th century AD.

2.3. Dion Archaeological Park

The significance of the archaeological site of Dion was recognized by the Greek state as early as 1963, when the fortified city and its environs were designated as an archaeological site (Government Gazette 583/B'/1963). Today, the Ministry of Culture safeguards an area of 1500 acres (Government Gazette 291/AAP/2013), encompassing the 650 acres of the archaeological park that is accessible to visitors.

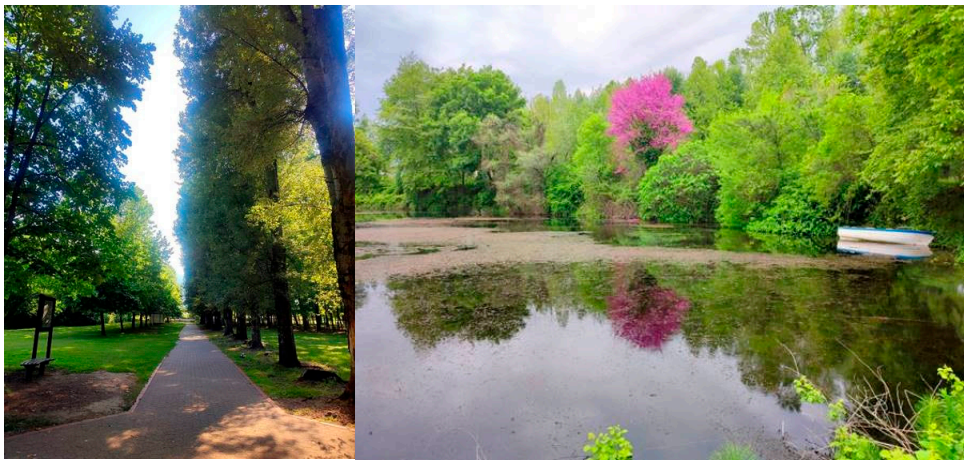
The archaeological park of Dion provides visitors with service facilities (museum shop, coffee shop, and sanitary facilities) [38], as well as with a network of landscaped paths [38] that extends for approximately four kilometers. Visitors are free to explore the site at their leisure, appreciating the historical remains, the lush natural environment (Figure 2), and the serene atmosphere. The tour can be completed with a visit to the nearby museum of Dion that exhibits numerous artifacts from the archeological site. Dion is easily accessible

by car, being situated in a flat area, close to the national highway, only 15 km away from Katerini, the capital of the Prefecture of Pieria, attracting thousands of visitors every year.



Figure 2. The entrance to the archaeological park (Ephorate of Antiquities of Pieria).

Visitors to the archaeological park of Dion can explore the two spatially separated areas of ancient human activity: the religious, spanning over an area of about 220 acres, to the south, and the urban, extending over an area of 430 acres, to the north (Figure 3).



(**a**) Visiting paths of the Park (**b**)Lush Environment of the Park

Figure 3. (**a**) Visiting paths across the archaeological park of Dion. (**b**) The lush environment in the archaeological park of Dion (Ephorate of Antiquities of Pieria) (Courtesy of Christos Koutroulos).

Over the sacred land, a number of sanctuaries have been unearthed, the most prestigious and venerable of which is the one designated to the worship of Zeus Olympios. It was here that Alexander dedicated the first great monument to his triumphs in battle, during his campaign in Asia. Twenty-five bronze horsemen, equestrian statues of the king's companions who had fallen during the Battle of Granikos in 334 BC were set in this sanctuary, created by the famous sculptor Lysippus, but were then transferred to Rome in 148 BC by the Roman praetor L. Caecilius Metellus as symbol of his victory over the Macedonians [38] (p. 19). The sanctuary was fiercely destroyed by the Aetolian army in 219 BC [42] (p. 67), but a monumental altar for the sacrifices to Zeus is still in sight [39] (p. 46) (Figure 4).

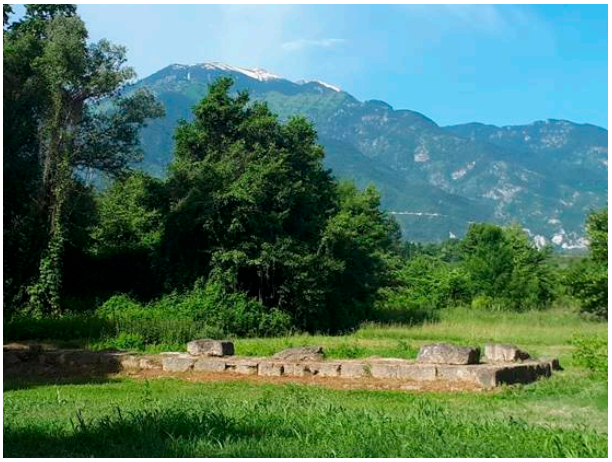


Figure 4. The altar of the sanctuary of Zeus Olympios in the foreground and Mt. Olympus in the background (Ephorate of Antiquities of Pieria).

Neighboring the sanctuary of Demeter is that of Asclepius, in which the most important healing god in ancient Greek religion, Asclepius, son of Apollo, was worshipped. The sanctuary, comprising a temple and a long stoa, was erected during the beginning of the Hellenistic period and was found containing numerous finds related to the God: fragments of sculptures; a head of daimon Telesforos, companion of Asclepius; and a sealstone depicting Eros holding a harp, dating to an earlier period [39] (p. 85), [43] (pp. 169–170). The sanctuaries of Zeus Hypsistos and Isis are also situated in the same area. In addition to the sanctuaries, this area of the archaeological park features a Hellenistic theater [44] (pp. 73–89) (Figure 5).



Figure 5. The Hellenistic theatre of Dion with Mt. Olympus in the background (Ephorate of Antiquities of Pieria).

The city was transformed into a Roman colony under the name of Colonia Iulia Augusta Diensis, and later, probably in the 3rd century AD, an extensive building program was carried out, during which the public spaces were renewed and new monumental complexes were added to the city: public and commercial buildings, such as the administrative center (the Roman agora or *forum*); numerous shops and workshops; a concert hall (*Odeum*); public toilets; accommodation for state officials; and guesthouses. The city was also equipped with many public bath complexes (*thermae*) scattered throughout its territory, the most monumental of which is the Great Thermae of the agora.

As for the private houses of the city, they were built by a wealthy and powerful elite, who did not consider home as a private space but as an element of public life and a means

of projecting their social prestige. The large residential complexes that have been identified (conventionally named the houses of "Dionysus", "Euboulos", "Epigenes", "Zosa", "Leda", and "Athena") are characterized by significant luxury, which is reflected in their large dimensions, mosaic floors, and valuable furnishings.

After the spread of Christianity, at the beginning of the 4th century A.D., Dion became the seat of a bishop and prospered. Despite the shrinkage of the city within a smaller fortification wall, a magnificent episcopal basilica was established near the former Roman agora along with a cemetery basilica, outside the city's walls.

Over the centuries, the ancient place of worship and urban life was covered with soil and Dion fell into oblivion. But its name survived until modern times, paraphrased as "Stadia" and the memory of the fortified city remained with the present inhabitants of the village, who call the site "Kastro" (*castle*).

3. Methodological Framework

The proposed methodology (Figure 6) focuses on establishing an approach where the use of geomatics in accordance with historical documentation can elevate the tourism management of archaeological parks. At the core of this approach is the integration of 3D documentation data with historical data regarding a monuments' preservation state that with analysis can lead to sustainable tourism management. Focus is given to the preservation and reintroduction of significant sites within archaeological parks to address the challenges of monuments', sites', and archaeological parks' vulnerability, especially in cases of on-going excavations or preservation works.

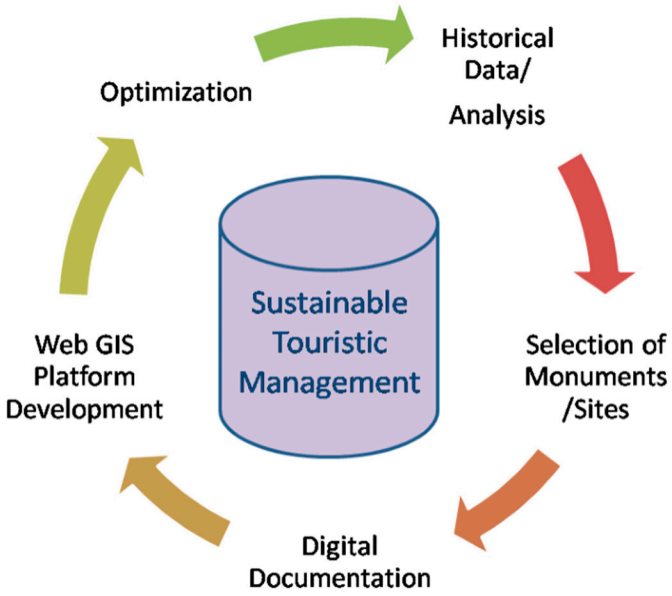


Figure 6. Methodological approach for sustainable tourism management.

Initially, a bibliographical review of all the historical and archaeological data for the archaeological park is necessary. All available data from the Ephorate of Antiquities archives were documented, and information on the current state of preservation of the sites, remains, or areas with ongoing excavations within the archaeological park was obtained. During this documentation process and analysis, specific monuments and sites were selected, focusing on the areas where excavation or restoration works are finished.

Following this, a thorough digital documentation was performed using terrestrial laser scanning (TLS) for a detailed 3D point cloud and consequently a 3D model of each monument and site. In addition, UAV image capturing was also used so that each monument

and site were fully documented, since often cultural heritage assets include complex and obscure surfaces. Moreover, this detailed 3D information should comprise georeferenced data for further investigation within the archaeological park.

The next step towards sustainable touristic management of these documentation data is the development of a web platform, incorporating all the relevant information such as historical data, photographs, structural information, building materials and decay data, past restoration works, and 3D models within a georeferenced map. Additional information was included with the administrative data, access network of the archaeological park, anthropogenic and environmental data, and other relevant information. A VR application was developed for an off-site experience of the archaeological park as well.

Therefore, concerning these vulnerable archaeological sites within the archaeological park, they can be accessed through an online experience, concluding with a decrease in the pressure of over-tourism. In addition, moreover, the development of the platform leads to an improvement of accessibility for both researchers and the public as well. Through the digital archives and the virtual exploration of the archaeological park, an immersive experience can be provided, leading to a reduction of physical damage of the vulnerable archaeological sites and monuments and conclusively to a lower environmental impact of travel and on-site visits.

The platform in its entity offers an integrated presentation of the archaeological park of Dion for different types of users, e.g., tourists, students, scientists, conservators, or even engineers. The significance of these virtual excursions should be highlighted; people's horizons are expanded via virtual tours, which removes both financial and physical constraints. Also, this project highlights the potential of immersive virtual technologies to safeguard cultural heritage and enhance educational outreach, setting a benchmark for future digital documentation initiatives in archaeological preservation.

A schematic representation of the three axes of information is presented in Figure 7.

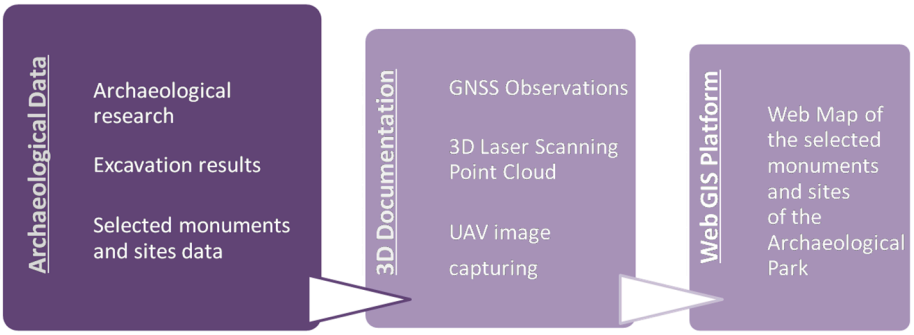


Figure 7. Schematic representation of the three axes of information in this research.

Finally, this process towards sustainability focuses on further optimization by upgrading the platform and including additional sites and monuments, as the works continue, leading to a circle of on-going investigation and integration within the platform. Information is available for both scientists and conservators, educators, and other visitors to the archaeological park since the off-site visitation from VR experience raises the touristic interest through time.

4. Materials and Methods

4.1. Historical Documentation of the Selected Monuments

Four monuments of public character were selected for the purposes of this work. They have been thoroughly excavated by the University of Thessaloniki, vary in their state of preservation, and have undergone a range of restorative interventions. Associated with

significant aspects of public life during the Roman imperial period, they form a distinct chronological, historical, and archaeological entity, while operating as individual tourist destinations within the archaeological park of Dion.

The religious element is illustrated by the sanctuaries of Isis and Zeus Hypsistos. Cultural life is represented by the Odeum, while the Great Thermae, the largest and most luxurious of the eleven public and private baths identified in Dion, are iconic of Roman urban culture, which emphasized the importance of hygiene and personal grooming [39] (p. 139). These two buildings along with shops and public toilets (vespasiane) arranged around a colonnaded courtyard were organic components of a large complex (Complex of the Great Thermae). Situated between the entrance to the city and the Forum, it would have been one of the most crowded public spaces of the city, where the local aristocracy and visitors with analogous social provenance spent their days in the comfort and luxury that their rank and the epoch demanded.

4.1.1. The Sanctuary of Isis

In Dion, the cult of the great Egyptian goddess Isis replaced that of Artemis Eileithyia, goddess of nature and birth, in the 2nd century BC. The worship of Isis flourished during the imperial period, when the architectural ensemble of her sanctuary near the waters of the Vafyras River and the ancient springs gradually developed around a large courtyard.

The western wing of this courtyard was occupied by three temples [43] (p. 157). The central temple, a four-column Ionic temple built on a high pedestal, was dedicated to Isis Lochia, who assisted mothers in childbirth and in the difficult time immediately thereafter. A relief depicting the goddess holding a sheaf of corn and a scepter, dedicated to the Egyptian triad of Serapis, Isis, and Anubis, was possibly fixed on the wall of its façade [43] (p. 157), [45] (p. 23). The naiskos to the north housed the cult of Aphrodite Hypolympidia, while to the south, a smaller temple with a niche was dedicated to Isis Tyche (Fortune). A long corridor in front of the central temple symbolized the Nile (Figure 8), while the marble bulls found on the steps of the altar depicted the Egyptian god Apis [39] (p. 89).



Figure 8. The sanctuary of Isis. In the foreground, the long corridor symbolizes the Nile, while in the background are the temples of the goddesses (Ephorate of Antiquities of Pieria).

Many sculptures and inscriptions were found in their place or lying next to the place where they were erected [39] (p. 90). In the northern wing were rooms for the overnight stay of worshippers and a hall where statues of female benefactors were placed, among

them the statue of Julia Phrygian Alexandra, who was honored by the city of Dion during the 2nd century BC [46] (pp. 24–25).

4.1.2. The Sanctuary of Zeus Hypsistos

During the imperial period, the cult of Zeus Olympios (associated with the former Macedonian kingdom) was replaced by the cult of Zeus Hypsistos (the Almighty). The new sanctuary of the god was located to the south of the city, next to that of Isis [43] (pp. 29, 309).

The sanctuary is rectangular with an altar in the middle of its northern side. The single-aisled cella is surrounded on three sides by a pteron (colonnade). The floor of the "peristalsis" (hallway) was covered with mosaics depicting a white bull and two double axes surrounded by geometric patterns. On the back wall of the cella, the marble cult statue of the god was placed on a built base. The statue is smaller than real-size and depicts the god enthroned, holding a scepter in his raised left hand and a thunderbolt in his right hand resting on his thigh. In addition to the cult statue, statues and reliefs of eagles, the most common offerings to Zeus, were also found (Figure 9).



Figure 9. The statue of Zeus Hypsistos, found in the temple, surrounded by statues and reliefs of eagles, as exhibited at the archaeological museum of Dion (Ephorate of Antiquities of Pieria).

The temple of Zeus Hypsistos, along with all the other temples of the ancient religion, was let to desertion towards the end of the 4th century A.D., when Christianity prevailed [38] (pp. 26–28), [47] (pp. 417–424).

4.1.3. The Complex of the Great Thermae: The Great Thermae

The Great Thermae (great baths) stands out for its size (2100 sq.m.) and luxury [39] (p. 139). The core of the building was a large reception hall where bathers, their followers, and their friends moved around, socialized, and chatted around various rooms. To the east of this hall were the changing rooms, whereas to the north were three luxurious rooms used for relaxation and recreation. The frigidarium to the west had a large cold plunge pool (piscina frigida) and two individual rectangular bathtubs [39] (pp. 139–140), [48] (pp. 289–291).

The southern wing included the warm rooms, where bathers could take first a lukewarm bath and then a hot one. The floor of these rooms was supported by a canavan of piles (Figure 10), creating an underground space, the hypocaust, where warm air, produced by fires burning in arched openings in the south exterior wall, circulated and then rose through double walls to the roof of the building [39] (pp. 139–140). The luxurious architecture of the complex was further embellished by sculptures, such as the six statues discovered on its northern side, identified as the children of Asclepius, a divinity favored by visitors to the baths [38] (p. 22).



Figure 10. The hypocaust of the warm rooms of the Great Thermae. The floors of the rooms have collapsed but the piles that supported them and allowed the circulation of warm air have survived.

The Great Thermae of Dion fell victim to a powerful earthquake [39] (p. 22), after the middle of the 3rd century A.D. Soon after the destruction, part of the building was demolished and reused [39] (p. 140).

4.1.4. The Complex of the Great Thermae: The Odeum

The Odeum (concert hall) dates to the 2nd century A.D. (Figure 11). It is the last in a series of edifices built for public spectacles in Dion, which in ancient Greece were directly linked to worship [49] (p. 13). With a capacity of 400 spectators, the small, roofed building was a multi-purpose hall, where various events such as recitation, music, dance, short theatre plays, pantomime, teaching, etc., were held [38] (pp. 23–25), [44] (p. 102), [50].

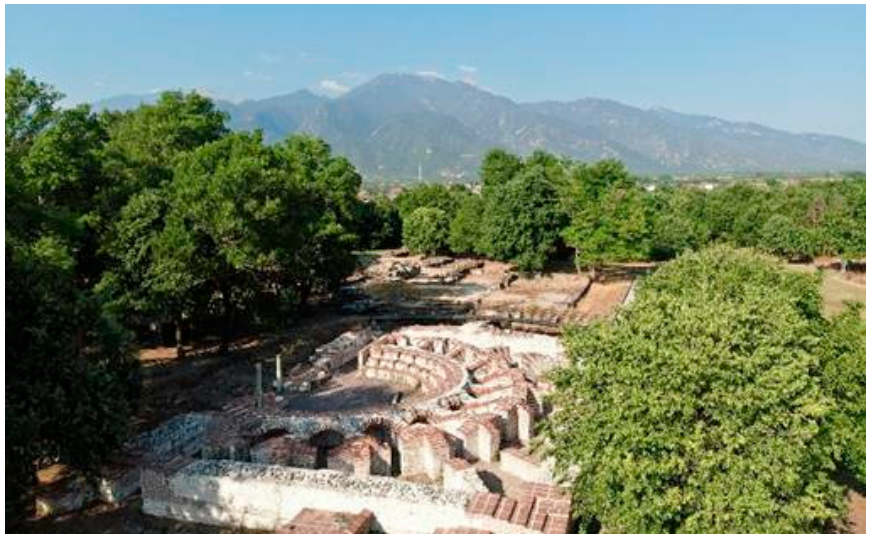


Figure 11. The Odeum in the foreground with the Great Thermae and Mt. Olympus in the background. © Ephorate of Antiquities of Pieria.

It presents all the main architectural elements of the ancient theatres: orchestra, "koilon" with a semicircular seating arrangement and four radial stairways, parodoi, a rudimentary scene, and two exterior L-shaped staircases. The masonries, diligently constructed, are characterized by a combination of local tradition and Roman architectural elements.

A solid outer wall, 1.55 m thick, served as a buttress for the transmission of the side impetuses of the koilon, supported the wooden roof and at the same time defined the exterior form of the building [32] (pp. 104–111), [37] (pp. 27–41). The tiers of the seats were supported by cuneiform arches, formed by walls radiating from the two concentric semicircular rings of different heights that define the koilon. The seats were covered with wood as was the orchestra floor. Four small monolithic columns were part of the decoration of the skene wall. Positioned on the low podium of the proscenium, they may have supported pediments of which no evidence has survived and together with the doors of the skene they created a permanent theatrical scenery [32] (pp. 108–111), [37] (pp. 30–41).

Big cracks on the walls, as well as sinking on the floors, provide evidence for the destruction of the building by a major earthquake, followed by an extensive fire [32] (p. 104), [37] (pp. 29–30). The monument was excavated between 1977 and 1979 by the University of Thessaloniki and was restored in 2014 by the Ephorate of Antiquities of Pieria with European funding through the Operational Program "Macedonia—Thrace 2007–2013" (Figure 12).



Figure 12. The Odeum after restoration. © Ephorate of Antiquities of Pieria.

4.2. Geomatics Data Collection

For the 3D documentation of the selected monuments, the following steps were followed: The first step was the data collection using GNSS receivers, a terrestrial laser scanner (TLS), and a UAV. A geodetic/trigonometric point was initially established, within the archaeological park, so that the whole project would be accurately georeferenced. The advantage of georeferenced dataset is the integration with the GIS platform, applying spatial analysis and visualization. Lastly, it aids management (tourist, public administration, etc.), as the sites are correctly mapped and can be used in future master plans.

The coordinates of the trigonometric point were determined using GNSS carrier phase observations. The measurements were conducted using dual frequency GPS-GLONASS geodetic receivers (Javad Triumph-1 3 mm $\pm$ 0.5 ppm in horizontal and 5 mm $\pm$ 0.5 ppm in vertical), (Javad, CA, USA), (source: Research Unit of Geodesy-Surveying & GNSS, Department of Surveying & Geoinformatics Engineering, UNIWA). Metrica's Smartnet Network (Metrica S.A., Athens, Greece) of continuously operating reference stations was used, specifically the "KATE" station, located in Katerini. The integer carrier phase ambiguities were solved for the baseline with a positional precision of $\pm$0.005 m (horizontal) and $\pm$0.008 m (vertical). The coordinates were calculated in the Greek Geodetic Reference System (GGRS '87) (Table 1).

Table 1. Coordinates of the trigonometric point.

Point	X/λ	Y/φ	H
GGRS 87	371,389.641	4,448,118.665	12.414
WGS 84	22.491245	40.176214	12.414

After that, laser scanning was performed for the geospatial documentation of the selected monuments. Leica Geosystems BLK360 was used [49]. The advantage of the specific TLS is that it captures and depicts the geometry, the texture, and the intensity of the object (Figure 13).



Figure 13. Scan processing at the sanctuary of Isis.

The scans were performed in high accuracy (4 mm step), and the distance between the scanner and the monument was not more than 15–20 m for each setup. The net time of each setup was 6 min. The percentage of the scan overlap ranged from 40% to 60%. This reinforced a strong geometry of the final model. The complexity of each monument led to a different number of setups per monument. For example, at the sanctuary of Zeus Hypsistos, only 9 setups were necessary, as the monument's structure is slightly elevated from the ground with very few of the monuments' details saved in its current form. On the other hand, the Great Thermae have lots of detail, like different rooms or short pillars and walls, that demanded several setups, some of them very close to each other (Table 2).

Table 2. Number of setups per monument.

Number of Setups	Code Area	Area of Interest
9	DND	Dios
15	DNI	Isida
13	DNO	Roman Odeum
25	DNT	Great Thermae

The point clouds were processed in the corresponding software (Leica Cyclone Register 360, 2022.1.0). Each site was treated separately. The alignment of the individual scans was performed using tie points in an independent reference system. The abundance of setups for each site and the high percentage of overlap led to a mean square error (RMS) ranging from 6 mm to 10 mm for the merged point cloud of each site (Figures 14 and 15). From the merged point cloud, several products were extracted (e.g., meshed model, orthophoto models).

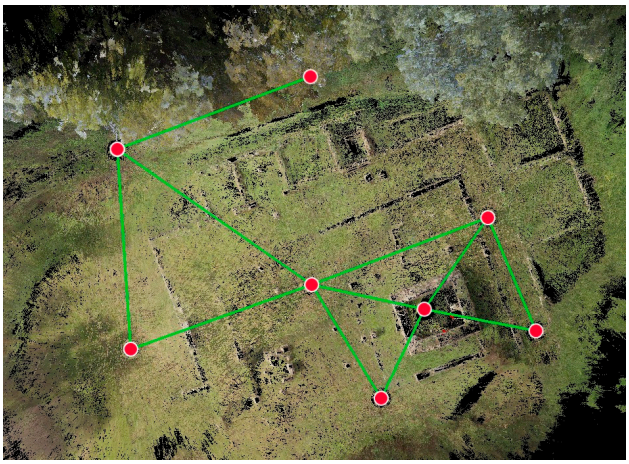


Figure 14. Setups and link as the sanctuary of Zeus Hypsistos.

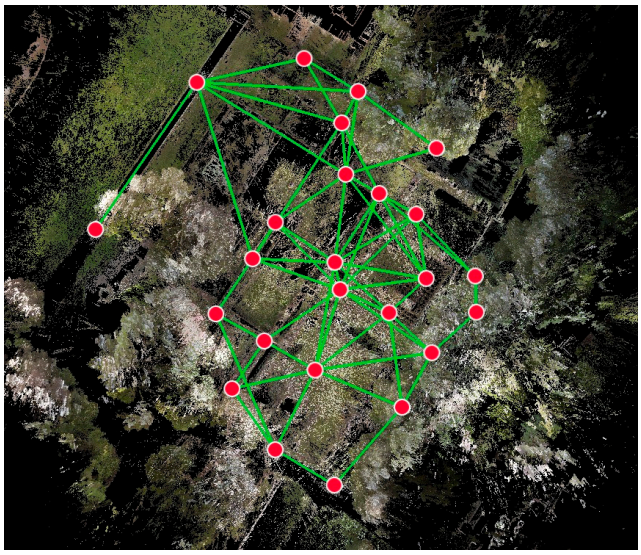


Figure 15. Setups and link as the Great Thermae.

Finally, the UAV DJI Mini 2 (DJI, Shenzhen, China) was used for both measuring and non-measuring purposes. In addition to image capturing for metric purposes and the creation of 3D models, panoramic images were taken from different heights (40 to 100 with a step of 10 m) for each monument. Vertical and oblique images were taken to create the 3D model and the orthophoto of each monument (Figure 16). The vertical images were taken from 30 m height with an overlap of approximately 50–60%. The oblique images were taken in angles of 30° and 60°, so that all the details of the monument were captured.



(**a**) (**b**)

Figure 16. (**a**) Vertical image from the Roman Odeum. (**b**) Oblique image from the sanctuary of Isis.

For the georeference of the 3D model and the orthophoto creation, ground control points (GCPs) were measured. Checkerboard targets were used as GCPs, uniformly distributed around every monument. For each monument, 6–8 GCPs were measured according to their complexity and were recorded using the GNSS RTK technique. The images were processed with the Agisoft Metashape 2.1.4. software. The 3D RGB point clouds and orthoimages of each monument were created.

The data acquisition procedure lasted 3 days. The measurements were carried out by a team of 2 surveying engineers with experience in similar projects. The fact that some tasks could be accomplished simultaneously (e.g., scanning one site, while the UAV took images in another) minimized the time in field. As in any field work, an important role was played by having good weather conditions. Last but not least, the period of the measurements played an important role. They took place in October, when visitors to the park are significantly less than in the summer months, so it was easier to have point clouds without the extra noise of moving people.

In order to eliminate potential errors, abundant measurements were carried out. In terms of techniques, this meant that GNSS observations were made for a much longer time than necessary, TLS setups were denser to ensure high overlap, and the UAV images were taken with a high overlap percentage and multiple oblique angles.

4.3. D Model Development

The point clouds of each site were merged together, and the high percentage of overlap led to high precision models. The links and total overlap of the scans are presented in Table 3, while in Table 4, the precision of each site is analyzed.

Table 3. Number of links and total overlap for each monument.

Overlap	Link	Area of Interest
49%	13	Dion
38%	26	Isida
35%	22	Roman Odeum
38%	61	Great Thermae

Table 4. The precision achieved at the merged point cloud of each monument.

MAX (m)	MEAN (m)	RMS (m)	Area of Interest
0.019	0.005	0.013	Dion
0.008	0.019	0.013	Isida
0.023	0.005	0.015	Roman Odeum
0.017	0.007	0.011	Great Thermae

Each monument's point cloud was imported in the TruView Enterprise 2022.0.1 software. The user can make a virtual tour around the monument and use it to measure dimensions, angles, or even the temperature of each building material during the day of the measurements. Concerning the photogrammetric process, 3D models (Figure 17) and orthophotos for each monument were created (Figures 18 and 19), and once the models were finalized, they were imported into the platform.



(**a**) (**b**)

Figure 17. Snapshot from the point cloud of (**a**) the sanctuary of Isis; (**b**) the Roman Odeum.



Figure 18. Textured model (Roman Odeum).



Figure 19. Orthophoto of the Roman Odeum and the Great Thermae.

5. Web Platform Development

A geographical information map was developed to promote the documentation of the archaeological park of Dion and other significant spots of the Olympus Riviera. It was developed using a combination of exclusively free and open-source software (FOSS) such as GNU-GPLv2 and v3 (QGIS (v. 3.38), PostGIS (v. 3.5.2), Geoserver (v. 2.15.1)

and GET SDI Portal (v. 4.0)) as well as PostgreSQL (v. 13.20), (accessed on 10 February 2025). The web platform is freely accessible (http://195.130.106.60/OlympusRiviera/) (accessed on 28 February 2025).

The collected data were systematically stored in a dedicated spatial database and were accessible via a server that supports the Web MapServices (WMS) standard for versions 1.1.1 and 1.3.0. The WMS endpoint is accessible at http://195.130.106.60/geoserver/olympusriviera/wms, (accessed on 28 February 2025), where users can query and retrieve all available geospatial information relevant to the project. The GET SDI Portal v4.0 mapping platform was used to disseminate all available data to citizens and the scientific community. Through this platform, users are provided with interactive map views and access to high-quality spatial data in support of research, public engagement, and decision-making processes.

These structured data are maintained in a PostgreSQL database with PostGIS extension, hosted on the University of West Attica's main server (Figure 20). This specialized configuration supports the efficient storage, management, and retrieval of comprehensive metadata for cultural heritage assets, including archaeological sites, monuments, and temples.

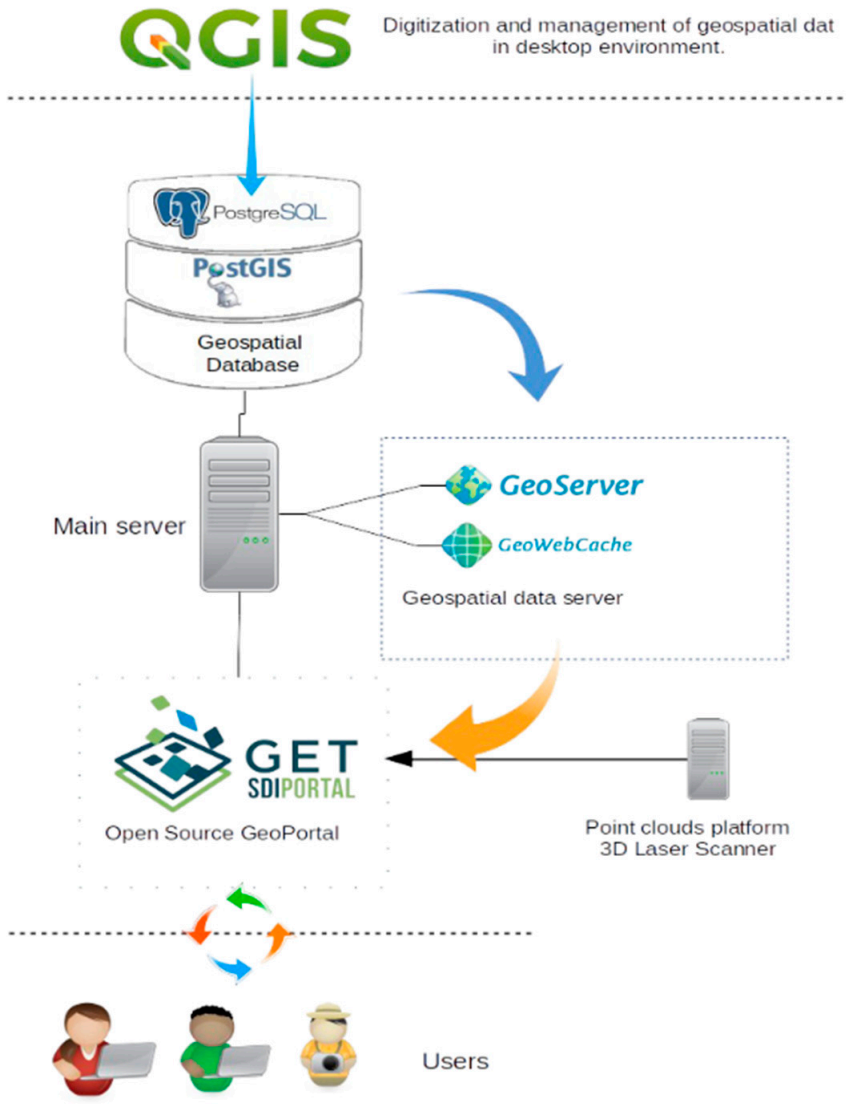


Figure 20. Workflow implementation portal [51].

The geospatial data in the platform are organized into seven thematic layers, with the following five serving as foundational background datasets:

- Administrative boundaries: Borders of Central Macedonia Region.
- Terrain features: coastlines and elevation contours with intervals of 20 m, produced by Shuttle Radar Topography Mission (SRTM) [52].
- Environmental features: Protected zones and significant terrain characteristics.
- Transportation networks: Complete digital representations of both primary and secondary road networks.
- Sites of interest: Comprehensive documentation of archaeological sites.

The web mapping interface serves as the primary access point to this rich geospatial repository, offering intuitive tools for both general users and specialist researchers. Designed with a dual-language interface (Greek and English), the platform accommodates diverse user groups while maintaining consistent functionality across language settings [53].

Key user-facing features include

- Advanced search capabilities, like spatial queries through interactive map interfaces, text-based searches across all metadata fields, and combined spatial-textual search workflows.
- Detailed heritage pages with information for each monument (Figures 21 and 22), contextual links to the related sites, and multimedia content integration.

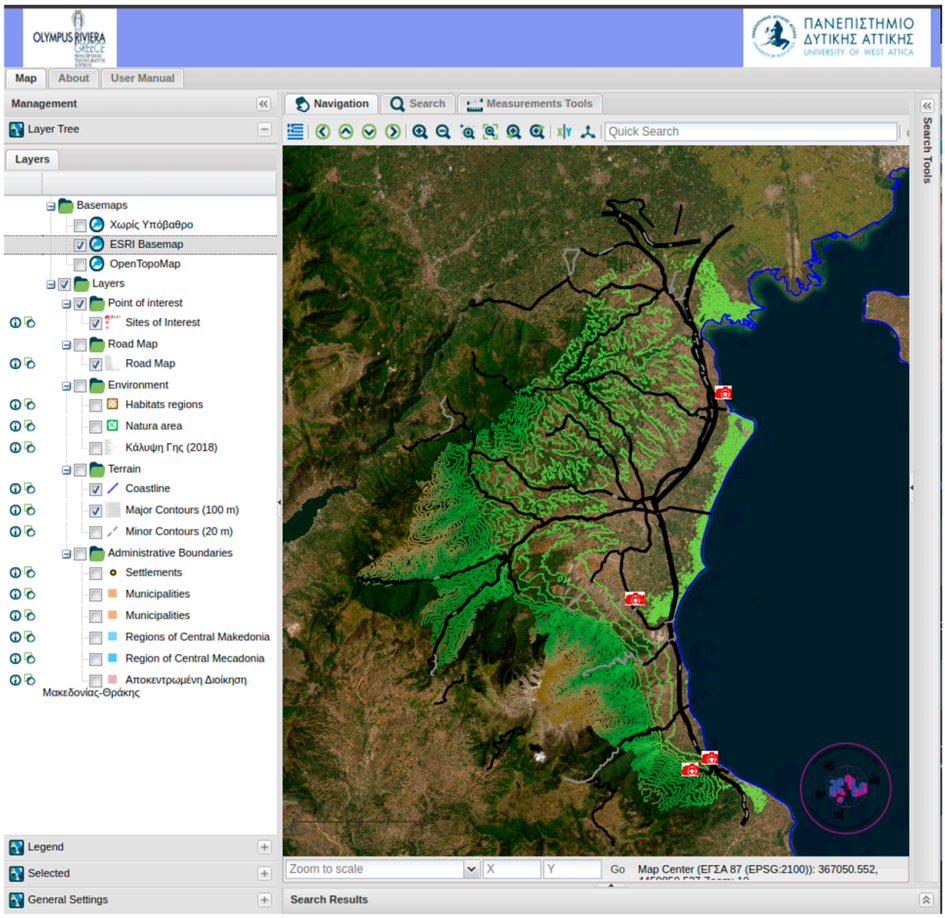


Figure 21. Implementation of web platform (http://195.130.106.60/OlympusRiviera/?lang=EN (accessed on 22 April 2025)).

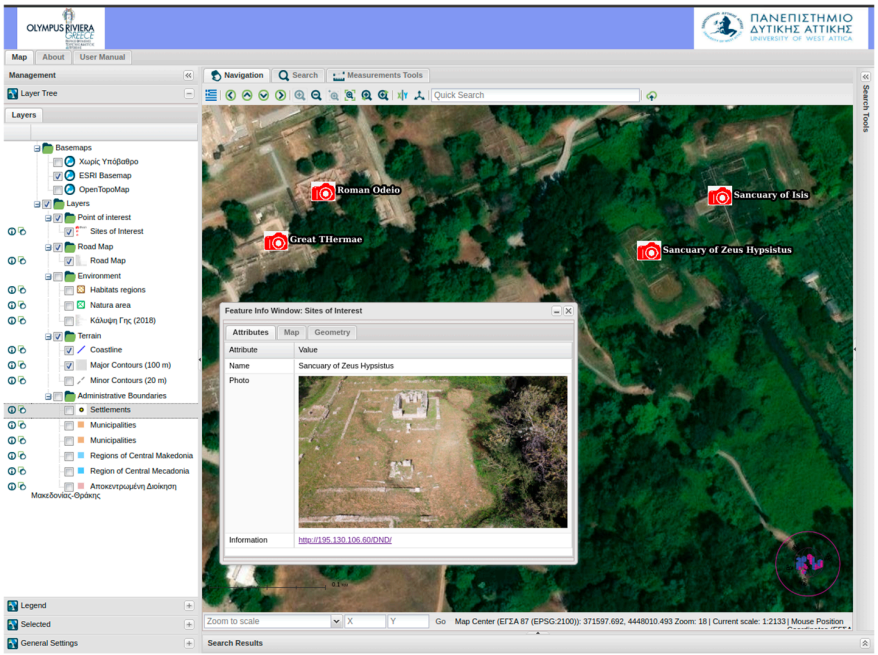


Figure 22. The web platform focused on the archaeological park of Dion (http://195.130.106.60/OlympusRiviera/?lang=EN (accessed on 22 April 2025)).

The platform's layer-based setup looks like the database form, letting users toggle between different thematic categories, combine datasets for complex analysis, and generate customized map views. This stacked way helps all kinds of easy place searches to clever study questions, with quick results kept up by improved space arrangements.

6. Discussion

For the digital documentation of the archaeological park of Dion, high-end equipment and techniques were used, not only in terms of measurement (high-resolution laser scanning, UAV-based photogrammetry), but also in terms of visualization with the use of web-platform and VR technologies. This section examines the project's theoretical and methodological foundations, comparing it with international examples to highlight its broader impact. It moves forward along two separate pillars. Firstly, it is a major step forward in cultural heritage preservation. But it also reflects and reinforces a global trend toward blending immersive digital environments with archaeological research.

The 3D models created for Dion are not only highly precise and interactive but they also represent a new way of representing the archaeological knowledge. Platforms like 3D Vista are not just visualization tools. They act as an interpretive mechanism that deepens historical understanding. The Dion project, along with similar projects, like MayaArch3D [54] and the Open-Source Web Platform for 3D Documentation [55], uses storytelling, models, and spatial interaction to make archaeology accessible not only to scientists (e.g., archaeologists, engineers, etc.), but also to the public.

The project's use of digital twins was also applied in the virtual restoration of Macedonian tombs, where digital replicas help monitor sites without physical intervention [56]. This approach reflects an ethical principle in cultural heritage management: prioritizing non-invasive documentation, long-term monitoring, and sustainable public access.

At the same time, the Dion project supports sustainable tourism, aligning with the objectives of CyArk's Open Heritage 3D Project. The digitization of vulnerable archaeological sites and the access through immersive online experiences respond to the increasing pressures of over-tourism while democratizing cultural access [55]. Fea-

tures such as interactive hotspots, embedded narratives, and panoramic 3D views do more than simulate presence—they foster inclusive, globally accessible forms of heritage engagement (Figures 23 and 24).

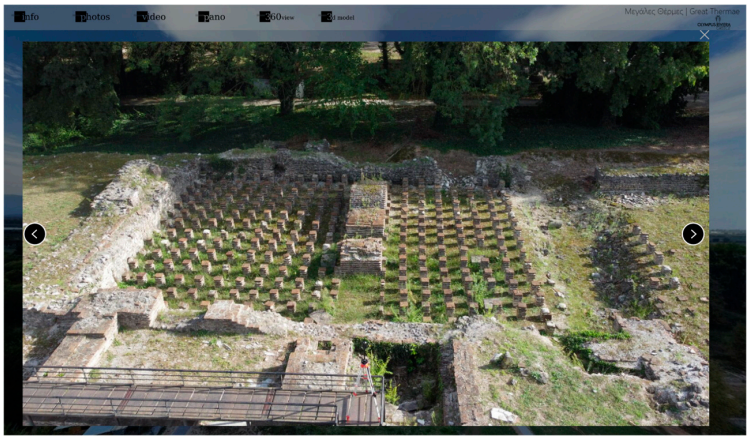


Figure 23. Virtual tour in the warm rooms (hypocaust) of the Great Thermae.



Figure 24. Snapshots of the 3D model of the Temple of Zeus in the platform with a detailed view of the preservation state of the structure.

The integration in a web GIS based platform enhances the capabilities of the virtual model. As seen in the 3D digital documentation efforts in Oman, spatial layering within the virtual environment allows for the examination of the archaeological remains in relation to topographical and urban development patterns [56]. Likewise, in the Dion case study, this facilitates a relational understanding of space, offering new perspectives on the evolution of the sanctuary's architectural landscape.

A key innovation in our project was the incorporation of a VR tour using the MetaQuest 2 headset, extending the platform's reach to virtual reality environments. This aspect highlights a shift in the pedagogical and experiential dimensions of digital heritage: from screen-based interaction to embodied immersion (Figure 25). Through this application, the management of the archaeological park becomes almost "tangible" to global audiences.



Figure 25. VR tour test of the archaeological park.

The platform in its entity offers an integrated presentation of the archaeological park of Dion for different types of users, e.g., tourists, students, scientists, conservators, or even engineers. Moreover, the significance of these virtual excursions should be highlighted; people's horizons are expanded via virtual tours, which removes both financial and physical constraints. Also, this project highlights the potential of immersive virtual technologies to safeguard cultural heritage and enhance educational outreach, setting a benchmark for future digital documentation initiatives in archaeological preservation.

Taken together, these components reveal that the Dion digital documentation project is not an isolated effort but a manifestation of broader theoretical and methodological trajectories in virtual heritage. By situating the Dion case study within this international landscape, we can better understand the potential of immersive technologies not only to preserve the past but to reconfigure how we engage with, interpret, and share it in the present.

7. Conclusions

While digital heritage initiatives are gaining traction, attention still focuses on famous or well-funded heritage sites—often leaving regional yet culturally valuable locations out of the digital spotlight. This imbalance is especially apparent when it comes to integrating digital tools into sustainable tourism strategies, where less-recognized archaeological sites frequently face challenges in adoption. This issue is particularly relevant in countries like Greece, where the cultural landscape is rich but often underutilized.

This study reveals and promotes the significance of the archaeological park of Dion, a regional complex, located in the Olympus region of Pieria, Greece. Being rich in history and architectural remnants from multiple historical eras, Dion serves as an ideal setting for combining high-precision digital documentation with community-centered heritage planning. The process is thoroughly described, starting from the early stages, i.e., historical documentation and geometric data collection, to their integration into a web-GIS platform, offering various options to different kinds of users.

Using modern techniques and high-end equipment, e.g., TLS and UAV-based photogrammetry, we produced high precision 3D models of four sites inside the park.

The 3D deliverables have an average precision of ± 1 cm and can be used for multiple purposes and different scientists. The following are provided as indicative examples:

- Architectural and structural information; dimensions which can be useful for architectural analysis, restoration, and preservation projects. Different types of drawings can also be produced (facade plans, horizontal and vertical cross-sections).
- Building materials' current state of preservation—condition assessment; from the 3D models and the orthophotos, the pathology of the monuments can be depicted.

Going a bit further, a web platform was designed to promote the monuments and the wider area of the park. It was developed using exclusively free and open-source software. The platform, apart from the monuments, contains elements like administrative boundaries, road network, and land cover. The platform is freely accessible (http://195.130.106.60/OlympusRiviera/ (accessed on 22 April 2025)).

The last step in our study was to create VR tours for the sites of the park and integrate them in the platform, in order to facilitate not only heritage visualization but also educational engagement, participatory planning, and sustainable tourism management.

The platform can also be used by the local authorities or the Ministry of Culture, as a means of promoting this important historical site. It can also be used for educational purposes for schools and universities. VR experience and interactive storytelling can be a creative and interesting way of learning, regardless of one's age.

Moreover, the platform improves accessibility for researchers and the public alike. This digital archive allows users to virtually explore the archaeological park, providing an immersive experience that reduces physical damage caused by tourism. Such virtual access promotes sustainable tourism by lowering the environmental impact of travel and on-site visits.

In terms of decision making, the platform can be used for urban planning for creating master plans for the park (evacuation plans in case of flood or fire, path marking, etc.).

The implementation of 3D digital geospatial documentation via a comprehensive web platform at the archaeological park of Dion illustrates a successful integration of heritage conservation and sustainable tourism. This approach serves as a valuable model for other heritage sites and parks seeking to balance public access with the need for preservation.

For future work, we will focus on two main pillars. The first concerns the creation of 3D models for all the sites of the archaeological park, so that the users have a complete experience from their virtual tour. These four sites that were modeled are only a small part of the Park. The second concerns the development of the web platform and the VR experience and, indicatively, to conduct qualitative and quantitative research on how different user groups (tourists, students, local communities) interact with the platform and VR tour. Other possible fields of research are the development of mobile-friendly or augmented reality (AR) components to expand accessibility on-site and off-site and the evaluation of how mixed-reality experiences affect tourist behavior, knowledge, and cultural appreciation.

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