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Article

Priene, a Monumental Disaster in the Aegean: Digital Approaches to the Doric Stoa's and the Theater's Lost Evidence

Elisabetta Caterina Giovannini [1,*], Giorgio Verdiani [2] and Vieri Cardinali [2]

[1] Department of Architecture and Design (DAD), Politecnico di Torino, 10125 Turin, Italy
[2] Department of Architecture (DIDA), University of Florence, 50121 Florence, Italy; giorgio.verdiani@unifi.it (G.V.); vieri.cardinali@unifi.it (V.C.)
* Correspondence: elisabetta.giovannini@polito.it

Abstract: This paper uses digital approaches to investigate Priene's (Turkey) archaeological area. The city was built ex novo, after a catastrophic earthquake around 350 BC, on a new site facing the Mediterranean Sea. The city suffered a slow decline following centuries of development and was abandoned after the 12th century. The remains of Priene were discovered in the 17th century, and different excavations and studies have been conducted in the last few centuries. The city's remains have been studied from various archaeological and historical points of view. It is documented that the city suffered different earthquakes during its existence, as demonstrated by the partial restorations and damage patterns visible within the remains. This contribution offers a methodological and interdisciplinary approach for studying and enhancing archaeological heritage. This paper presents the preliminary results of the first comprehensive digital acquisition of the Aegean city of Priene. The digitization approaches here described focused on digital acquisition and 3D modeling restitution in the form of virtual reconstructions of two monumental buildings: the Doric Stoa near the Temple of Athena Polias and the Theater. The procedure was complementary to the analysis and comprehension of previous numerous studies carried out by British and German institutions, where digital acquisition and restitution techniques have led to the validation of previously obtained results. For the first time, digital models have been used as tools for accessing heterogeneous knowledge, and they have been incorporated into the discourse of archeological studies. Indeed, the interdisciplinary team went beyond archaeological data to attempt to digitally reconstruct monumental complexes and conduct preliminary structural evaluations scientifically.

Keywords: Priene; archaeological sites; natural disasters; digital survey; integrated approach; digital 3D reconstruction; Masonry Quality Index analysis; Extended Matrix; Greek theater; Stoa

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1. Introduction

The presented study and in situ considerations were part of the outcomes of the International Summer School 'Priene, Architecture, and Archaeology. Survey, Documentation and Design, 20–27 July 2022, Priene, Turkey'.

This contribution aims to investigate the use of new digital technologies to study and enhance the archaeological site of Priene in Turkey. The activity within the Summer School involved an interdisciplinary group composed of 26 international professors and researchers and five students from Özyeğin University who applied for summer internships (ARCH200). The researchers and scholars came from the Dynamic Research on Urban Morphology-DRUM laboratory, the Department of Interior Architecture and Environmental Design of Özyeğin University and GEKA: Güney Ege Kalkınma Ajansı/South Aegean Development Agency, in cooperation with Bursa Uludağ Üniversitesi, University of Florence, Polytechnic University of Turin, Abdullah Gül Üniversitesi, University of Naples "Federico II", University of Novi Sad and "Sapienza" University of Rome. For the first time, the group had the opportunity to work closely with the archaeological heritage of the city of Priene. At the beginning, part of the teaching and research program was dedicated to the digital acquisition of the remains of the Priene ruins using integrated digital acquisition technologies.

Therefore, the team was divided into five groups. Three of them were dedicated to different acquisitions: photogrammetric, unmanned aerial vehicle (UAV), and laser scanner. The figures involved are related to the discipline of drawing and surveying built heritage to define photogrammetric acquisition protocols in the archaeological field. The company LiTech Engineering managed the laser acquisition phases using a laser scanner (Leica RTC 360) controlled by a remote device, acquiring a total of 640 scan stations.

Another group was dedicated to analyzing the wall structures of the city's main sites, with an interdisciplinary team of architectural historians, archaeologists, and experts in the structures and restoration of architecture and cultural heritage. The theme addressed concerned the analysis of the structural features of different parts of the ruins, the proposal of hypotheses on the damage patterns and their past causes [1].

Finally, the last group included architects and town planners to define a possible project master plan for creating a new system of visitor paths within the archaeological area. The aim was to define a possible relationship between archaeology and architecture. This theme has always been characterized by several interlinking factors, including historical perspectives, technological aspects, issues relating to restoration and the link with the local territory [2].

The ancient Aegean city of Priene, located in modern-day Turkey, has a long history, being one of the many interesting examples of Aegean urban settlement that defines the architecture and the urban setup that would become a reference for all the Classical age. It is known to have experienced earthquakes throughout the centuries. One notable ancient earthquake occurred in the region in the 4th century BCE. During the Hellenistic period, Priene was struck by a devastating earthquake that caused significant damage to the city, destroying many buildings and structures. Several ancient historians, including Pliny the Elder and Strabo, a Greek geographer and historian, mentioned the event. This significant earthquake led to Priene's relocation and reconstruction at a new site, approximately twenty stadia (around 3.7 km) from the original city [3].

The new city was discovered in 1673 by English merchants, and it subsequently attracted numerous archaeologists from Germany, who have carried out and performed multiple scientific excavations. Carl Humann carried out the first excavations in 1894 with the permission of the Ottoman authorities. Between 1895 and 1899, excavations were carried out by archaeologists Theodor Wiegand and Hans Schrader [4], who focused on the ancient part of the city. In this paper, we focus on two areas. One pertains to the Hellenistic area of the city and includes the Doric Stoa (2nd century BC), which has a large part of the base wall still standing. The other area under consideration is the Theater, which was built in the second half of the 4th century BC. Moreover, it was renovated at the beginning of the 2nd century BC, in the middle of the 2nd century BC, and finally, in the 2nd century AD. Between 1992 and 1998, architect Jens Misiakiewicz elaborated a restoration and maintenance plan for the ruins, leading to the current configuration of the Theater [5]. The interventions carried out included repairing minor damage, relocating recognizable elements within their context, and improving the legibility of the proscenium's architecture to ensure its overall image and stability. The excavations brought to light significant and interesting buildings.

During the Summer School, the previously described groups analyzed and investigated most of the archeological areas of the city of Priene, including houses, the Temple of Athena Polias, the Agora, the Bouleuterion, and the Gymnasium. In this paper, two areas in particular are analyzed in depth regarding their history of violent transformation and slow decay: the Wall of the Doric Stoa and the Theater (Figure 1).

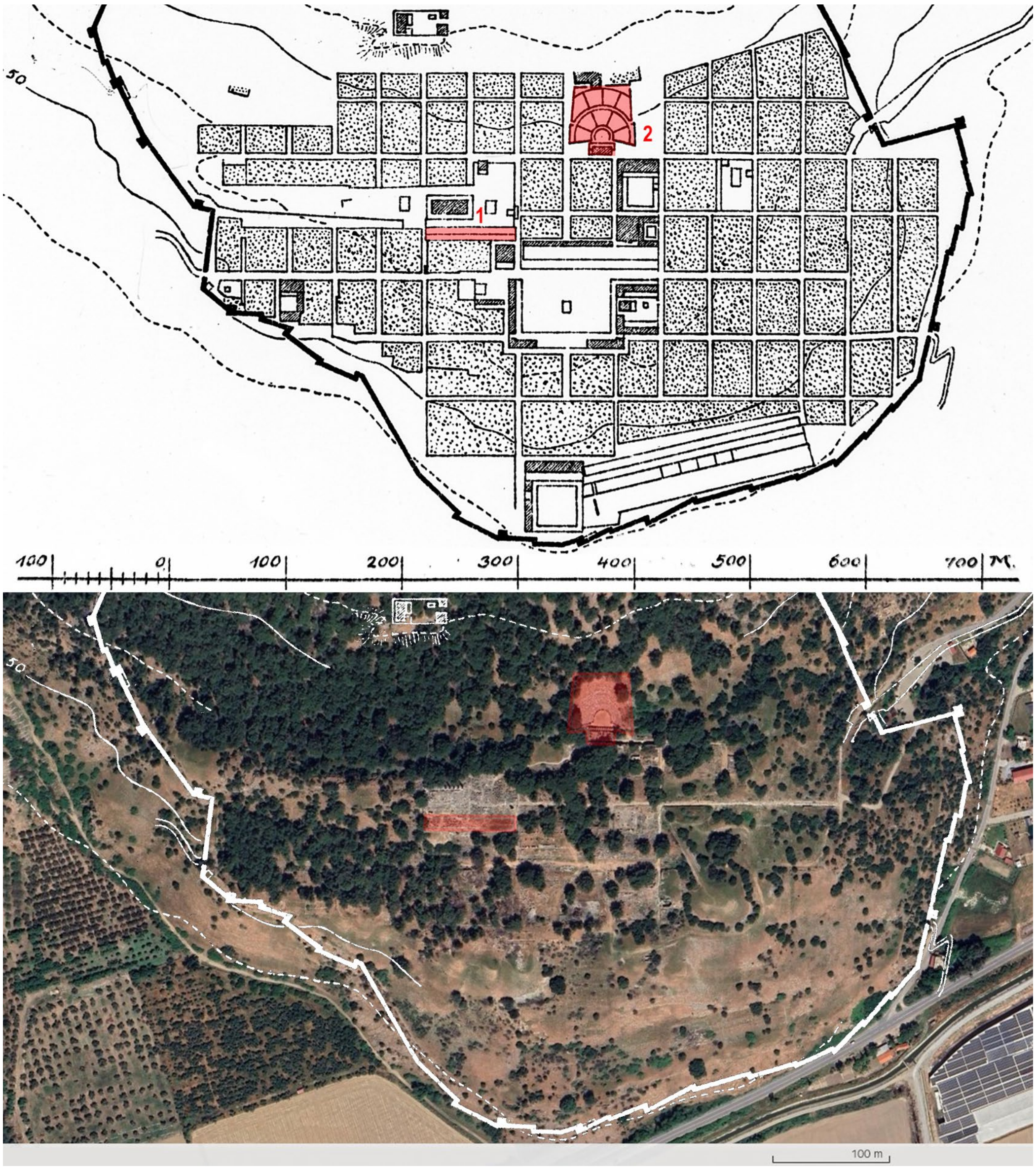


Figure 1. On the top, a portion of the plan of Priene in 'Griechische Stadeanlagen' [6,7], with the locations investigated during this study. 1. Terrace of the Doric Stoa near the Temple of Athena Polias. 2. Theater. On the bottom, superimposition with the Google Earth view. (E.C.G. and G.V.).

2. Materials and Methods

The interdisciplinary team addressed the issues of virtual reconstructions, philological anastylosis of architectural complexes, and structural considerations regarding the different historical techniques and damage observed in Priene.

The methodological approach was devoted to diverse objectives. First, the didactic activities were carried out with internship students, and then, research activities related to archaeological and historical evidence were conducted to understand the history and evolution of the city's diverse areas. Finally, the method involved the creation of storytelling and narratives accessible on-site (design projects and open-air exhibit layouts) and online (digital maps, digital galleries, and extended reality solutions).

This paper describes the definition and development of online digital assets to create extended reality solutions for both the public and academics. Digitization is part of the European Agenda initiative for the 3D digitization of cultural heritage artifacts and monuments [8] and follows the Convention on the Value of Cultural Heritage for Society (2005), which considers knowledge and use of heritage to form part of the citizen's right to participate in cultural life as defined in the Universal Declaration of Human Rights. Furthermore, cultural heritage is also recognized as a resource for human development, the enhancement of cultural diversity, the promotion of intercultural dialogue, and an economic development model based on the principles of sustainable resource use [9]. Digitization processes and actions are essential for preventing risks and managing maintenance, as they can help address risks arising from natural events, climate change, political instability, or armed conflict. Additionally, the scenarios for experiencing heritage during and after the COVID-19 pandemic have highlighted the importance of digital technologies in ensuring accessibility to heritage sites [10].

These key factors were used to plan and manage the digitization of the city of Priene, which aims to enhance its accessibility from abroad and contribute to the creation of novel knowledge for cultural valorization and dissemination.

This project re-proposes the methodology of Virtual Reconstruction Information Modeling (VRIM), which has been expanded and revised to standardize digital reconstruction processes using historical documentation for partially documented architectural and archaeological heritage [11].

The ‘Knowledge Acquisition’ phase involves historical research and the collection of metric data. This phase also includes gathering previously published works and collecting data and metadata already available from digital repositories.

The ‘Data Analysis’ phase prepares for defining the possible levels of knowledge representation, aligning with the multidisciplinary nature and objectives of 3D models that integrates reality-based representations with source-based ones. In this case, the data analysis was focused on the Stoa wall and its structure.

The ‘Knowledge Interpretation’ phase establishes the critical and methodological approach to 3D reconstruction in a digital environment [12]. It includes the semantic structuring of the model’s components, which is crucial for organizing knowledge within the model. This phase was developed using, in this case, the methodology offered by the Extended Matrix (EM) [13].

The ’Knowledge Representation’ phase aims to create a digital ecosystem that complements the primary digital asset (reality-based models). It serves as a primary access point for multidisciplinary information accessible online and consistent with its disciplinary context.

3. Knowledge Acquisition and Data Gathering

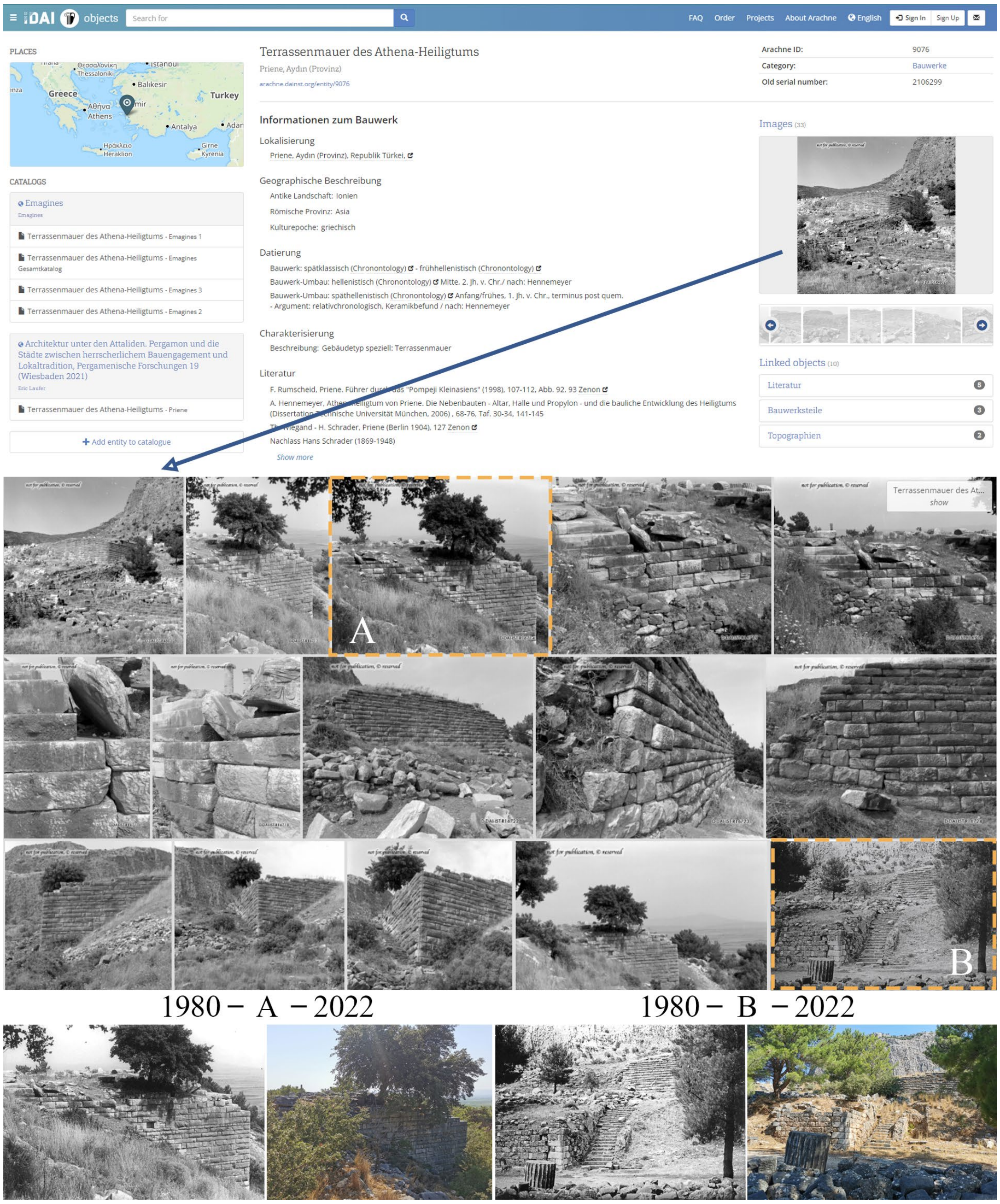
Numerous, predominantly German, studies have allowed us to collect archaeological documentation of Priene’s historical events and monuments. The extensive documentation already available in the literature posed a significance limitation due to the language barrier, effectively making most of the contents inaccessible to non-German-speaking researchers. Luckily, the recent enhancement of online translators (e.g., Google Translator and DeepL) has made these resources more retrievable and easier to share. Among the studies analyzed, reference was made to the extensive iconographic and photographic resources accessible from the iDAI platform, which documents previous German excavations in Priene. By employing Semantic Web strategies, Arachne provides a low-threshold structure for data and part of the ‘iDAI.world’ is a comprehensive digital infrastructure developed by the German Archaeological Institute (Deutsches Archäologisches Institut, DAI) to support archaeological and cultural heritage research [14]. It is a central platform for collecting, managing, and sharing archaeological data and resources. The ‘iDAI.world’ infrastructure encompasses several interconnected modules and databases that cover different aspects of archaeological research.

The other digital repositories consulted were developed by international initiatives. The ‘Perseus Digital Library’ [15] covers the Greco-Roman world’s history, literature, and culture. The ‘Ancient Theater Archive’ [16] is a non-profit, educational project from Whitman College, USA. The ‘Heidelberg University Library’ [17], the oldest and, at the same time, one of Germany's largest academic libraries provides access to the digitalized German references that we used for this study.

3.1. The Doric Stoa

Nowadays, the Doric Stoa near the Athena Polias Temple has completely disappeared. The wall on which it stood has also been disrupted by a ruinous landslide. The side walls, previously surveyed and analyzed by Hennemeyer [18], remain visible.

The Acropolis, including the Athena Temple, is characterized by a Stoa facing the southern part of the city. Here, a retaining wall stabilizes the plane of the acropolis, elevating its level to the slope of the descending hill. Specifically, the Stoa was realized with a portico located a few meters north of the terrace. The traces of the Stoa remain at the basement level, while the retaining wall of the terrace has partially collapsed. The central part is undefined, and only the two corners (occidental and oriental sides) are well conserved (Figure 2).



Terrassenmauer des Athena-Heiligtums
Priene, Aydın (Provinz)
arachne.dainst.org/entity/9076

Arachne ID: 9076
Category: Bauwerke
Old serial number: 2106299

Informationen zum Bauwerk

Lokalisierung
Priene, Aydın (Provinz), Republik Türkei.

Geographische Beschreibung
Antike Landschaft: Ionien
Römische Provinz: Asia
Kulturepoche: griechisch

Datierung
Bauwerk: spätklassisch (Chronontology) - frühhellenistisch (Chronontology)
Bauwerk-Umbau: hellenistisch (Chronontology) Mitte, 2. Jh. v. Chr./ nach: Hennemeyer
Bauwerk-Umbau: späthellenistisch (Chronontology) Anfang/frühes, 1. Jh. v. Chr., terminus post quem.
- Argument: relativchronologisch, Keramikbefund / nach: Hennemeyer

Charakterisierung
Beschreibung: Gebäudetyp speziell: Terrassenmauer

Literatur
F. Rumscheid, Priene. Führer durch das "Pompeji Kleinasiens" (1998), 107-112, Abb. 92. 93 Zenon
A. Hennemeyer, Athena-Heiligtum von Priene. Die Nebenbauten - Altar, Halle und Propylon - und die bauliche Entwicklung des Heiligtums (Dissertation Technische Universität München, 2006) , 68-76, Taf. 30-34, 141-145
Th. Wiegand - H. Schrader, Priene (Berlin 1904), 127 Zenon
Nachlass Hans Schrader (1869-1948)

Emagines
Emagines
Terrassenmauer des Athena-Heiligtums - Emagines 1
Terrassenmauer des Athena-Heiligtums - Emagines Gesamtkatalog
Terrassenmauer des Athena-Heiligtums - Emagines 3
Terrassenmauer des Athena-Heiligtums - Emagines 2

Architektur unter den Attaliden. Pergamon und die Städte zwischen herrscherlichem Bauengagement und Lokaltradition, Pergamenische Forschungen 19 (Wiesbaden 2021)
Eric Laufer
Terrassenmauer des Athena-Heiligtums - Priene

Literatur 5
Bauwerksteile 3
Topographien 2

Figure 2. Historical photographic from the iDAI platform [19], and on the bottom, comparisons of images A and B from the 1980 to 2022 photographic campaigns. (E.C.G.).

The Wall of the Doric Stoa is made of huge stones, partially refined and well preserved despite the heavy impact of earthquakes and centuries of abandonment. Through their positioning and evident alterations, the stones allow the interpretation of the “movement” received by the original structure. This is also well documented by the ‘iDAI.objects arachne’ platform, which collects several historical pictures of the archaeological area. All the digitized images and textual data in Arachne are preserved for the long term and are available online.

A simple visual check of the available contents confirms that the prevalent changes happened before any historical photographic documentation as shown in Fgure 2.

Regarding the Doric Stoa, LiTech Engineering used a 3D laser scanner unit and a Leica Geosystem RTC 360 to perform the digital acquisition. The data acquired were extensive, and the group planned to divide the archaeological area of Priene into different sub-areas: the Temple area, the *Agorà*, and the House 33, as encoded by previous studies [18,20–22].

The Temple area also comprises the Stoa area, consisting of 465 scan stations aligned using ReCap Pro. After the point clouds were registered, the merged point cloud of the Temple area was exported and cleaned using Leica Cyclone. This post-processing phase was necessary due to the presence of people and visitors within the archaeological area during the acquisition phase. Raw point clouds often contain noise due to sensor inaccuracies or environmental factors such as trees and vegetation (Figure 3).

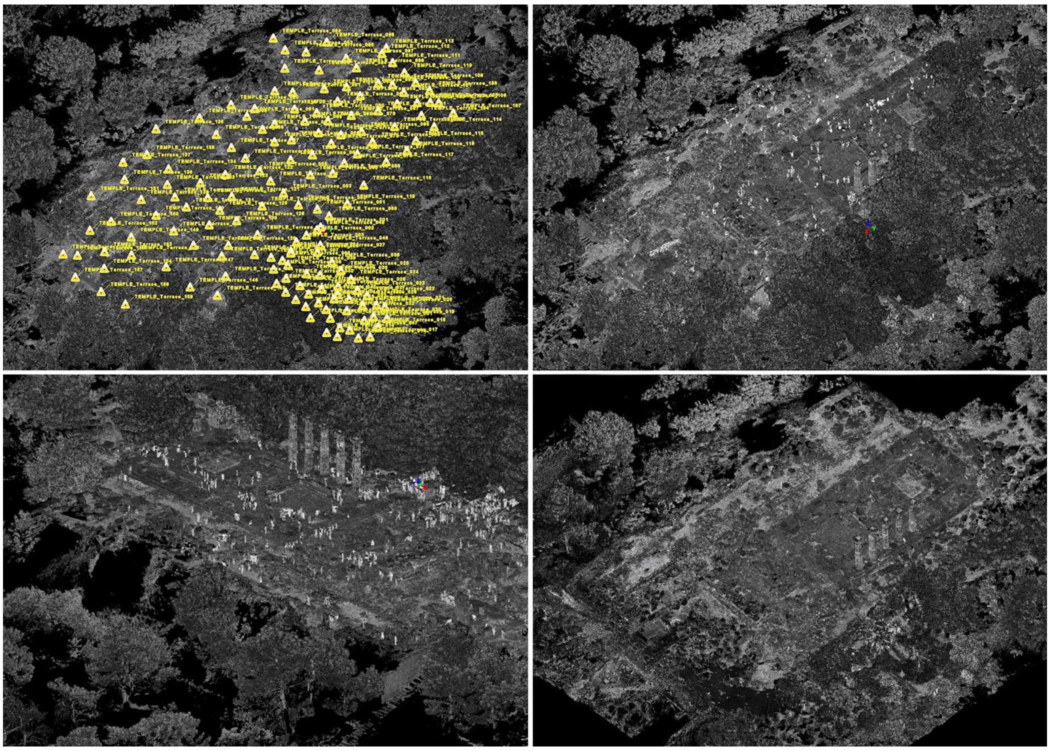


Figure 3. On the left are axonometric views of the aligned point clouds of the Temple area: image with 465 scan station positions (**top**) and a southwest view (**bottom**). On the right, images of post-processing: a comparison between the raw data (top) and cleaned point cloud (**bottom**). (E.C.G.).

3.2. *The Theater*

The Theater of Priene is considered a typical Hellenistic theater due to its limited modifications in the Roman period, unlike most Greek theaters in Anatolia. Armin Von Gerkan confirmed this condition during his archaeological campaign from 1911 to 1912. During the period of the two world wars, excavations were suspended and then resumed by numerous scholars: Wolfgang Müller-Wiener (1977–1982), Wolf Koenigs (1990), Wulf Raeck (2013), Hasibe Akat (since 2014).

For the Theater, the analysis followed an acquisition campaign that involved an integrated survey: the photogrammetric acquisition was performed with an unmanned aerial vehicle (UAV) by specialized operators using a DJI Mavic Mini drone equipped with a 1/2.3-inch CMOS sensor (Figure 4). At the same time, the terrestrial photogrammetric acquisition campaign was part of the educational experience offered to the participants by the International Summer School [23][1] and was performed using students' smartphones. A total of 1502 images were aligned and post-processed using MetaShape (Figure 5). The obtained point cloud was then scaled using target points and dimensional references acquired in situ. Using elements of known length for dimensioning point clouds is a common practice and generally produces dimensional accuracy within a few centimeters [24].

Figure 4. Images of the Theater and UAV acquisition. (E.C.G.).

Figure 5. Images of the post-processing of data for the Theater. From the left, the alignment of cameras (1,256,561 points), dense cloud (261,238,304 points), and textured mesh (43,646,219 faces and 21,831,522 vertices). (E.C.G.).

The numerous investigations and studies conducted on the Theater of Priene have made it possible to understand how the monumental building has changed, highlighting its complexity. In this case, diverse authors have made diverse assumptions regarding its layout and various configuration phases, including its *skené*, which had a similar function to the modern proscenium.

According to Gerkan [25], the Theater had three configurations. The first was a Hellenistic era configuration with a *skené* composed of a single level of Doric order and eventually an upper level with a central main entrance to access the scene (Figure 6). The late Hellenistic age saw a shift of the theatrical action from the orchestra level to the first level of the *skené*, with the spectacular presence of three huge niches simulating big entrances (Figure 7). Finally, the Roman configuration featured a *scenae frons* with two levels (Figure 8).

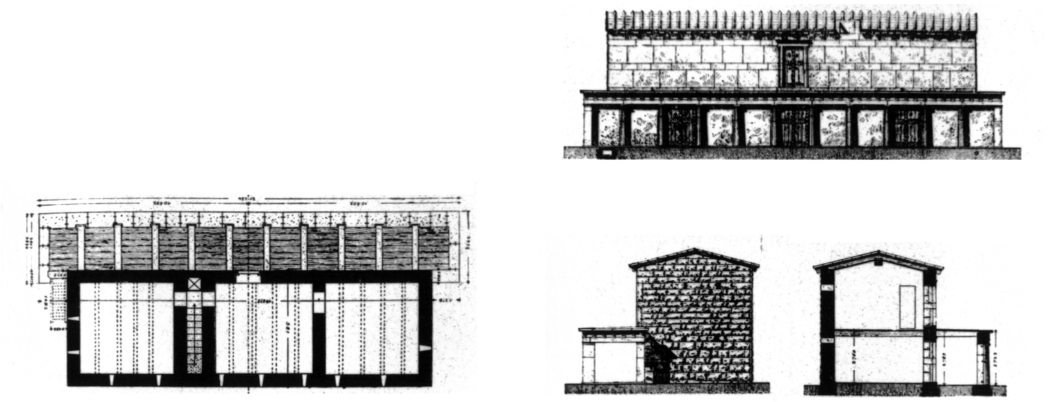


Figure 6. The hypothesis of the first configuration of the Theater (image from the *Salt Araştırma, Harika-Kemali Söylemezoğlu Arşivi*) [26,27].

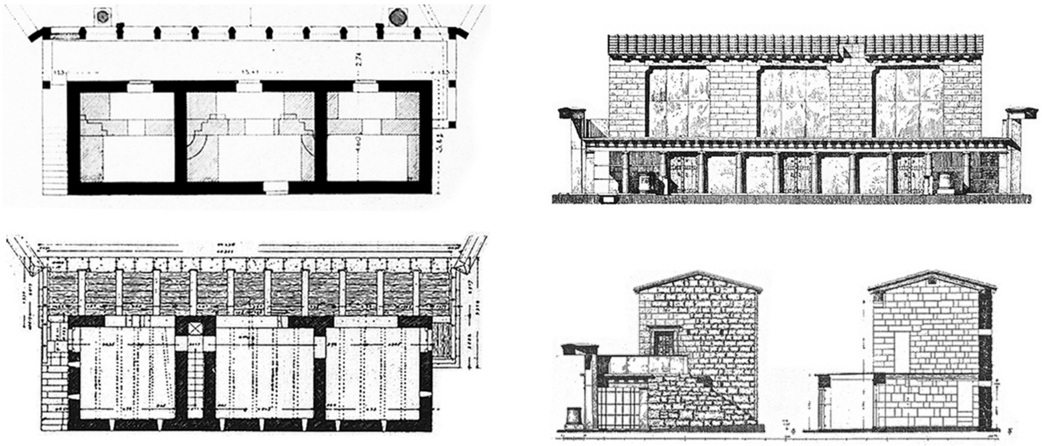


Figure 7. The hypothesis of the Hellenistic Age of the Theater according to Gerkan [25,28].

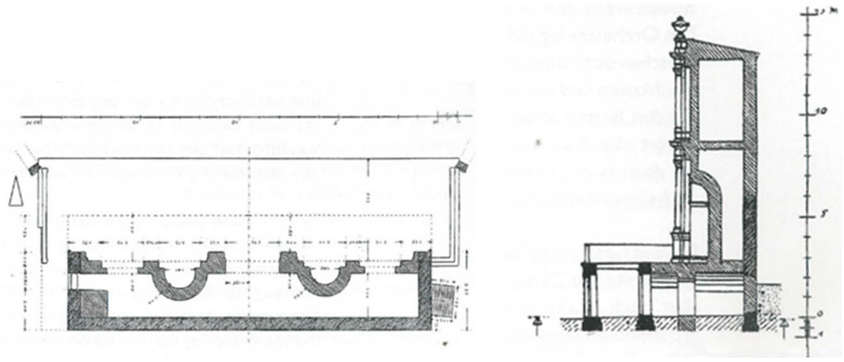


Figure 8. The hypothesis of the Roman Age of the Theater according to Gerkan [5,25].

4. Data Analysis of the Retaining Wall of the Doric Stoa

The retaining wall comprises two parts, the eastern and the western sides. Both parts are characterized by corners that are well interlocked between the elements. The analysis of the digital survey shows that the eastern side of the wall, which is the most visible one, is not aligned with the axis of the terrace and the Stoa behind, exhibiting a deviation of 2 degrees. However, the limited angle results in a displacement around 79 cm in the total length of the non-aligned portion. Hennemeyer [18] has documented this variation, indicating the two external sides to be constructions of different phases, while the original retaining wall appears to be the one in the central part. However, an observation of the remains of the wall reveals how all the central part has collapsed, with only a few remains lying on the bedrock.

The horizontal alignment between the different wall parts immediately points out the diverse characteristics of the retaining walls (Figure 9). The layers between the two sides do not correspond, and the stone elements have different dimensions in terms of the length and height. According to the masonry quality index method [29], although there are morphological differences between the eastern and western sides of the terrace, the two walls present similar peculiarities from a structural perspective, indicating good realizations (Figure 10 and Table 1).

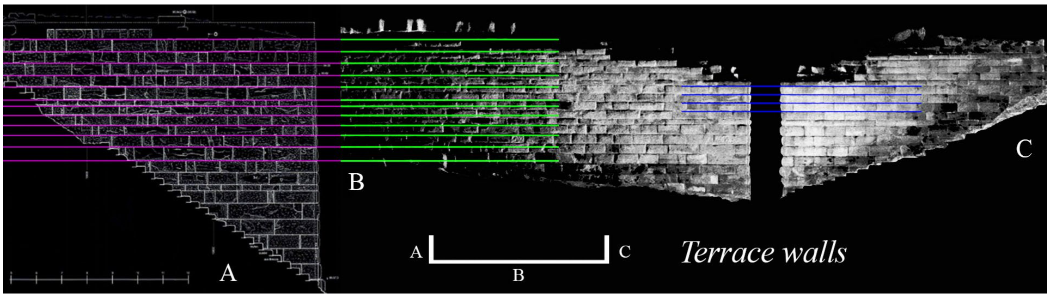


Figure 9. Horizontal misalignment between the three parts of the retaining walls (**A**–**C**). The position of the three parts is detailed in the legend. On the left is the west corner of *Beilage* 4 [18]. On the right are the two fronts of the east corner from digital acquisition. (V.C.).

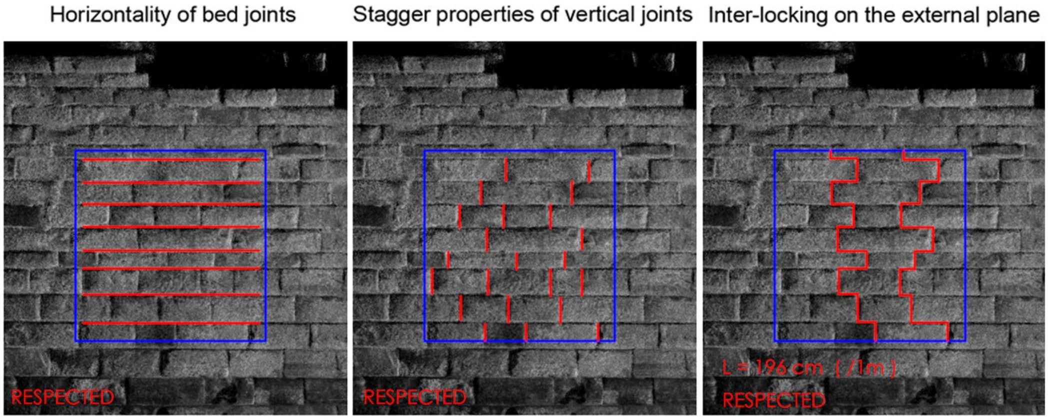


Figure 10. The Masonry Quality Index (MQI) analysis [29] applied to wall B from Figure 9. (V.C.).

Table 1. Parameters to consider in the visual analysis of the MQI method for wall B from Figure 9. (V.C.).

Description of the Parameter	Acronym	Outcome [1]
Mechanical characteristics and quality of masonry units	*SM*	F
Dimensions of the masonry units	*SD*	F
Shape of the masonry units	*SS*	F
Level of connection between adjacent wall leaves	*WC*	F
Horizontality of mortar bed joints	*HJ*	F
Staggering of vertical mortar joints	*WJ*	F
Quality of the mortar/interaction between masonry units	*MM*	NF

[1] Fulfilled—F, partially fulfilled—PF, and not fulfilled—NF.

On the west side, the wall offers a large number of *diathon* elements connecting the retaining wall to the ground. On the other hand, the east wall presents a different configuration along the height, with three minor courses defining a different geometric pattern. Concerning the *diathons*, there are still elements connected to the ground behind them.

Although these are less identifiable in terms of the dimensions, they are visible in the part adjacent to the collapse, where the inner section is reachable. In all cases, all the walls lie directly on the bedrock layer. Where this emerges from the slope of the hill, the construction of the wall began following the natural inclination of the bedrock, leading to portions with a greater or lesser height as a function of the site's natural characteristics. This is observable in the connections of both sides; furthermore, looking at the eastern part, some non-horizontal elements seem to result from successive additions to tuck the wall in its closing part. This is still coherent with the ground survey performed in part below the terrace to observe the composition of the ground beneath the podium, where a series of filling with incoherent materials were identified [18].

Discussion on Historical Damage, Earthquakes, and Vulnerabilities

According to Altunel [30], a damaged corridor in the Agorà is the more evident evidence of historical damage suffered by Priene due to ground motions. Considering the territory where Priene is located, it is plausible that different earthquakes have struck the region, thus leading to different consequent damages. In addition, many excavations and alterations have been performed over the years, e.g., considering the tumuli of debris made by the English excavations right below the western side of the terrace. Stiros [31] shows clearly how the falls and damage that happened to most historical temples made by the drum of stones depend on complex mechanics. The main effects can be identified, but the disruption process is challenging to define fully. Observing the terrace of the Stoa area, near the Athena Temple, it is possible to speculate that the central part is the most vulnerable due to the absence of orthogonal walls impeding the out-of-plane failure. Due to the presence of walls from different periods, local discontinuities could have increased the tendency to overturn the central part because of weak connections to the side parts. On the other hand, the presence of walls realized at different times could still be the consequence of a failure, given by the shape of the wall, which is long, around 78 m, and thus vulnerable to horizontal flexural mechanisms.

5. Knowledge Interpretation

New digital tools offer multiple possibilities for preserving and enhancing knowledge about archaeological heritage. Semantically structured digital models emerge as a product for dissemination from the digital acquisition of metric data. Within this specific topic, virtual reconstructions, widely used in digital cultural heritage, represent a challenge and a still open field of investigation. The question, still open, concerns not so much the morphological aspects of a reconstructed asset but rather the need to make accessible the critical reasoning behind the reconstructive process itself. This research, therefore, considers, starting from the open debate on the matter and from the existing guidelines, such as the 'London Charter for the computer-based visualization of Cultural Heritage' [32,33], the 'International Principles of Virtual Archaeology' [34,35] and the FAIR Guiding Principles for Scientific Data Management and Stewardship [36], what could be a methodological workflow capable of gathering the complexity of knowledge related to the archaeological area and architectural complexes under consideration.

The virtual reconstruction process involved data collection, digital acquisition, data analysis, and interpretation. In this phase, a data modeling approach was chosen for both the morphological and informative layers. The data modeling visualization consisted of the knowledge representation of the reconstruction process using 3D models, visual graphs, and digital tools [37,38]. This approach is in line with studies about transparency and the use of paradata to describe 3D critical modeling processes [39–41].

This approach has also recently been used within the European Erasmus Plus project titled 'Computer-based Visualization of Architectural Cultural Heritage-CoVHer' (2022–2025) [42], which aims to sensitize the public to distinguishing accurate from inaccurate historical reconstructions. Past projects also considered the possible implementation of platforms capable of using 3D models to narrate and explain the historical evolutions of an urban-scale asset. Examples are the 'Visualizing Venice' project (2009) resulting from the collaboration between Iuav University of Venice and Duke University (North Carolina) [43] and now expanded into 'Visualizing Cities', the European 'Time Machine' project (2019–2020) [44], and the ERC Venice's Nissology: Reframing the Lagoon City as an Archipelago (VeNiss) project (2023–2027) [45]. These can also be classified as projects of the so-called 'digital urban history' discipline, including the historical application of geographic information system (H-GIS).

In contrast, the search for semantically structured approaches to virtual reconstructions is addressed in the 'German-speaking area' by the 'DFG-3D Rekonstruktions Netzwerk'. Starting with the project 'Digitale 3D-Rekonstruktionen als Werkzeuge der architekturgeschichtlichen Forschung' [46] and the subsequent 'DFG-Viewer 3D-Infrastruktur für digitale 3D-Rekonstruktione' (since 2020), the aim has been to develop a digital 3D viewer infrastructure for 3D cultural heritage models [47,48]. The nature of all the above projects is their willingness to use FAIR processes and the use and generation of OpenData. These last two projects have a historical and digital humanities-oriented approach.

Another relevant and interesting project in the field of conservation and restoration of architectural heritage is the European 'Inclusive Cultural Heritage in Europe through 3D semantic modelling–INCEPTION' project (2015–2019) [49,50], which focuses on heritage digitization and documentation using structured 3D data with a Historic Building Information Modeling (HBIM) approach. More recently, also the ERC project 'n-Dame_Heritage. n-Dimensional analysis and memorisation ecosystem for building cathedrals of knowledge in Heritage Science' (2022-2027) addresses the production of collective knowledge to build an emblematic corpus of data on scientific practices in heritage science, in the digital age [51]. The need to lay the foundation for a 3D model semantically structured outside HBIM methodologies [52] was also addressed in the field of unbuilt heritage [53].

The activity turned out to be ambitious but, unfortunately, is still far from being a standardized procedure accessible to the general public, which still remains anchored to the idea of the digital replica with low interaction.

This study decided to use another method, one more widely used in archaeology, based on a stratigraphic approach. As a data-modeling tool, this study investigates the use of the Extended Matrix [54] to manage and visualize the data beyond the virtual reconstruction processes of the Doric Stoa (Figure 5). The Extended Matrix (EM) is a stratigraphic reading approach that aims to create a common framework connecting archaeological documentation and virtual reconstruction. The EM can be considered a novel visual form of knowledge production and a visual template for creating knowledge graphs. The theoretical approach and developed application are based on Steno's stratigraphical theory of lacunose systems [13].

The EM process is defined by a virtual reconstruction pipeline based on five main phases: (1) data collection, (2) data management/analysis, (3) implementation/virtual reconstruction with the creation of the EM and the development of a 3D model that can have two types of visualization: the proxy visualization for scientific purposes and the digital representation for the large public (4). The last step (5) is publishing and disseminating the reconstruction hypothesis [55]. Considering the EM schema as a conceptual model for formalizing virtual reconstruction processes, the stratigraphical approach is functional where archaeological evidence is available. An archaeological background is necessary to identify and analyze different layers of knowledge referred to as a temporal construction sequence.

The graphic visualization of the interpretation processes within the EM is represented through a series of visual nodes describing a 'Stratigraphic Unit' (US), where a gap (-SU) corresponds to a 'Negative Stratigraphic Unit' that can be integrated or reinterpreted using a 'Virtual Stratigraphic Unit' (USV). The USV/s is used to represent archaeological evidence, not in situ, and it allows the anastylosis process to be represented. The source-based hypothesis is declared using the USV/n 'Node'. A 'Special Find' (SF) is used to encode archaeological fragments, and a USV series is used to identify a whole composed of a series of objects.

The EM is also composed of a series of other nodes that can be used to track paradata and describe virtual reconstruction processes. In this case, the 'Property node' describes the type of information extrapolated by a source (represented by the source node) using an 'Extractor node' that highlights the correlation between these two nodes descriptively. Finally, the 'Combiner node' allows for validating property assumptions and how different sources or stratigraphic units can deduct or interpret them.

5.1. Insights on the Doric Stoa

The Doric Stoa in Priene was a monumental portico made of 32 Doric columns (*Beilage 7*) [17]and two pillars at the ends, and it was built against the polygonal wall supporting the terrace of the Temple of Athena Polias. The Priene Stoa is a portico with a back wall and a colonnade in the front, supporting a roof. For its virtual reconstruction, the group considered the work performed by Hennemeyer [18] as the primary reference.

The group focused on drawing with reconstructive details (*Tafeln* from 84 to 88 and *Beilage* 7). Unlike the previous study, digital technologies and 3D laser scanner acquisition allowed further validation of previous measurements and assumptions. The point cloud obtained was finally superimposed on the previous survey drawing (Figure 11) and was used for dimensioning the 3D model of the Doric Stoa.

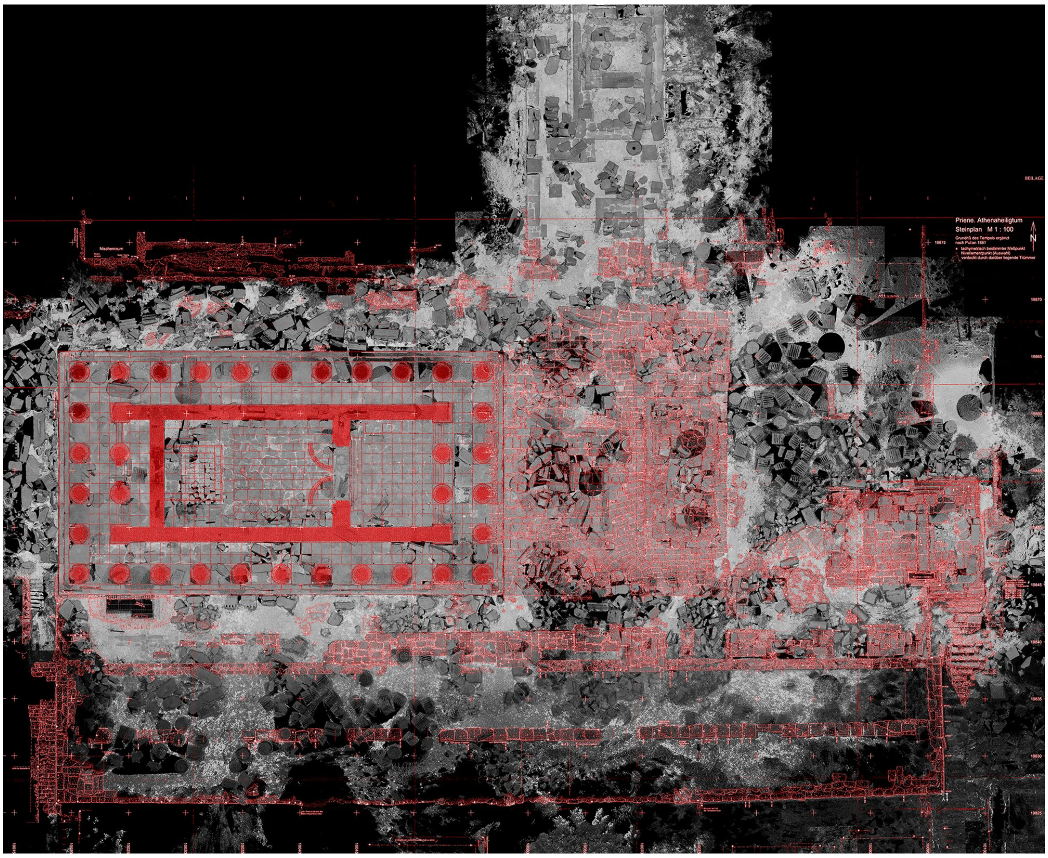


Figure 11. Superimposition between the digital acquisition (2022) and the archaeological survey drawing from *Beilage* 1 [18] (E.C.G. and G.V.).

In the case of the Doric column, a reality-based element was used as a Doric capital, which was probably moved from the Athena Temple area near the Theater. Its presence by the Theater is due to its proximity to the ruins of a Byzantine basilica. The place of worship was completely built from reused materials taken from the area [56]. For dimensioning and representing the shaft of the column, the reconstruction was based on diverse drawings and a table of measurements produced by Hennemeyer [18] (Figure 12).

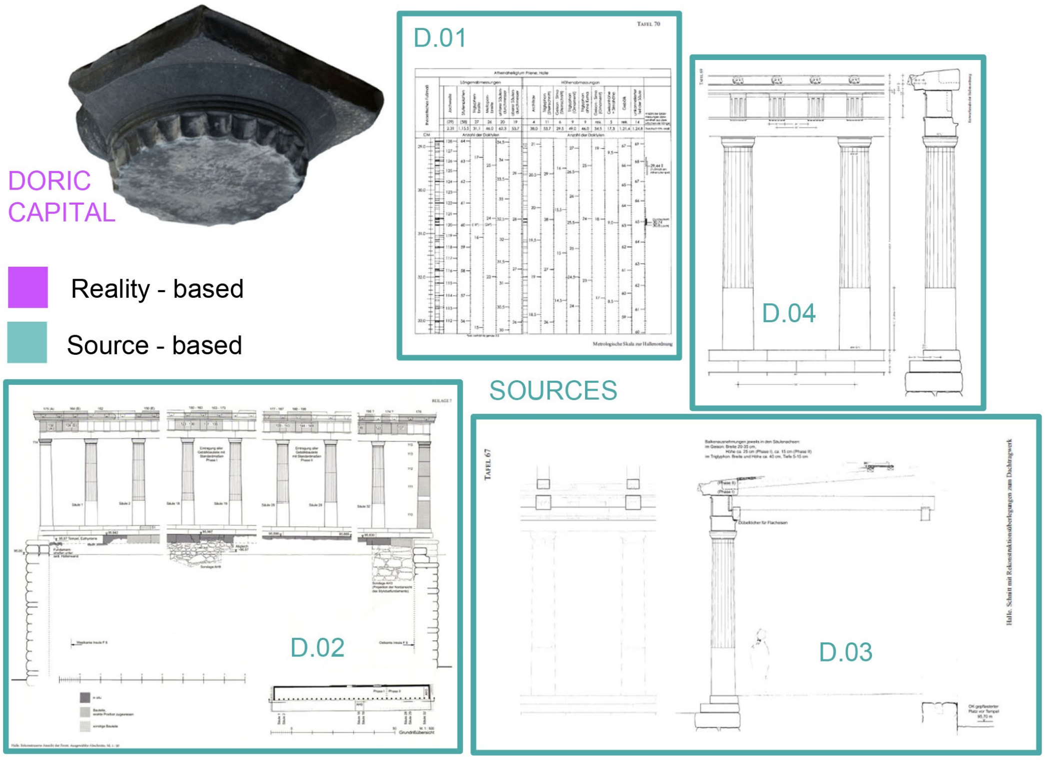


Figure 12. Reality-based capital (magenta) and source-based references (cyan) for the virtual reconstruction of the column of Doric Stoa, according to Hennemeyer [18]. (E.C.G.).

Figure 13 presents the knowledge graph based on the Extended Matrix. The various elements of this stratigraphic visualization system have been previously described, and they form the conceptual basis for defining a Doric column instance.

The columns in the table represent the location of the elements. In fact, SF01 represents the capital found in the Byzantine basilica. It is placed in the first row in the 'Theater area' and thus belongs to the current location of the object. The second row represents a time interval, referred to here as 'Greek time', which can be coded as a more defined historical period using standard dating systems such as PeriodO. PeriodO is, in fact, a period gazetteer that documents historical period definitions [57].

Within the 'Greek period', it is possible to find the two main elements of the column: the capital (USV107) and the column (USV106), which are represented here as virtual stratigraphic units as we refer to their digital representation. The main characteristics of these elements include, for example, material, dimensional, and shape properties. Concerning the capital (USV107), this information can be deduced through a critical/interpretive process (extractor node SF01b.01) from the reality-based model (SF01b) obtained from the digital acquisition of the in situ find (SF01). For the virtual column instance (USV106), the dimensional and shape properties are inferred from different sources. In this case, a series of *Combiner nodes* (C.01 and C.02) are required to combine information inferred from multiple sources (D.01, D.02, D.03, and D.04) through different *Extractor nodes* (D.01.01, D.02.01, D.03.01, and D.04.01). Finally, the USM01 corresponds to the archeological evidence of the retaining wall of the Doric Stoa.

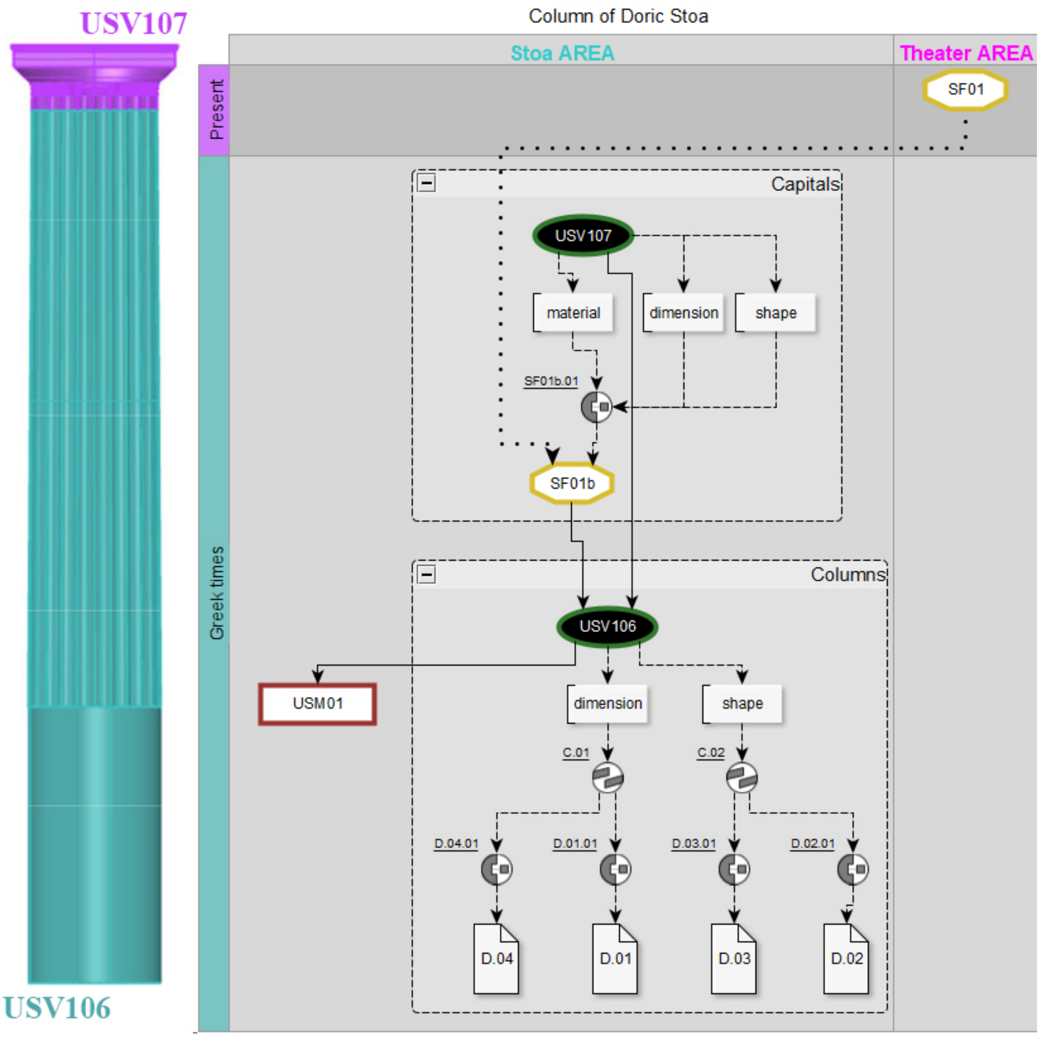


Figure 13. Extended Matrix visual graph (v.1.4) for the description of the reality-based capital (magenta) and source-based virtual reconstruction of a column (cyan) of the Doric Stoa according to Hennemeyer [18]. (E.C.G.).

Dimensioning of the Doric Order for columns was based on the ‘Table of Dimensions’(*Tafel* 88), (D.01), that indicates the columns’ measurements, *ratios*, and geometrical appearance.

The hypothetical reconstruction produced by Hennemeyer [18] (*Tafeln* 86–87) (D.03, D.04) considers Doric columns, tapering at the top 1/3 of their height. The column is assumed to have a smooth shaft and a straight section at the bottom of *Beilage 7*, (D.02). Above, the shafts appear fluted, as indicated by the column portions and other archaeological fragments (*Tafel* 55). As shown in the caption of the ‘Table of Dimensions’ ,the proportioning and sizing of the Order refers to Phase I of the construction of the Stoa. Above the column, the entablature consists of a plain architrave, a frieze with triglyphs, and a cornice with a lion’s head-shaped drip molding. The roof, probably in terracotta, was supported by a truss system.

The final 3D output comprises reality-based and source-based 3D models linked to the list of references used for their three-dimensional modeling using the EM plug-in inside Blender. Since its initial development, it has consisted of a visual graph system that can be linked to the 3D model. The semantic structure of the 3D model and its components, divided into layers, are encoded with the ID of the digital object inside Blender. They are then associated with the same encoded element in the graph system developed inside the *yEd* graph editor software (v. 3.24).

The graphic visualization of the model considers a clay representation labeled to obtain a more comprehensive representation of each building, superimposing non-textured reality-based models and source-based ones (Figure 14). This approach differs from the reliability representation available in the EM tool and could be considered an alternative for visualizing source-based critical reasoning.

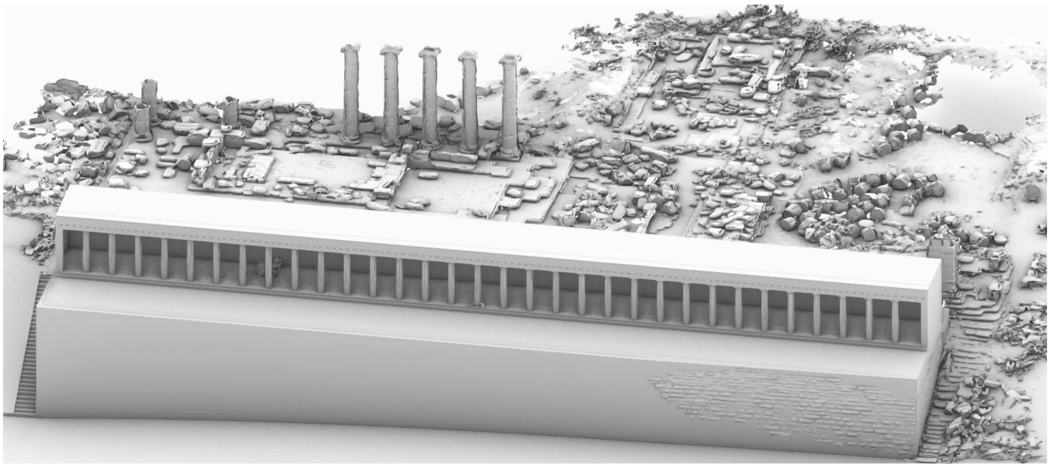


Figure 14. Three-dimensional virtual reconstruction of the Doric Stoa. Superimposition from a reality-based 3D model obtained from the point-cloud and source-based 3D model, according to Hennemeyer [18]. (E.C.G.).

As can be easily understood, the Extended Matrix provides a structured methodology for the graphical representation of virtual reconstructions. Its structure, despite being codified, is constantly evolving. The latest release allows you to create JSON databases by offering a structured data format that is interchangeable and eventually readable by other software [56]. Since the EM is not a standard, it can be understood as a 'conceptual model' that can be mapped to known standards such as CIDOC-CRM in the future [59].

5.2. Insights on the Theater

As with the Doric Stoa, in this case, the architectural elements were dimensioned according to the metric acquisition made using the UAV technology. The point cloud was then compared with historical documentation and hypothetical reconstructive drawings produced by Gerkan and proposed again by Dörpfeld [60].

Unlike the case of the Stoa, the fragments of the Theater area were relocated between 1992 and 1998, according to the conservation plan designed by Misiakiewicz. The statues and monumental fragments, now displaced from their original positions, did not allow for new considerations. They resemble earlier authors who first studied the Theater and visited the sites before the 'modern' interventions of partial anastylosis.

The most represented configuration of the Theater, also shown in informative panels along the archaeological area, usually shows the late Hellenistic phase. The reconstructive representation is aligned with its configuration to provide 3D models accessible in the archaeological area.

The point cloud was scaled and cleaned to obtain a textured reality-based model, and Gerkan's drawings were used as reference sources for missing elements (Figure 15). Digital technologies and virtual reconstruction allowed for investigating, in this phase, the three-dimensional modeling of the *skené* area, adding the first level, superimposing the archaeological evidence, and mixing reality-based and source-based 3D models (Figure 16). This configuration represents the late Hellenistic Age solution of the Theater and it is far for defining the upper area of the cavea over *diazoma*. The model shows only the first level of stairways or *klimakes*, the superior *klimakes*, and the *theatron*, which follow the slope of the mountain and are partially recognizable by analyzing the digital acquisition.

The *cavea*, as it stands today, probably represents a later configuration than the Hellenistic-era representation chosen in this study. Instead, a proposal for its final configuration is found, for the record, as indicated in Figure 15 (right). As shown by a comparison between the data acquired during this campaign and previous campaigns, the group did not have enough data for the upper area to state its configuration. The lack of information did not allow for digital modeling of that portion of the stairways, opting for a representation faithful to Gerkan's hypothesis [25].

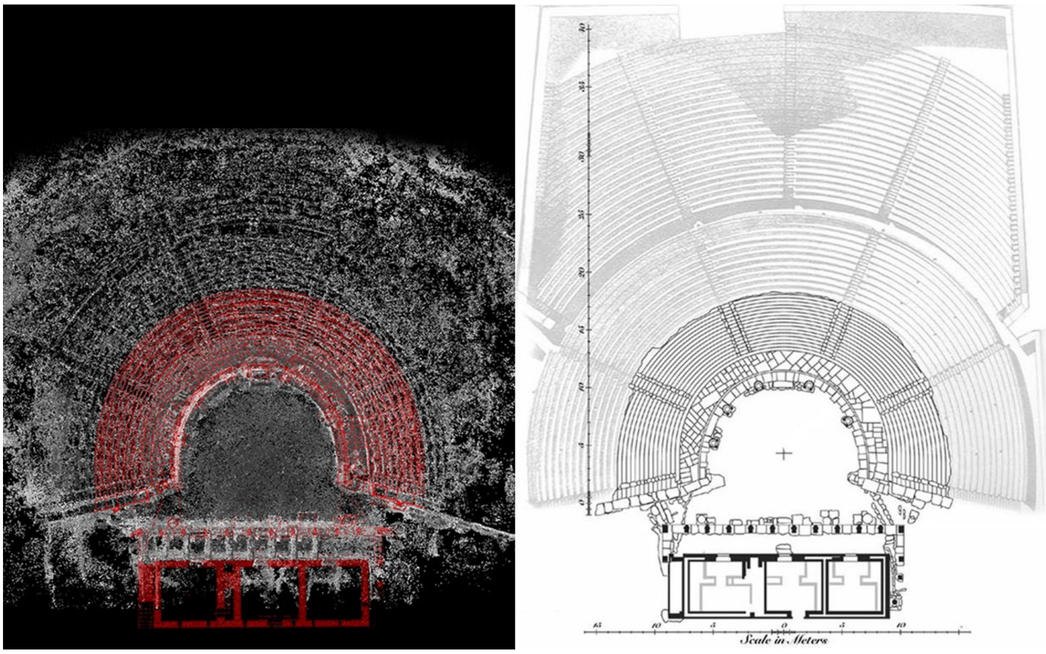


Figure 15. On the **left**, superimposition between the UAV digital acquisition (2022) and the hypothetical reconstructive drawings by Dörpfeld [60] used as references for the source-based 3D. (E.C.G. and G.V.) On the **right**, reconstructive hypothesis from 'The Ancient Theatre Archive' [61].

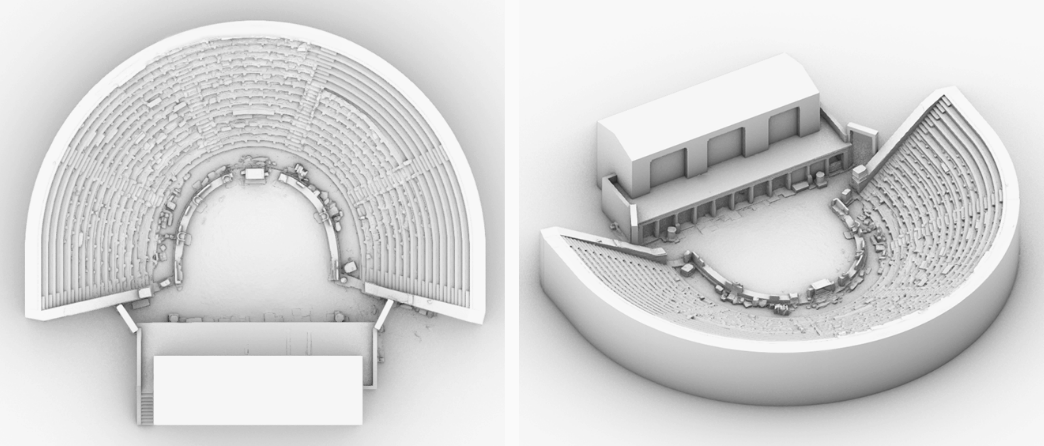


Figure 16. Three-dimensional virtual reconstruction of the Priene Theater. Superimposition from a reality-based 3D model obtained from the UAV point cloud and source-based 3D model, according to Dörpfeld [60]. (E.C.G.).

6. Knowledge Representation and Visualization

The 3D models obtained for the virtual reconstruction processes previously explained are not yet accessible through digital galleries that offer visualization of 3D models (e.g., Sketchfab). The most suitable platform for publishing the scientific reconstruction material is still being evaluated. Numerous platforms offer the visualization of 3D models, but few are customizable ones that offer the ability to display various objects separately [62,63]. Indeed, it would be interesting to visualize the reality-based and source-based parts of both scenes using different colors, showing the uncertainty grade of the 3D elements that compose the scene [64]. Representing various layers would also allow for augmenting the data visualization developed within Blender using the EM tool plug-in and, eventually, the *Extended Matrix Visual Inspector and Querier tool* (EMviq) [65] implemented within the ATON platform [66,67].

Other visualization tools offer the possibility of integrating 3D models using FAIR principles and Linked Open Data [68–72]. They require a structured 3D data model that is still being implemented within the Extended Matrix research community group.

Finally, semantic platforms can eventually be implemented with 3D semantic viewers. Some possibilities are *Arches*, an open-source data management platform for the heritage field [73], and *ResearchSpace,* developed by the British Museum for galleries, libraries, archives, and museums (GLAM institutions) [74].

The use of virtual reconstructions of the ruins of Priene showed the efficient uses of virtual experience to better understand the relationship between the archaeological remains, the original architectural setup, and the ‘effect’ that urban space was imposing on its visitors and inhabitants. The 3D modeled areas of the city are a pretty limited result, but they add impressions about the quality and complexity that may be enhanced over time with new studies and integration of details.

Nowadays, part of the research process also involves communicating and enhancing the object of study. In this panorama, digital technologies such as augmented, virtual, and immersive reality allow users to experience the visit actively. Again, many applications and technologies are available, so the group focused on using web-based applications. Platforms such as Sketchfab.com allow the creation of real digital galleries at low costs. They are accessible through diverse devices such as desktops, smartphones, and VR headsets with a stable Wi-Fi connection.

Unlike other applications, such as Unity, Unreal Engine, Twinmotion, and Enscape, web-based applications do not need to be installed on devices generally designed to be cross-platform and accessible from a webpage. One disadvantage, however, is that they face limitations in uploading 3D models, which must then be retopologized and reduced in file size and texture definition. These solutions are, therefore, preferable when developed for the general public and for dissemination purposes rather than toward an academic and scientific target audience.

Sketchfab allowed the research team to work in parallel on multiple 3D models and then create a digital asset connecting the various 3D assets (*prohedria* marble seats), developed by photogrammetric acquisition, into a single digital collection [23]. The reality-based model of the Theater, previously used as a reference for the virtual reconstruction of the Hellenistic phase, was then used to create a digital immersive collection (Figure 17 and Table 2).

The 3D models of the *prohedria* seats were linked to the Theater 3D scene (Figure 18), allowing access to a higher-resolution 3D model of the first-order magnificent seats. This initial configuration can be accessed directly in VR via mobile and desktop through the Sketchfab Virtual Reality experience. The experience can be considered a virtual exhibition where the user, through the digital environment (container), can access the 3D models (collection). This relationship, sometimes impossible to experience in reality—such as with relocated objects conserved abroad—is made possible through extended reality (ER) solutions that allow social interactions [75,76].

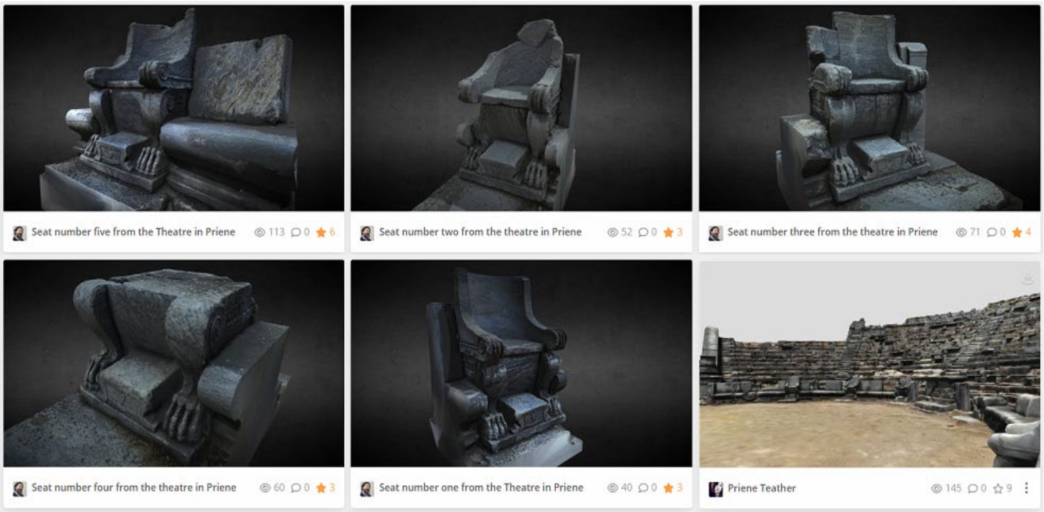


Figure 17. Reality-based 3D models developed for the VR experience. (E.C.G. and G.V.).

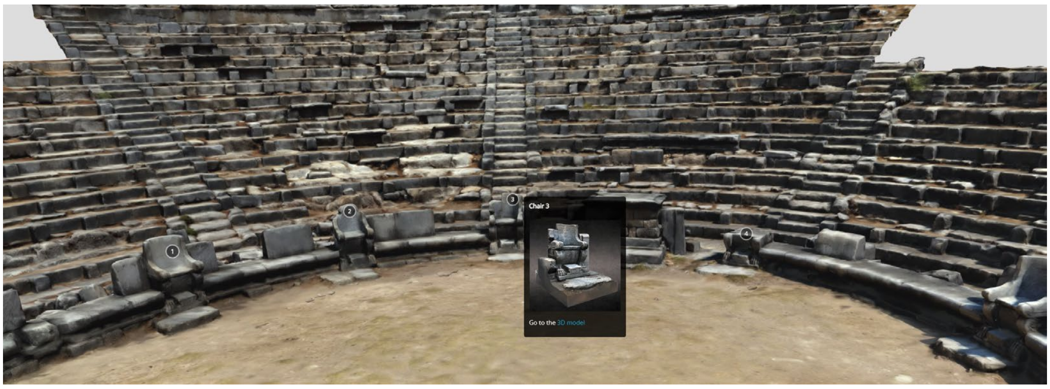


Figure 18. VR experience with annotations and links to detailed digital assets of *prohedria* marble seats. (E.C.G. and G.V.).

Table 2. Three-dimensional data* about the digital assets (Figure 17) developed and stored online in a digital gallery.

3D model	N. Pictures	Geometry (Triangles)	Vertices	Materials	N. Textures	Texture Resolution	Direct Link
Seat one	809 shots	6 M	3.1 M	7	7	16,384 × 16,384	https://skfb.ly/owPAH
Seat two	490 shots	8 M	4 M	3	3	16,384 × 16,384	https://skfb.ly/owODH
Seat three	732 shots	7 M	3.5 M	2	2	16,384 × 16,384	https://skfb.ly/owOsy
Seat four	416 shots	7 M	3.6 M	7	7	16,384 × 16,384	https://skfb.ly/owO8 N
Seat five	732 shots	7 M	3.6 M	15	15	16,384 × 16,384	https://skfb.ly/owOoG
Theater	1502 shots	800 k	403.5 k	1	1	16,384 × 16,384	https://skfb.ly/oDNEG

* Post-processed data uploaded into the SketchFab platform. All direct links have been accessed on 13 August 2024. (E.C.G. and G.V.).

For immersive reality within Sketchfab, the access point to the model was set at 120 cm, considering the eye height of a seated individual. This is possible thanks to the VR setup that allow content creators to configure VR using the preview of the experience (Figure 19). Sketchfab reduces resolution to ensure a frame rate for a good VR experience but it is also possible to define custom parameters at the end of the model's URL according to the VR device specifications. A Meta Quest 3 was used for the immersive visualization test. Through the VR device connected online, the observer can access the gallery using the Meta Quest Browser and thus experience the digital asset as if they were inside the Theater, either sitting in a main chair or walking through the digital scene (Figure 20). The main lesson learned in this case is that the virtual visit confirms the authors' ideas and enhances the understanding of the original scenario, which may lead to valuable insights.

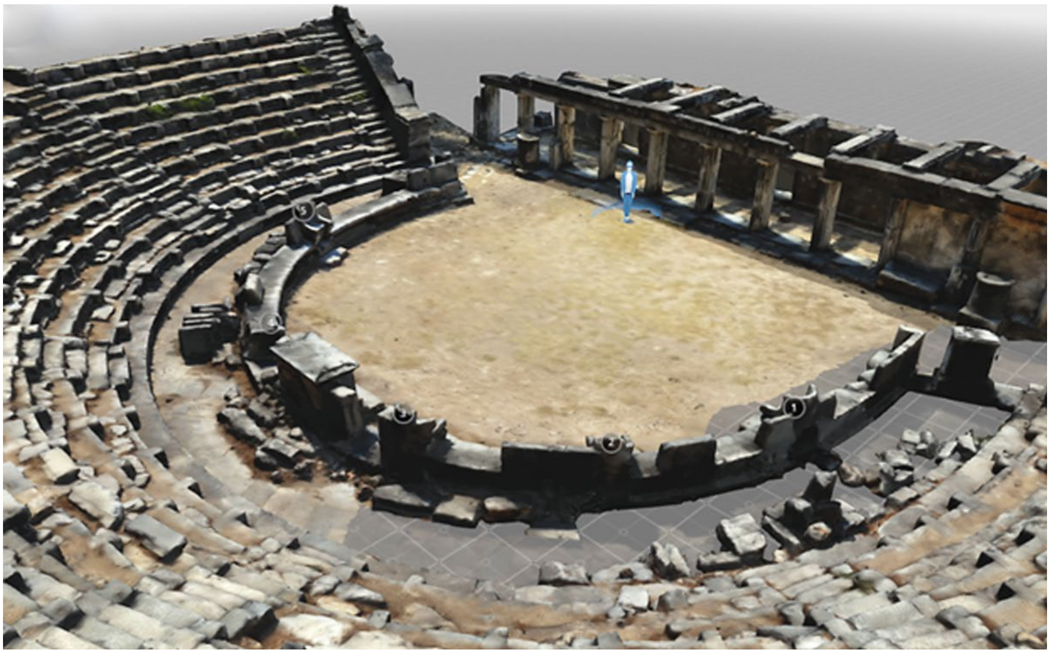


Figure 19. VR experience Meta Quest 3 preview using the Direct Link. (E.C.G and G.V.).

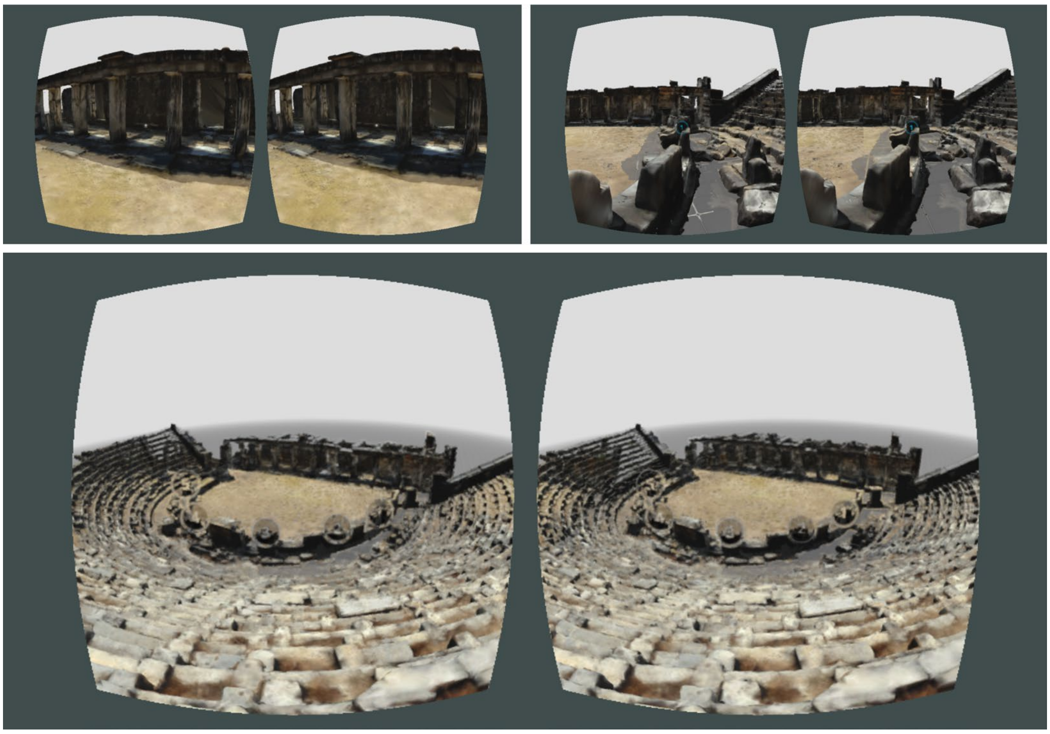


Figure 20. VR visualization with a mobile device of the walkthrough experience. (E.C.G.).

7. Conclusions

This manuscript presents the outcomes of interdisciplinary research on Priene's ancient ruins. The research involved researchers from different fields, including geometric and material surveys, historical and structural experts, designers, etc. The present work aims to provide insights based on advanced digital tools to understand archeological areas. Regarding the area of Priene, the generation of 3D models allowed for operating analysis and reasoning on accurate representations of both sites, with a detailed representation of the shapes, dimensioning, and alterations, which supported well the study and understanding of the transformations caused by striking events (like earthquakes and floods), transformations due to nature reclaiming the sites, transformations, and human interventions for archaeological operations and for moving and storing the fragments for various reasons.

The interpretation of the structural evidence of the ancient remains took advantage of different sources. On the one hand, historical information and previous studies on the development of the Priene were acquired. Hence, this information has been combined with the outcomes of the integrated survey campaigns and the in situ evidence of damages, vernacular construction techniques, and building typologies.

The city of Priene represents an important opportunity to deal with different issues, like understanding the original landscape and urban asset, reconstructing the whole urban asset and refining the relationship between architectural elements and their details, and defining possible digital visualization for the conservation and preservation of cultural heritage and archaeological sites. However, the lack of information about the original appearance of both monuments caused by the historical gap between the current times and Priene's era has limited the outcomes of this research. The case study presented herein is not the most suitable example to show the new opportunities for integrating such digital tools in archeological areas.

However, the authors believe that the proposed methodology can set a path for further studies in other contexts, providing interesting (and maybe new) perspectives. It is worth noting that the quality of the gathered information depends on a case-by-case basis, according to available information, previous knowledge, and past operations on the sites. Integrating new digital technologies, historical sources, and constructive appraisals can allow for gaining new insights related to several disciplines, dealing with ancient natural disasters, past restoration interventions, and managing archaeological ruins.

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References

1. Arrighetti, A. *Archeosismologia in Architettura*; Firenze University Press: Florence, Italy, 2015. https://doi.org/10.36253/978-88-6655-814-9
2. Imperadori, M.; Vanossi, A.; Liotta, S.J.; Ito, Y.; Della Croce, D. *Architecture for Archeology. Identifying New Modular and Flexible Types of Shelter Adaptable to the Diverse Needs of Archaeological Sites*; International Association for Bridge and Structural Engineering—IABSE: Zurich, Switzerland, 2016. https://doi.org/10.2749/222137815815774197
3. Demand, N. The Relocation of Priene Reconsidered. *Phoenix* **1986**, *40*, 35–44. https://doi.org/10.2307/1088963
4. Wiegand, T.; Schrader, H. *Priene: Ergebnisse der Ausgrabungen und Untersuchungen in den Jahren 1895–1898*; Georg Reimer: Berlin, Germany, 1904. (In German) https://doi.org/10.11588/diglit.1000
5. Schumacher, A.; Misiakiewicz, J. *Priene—Die Restaurierung des Theaters 1992–1998*; Verlag Philipp von Zabern: Mainz am Main, Germany, 2007, ISBN 978-3-8053-3744-1 (In German)
6. von Gerkan, A. *Griechische Städteanlagen: Untersuchungen zur Entwicklung des Städtebaues im Altertum*; De Gruyter: Berlin, Germany, 1924; pp. 1–175. (In German) https://doi.org/10.1515/9783111502212
7. Wikimedia Commons. Plan of Priene in Griechische Stadeanlagen. Available online: https://commons.wikimedia.org/wiki/File:Plan_of_Priene,_in_Griechische_Stadeanlagen_Wellcome_M0009550.jpg (accessed on 20 August 2024)
8. Petit, A.; Wala, Z.; Ciucci, M.; Martinello, B. Digital agenda for Europe. Available online: https://www.europarl.europa.eu/factsheets/en/sheet/64/digital-agenda-for-europe (accessed on 5 August 2024).
9. Council of Europe. *Explanatory Report to the Council of Europe Framework Convention on the Value of Cultural Heritage for Society [CETS No. 199]*; Council of Europe: Strasbourg, France, 2005. Available online: https://rm.coe.int/16800d3814 (accessed on 20 August 2024)
10. Maietti, F. Heritage Enhancement through Digital Tools for Sustainable Fruition—A Conceptual Framework. *Sustainability* **2023**, *15*, 11799. https://doi.org/10.3390/su151511799
11. Giovannini, E.C. VRIM workflow: Semantic H-BIM objects using parametric geometries. In *3D MODELING &BIM. Progettazione, Design, Proposte per la Ricostruzione*; Empler, T., Ed.; DEI Tipografia del Genio Civile: Rome, Italy, 2017; pp. 212–229.
12. Münster, S.; Apollonio, F.I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P.H.; Kurdiovsky, R.; Kuroczyński, P.; et al. *Handbook of Digital 3D Reconstruction of Historical Architecture,* Synthesis Lectures on Engineers, Technology, & Society; Springer Nature: Cham, Switzerland, 2024. https://doi.org/10.1007/978-3-031-43363-4
13. Demetrescu, E. Archaeological stratigraphy as a formal language for virtual reconstruction. Theory and practice. *J. Archaeol. Sci.* **2015**, *57*, 42–55. https://doi.org/10.1016/j.jas.2015.02.004
14. Deutschen Archäologischen Instituts. iDAI.World. Available online: https://idai.world/ (accessed on 10 August 2024).
15. Tufts University. Perseus Digital Library. Available online: https://www.perseus.tufts.edu/hopper/ (accessed on 12 August 2024).
16. Whitman College USA. Ancient Theatre Archive. The Theatre Architecture of Greece and Rome. Available online: https://ancienttheatrearchive.com/ (accessed on 12 August 2024).
17. Heidelberg University Library. Heidelberg Historic Literature—Digitized. Available online: https://www.ub.uni-heidelberg.de/Englisch/helios/digi/digilit.html (accessed on 12 August 2024).
18. Hennemeyer, A. *Das Athenaheiligtum von Priene. Die Nebenbauten—Altar, Halle und Propylon—Und die bauliche Entwicklung des Heiligtums*; Reichert Verlag: Wiesbaden, Germany, 2013; Priene 2, ISBN: 9783895009242. (In German)
19. iDAI—Deutschen Archäologischen Instituts. Terrassenmauer des Athena-Heiligtums. Available online: https://arachne.dainst.org/entity/9076 (accessed on 10 August 2024). (In German)
20. Rumscheid, F. *Die figürlichen Terrakotten von Priene. Fundkontexte, Ikonographie und Funktion in Wohnhäusern und Heiligtümern im Licht antiker Parallelbefunde*; Reichert Verlag: Wiesbaden, Germany, 2006; Priene 1, ISBN: 9783895004841. (In German)
21. Koenings, W. *Der Athenatempel von Priene*; Reichert Verlag: Wiesbaden, Germany, 2015; Priene 3, ISBN: 9783954900640. (In German)
22. Fenn, N. *Späthellenistische und Frühkaiserzeitliche Keramik aus Priene. Untersuchungen zu Herkunft und Produktion*; Reichert Verlag: Wiesbaden, Germany, 2016; Priene, 4, ISBN: 9783954900954. (In German)
23. Giovannini, E.C.; Tomalini, A.; Bono, J.; Pristeri, E. 3D Outputs for an Archeological Site: The Priene Theater. In *Beyond Digital Representation: Advanced Experiences in AR and AI for Cultural Heritage and Innovative Design*; Giordano, A., Russo, M., Spallone, R., Eds.; Springer Nature: Cham, Switzerland, 2024; pp. 621–638. https://doi.org/10.1007/978-3-031-36155-5_40
24. Calantropio, A.; Chiabrando, F.; Spanò, A. Impiego di tecniche di fotogrammetria digitale speditiva a supporto delle opere provvisionali negli interventi tecnici in emergenza sismica. *Boll. Della Soc. Ital. Fotogramm. Topogr.* **2018**, *3*, 22–31. Available online: https://www.sifet.org/bollettino/index.php/bollettinosifet/article/view/2178 (accessed on 20 August 2024).
25. Gerkan, A.V. *Das Theater von Priene, als Einzelanlage und in Seiner Bedeutung Für das Hellenistische Bühnenwesen*; F. Schmidt: München, Germany, 1921. (In German)
26. Salt Araştırma Digital Archive. Erken dönemde Priene Antik Tiyatrosu'nun sahne binası planı ve kesiti. Available online: https://archives.saltresearch.org/handle/123456789/79750 (accessed on 5 August 2024). (In Turkish)
27. iDAI—Deutschen Archäologischen Instituts. Theater, Rekonstruktiond Skene. Available online: https://arachne.dainst.org/entity/1987796 (accessed on 10 August 2024). (In German)

28. iDAI—Deutschen Archäologischen Instituts. Theater. Available online: https://arachne.dainst.org/entity/5898 (accessed on 10 August 2024). (In German)
29. Borri, A.; Corradi, M.; Castori, G.; De Maria, A. A method for the analysis and classification of historic masonry. *Bull. Earthq. Eng.* **2015**, *13*, 2647–2665. https://doi.org/10.1007/s10518-015-9731-4
30. Altunel, E. Evidence for Damaging Historical Earthquakes at Priene, Western Turkey. *Turk. J. Earth Sci.* **1998**, *7*, 25–36. Available online: https://journals.tubitak.gov.tr/earth/vol7/iss1/3 (accessed on 20 August 2024).
31. Stiros, S.C. Monumental articulated ancient Greek and Roman columns and temples and earthquakes: Archaeological, historical, and engineering approaches. *J. Seismol.* **2020**, *24*, 853–881. https://doi.org/10.1007/s10950-019-09902-6
32. Denard, H. *The London Charter. For the Computer-Based Visualisation of Cultural Heritage, Version 2.1*; King's College: London, UK, 2009; Available online: https://www.londoncharter.org (accessed on 20 August 2024).
33. Denard, H. A New Introduction to the London Charter. In *Paradata and Transparency in Virtual Heritage,* 1st ed.; Bentkowska-kafel, A., Denard, H., Baker, D., Eds.; Ashgate: Farnham, UK; 2012; pp. 57–78. Available online: https://londoncharter.org/introduction.html (accessed on 20 August 2024).
34. Principles of Seville. 'International Principles of Virtual Archaeology'. Ratified by the 19th ICOMOS General Assembly in New Delhi, 2017. Available online: https://icomos.es/wp-content/uploads/2020/06/Seville-Principles-IN-ES-FR.pdf (accessed on 20 August 2024).
35. Gabellone, F. The Scientific Transparency in Virtual Archaeology: New Guidelines Proposed By the Seville Charter. In *Remote Sensing and ICT for Cultural Heritage: from European and Chinese perspectives,* Series "Along Silk Road" 1; Chen, F., Gabellone, F., Lasaponara, R., Leucci, G., Masini, N., Yang, R., Eds.; Institute for Archaeological and Architectural Heritage and Architectural Heritage, National Research Council (CNR-IBAM): Rome, Italy; Institute of Methodologies for Environmental Analysis, National Research Council (CNR-IMAA): Rome, Italy; Chinese Academy of Sciences (CAS): Beijing, China; 2013; pp. 77–112. 2015.
36. Wilkinson, M.D.; Dumontier, M.; Aalbersberg, I.J.; Appleton, G.; Axton, M.; Baak, A.; Blomberg, N.; Boiten, J.-W.; da Silva Santos, L.B.; Bourne, P.E.; et al. The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data.* **2016**, *3*, 160018. https://doi.org/10.1038/sdata.2016.18
37. Giovannini, E.C. *Knowledge Representation in Architecture. Data Modelling Between Digital Humanities and H-BIM*; Aracne: Genzano di Roma, Italy, 2022; ISBN 979-12-5994-798-7.
38. Verdiani, G. *Retroprogettazione. Metodologie ed Esperienze di Ricostruzione 3D Digitale per il Patrimonio Costruito*; Didapress: Florence, Italy, 2017; ISBN 978-88-9608-089-4.
39. Apollonio, F.I.; Giovannini, E.C. A Paradata Documentation Methodology for the Uncertainty Visualization in Digital Reconstruction of CH Artifacts. *SCIRES-IT-Sci. Res. Inf. Technol.* **2015**, *5*, 1–24. http://dx.doi.org/10.2423/i22394303v5n1p1
40. Apollonio, F.I. Classification Schemes for Visualization of Uncertainty in Digital Hypothetical Reconstruction. In *3D Research Challenges in Cultural Heritage II*; Münster, S., Pfarr-Harfst, M., Kuroczyński, P., Ioannides, M., Eds.; Springer International Publishing: Cham, Switzerland, 2016; Lecture Notes in Computer Science vol 10025, pp. 173–197. https://doi.org/10.1007/978-3-319-47647-6_9
41. Bentkowska-kafel, A.; Denard, H.; Baker, D. *Paradata and Transparency in Virtual Heritage*; Ashgate: Farnham, UK, 2012; ISBN 9781138245655.
42. Computer-based Visualization of Architectural Cultural Heritage - CoVHer project. Available online: https://covher.eu/ (accessed on 20 August 2024).
43. Huffman, K.L.; Giordano, A.; Bruzelius, C.A. (Eds.) *Visualizing Venice: Mapping and Modeling Time and Change in a City*; Routledge, Taylor & Francis Group: New York, NY, USA, 2018; ISBN 9780367885717.
44. TIME MACHINE Project. Available online: https://www.timemachine.eu/ (accessed on 13 August 2024).
45. Panarotto, F.; Galeazzo, L.; Dellabartola, G. *Integration of Historical Sources, HGIS and HBIM for Cultural Heritage Sites: The Digital Reconstruction of the Islands in the Venice Lagoon*; Universitat Politècnica de València: Valencia, Spain, 2024. https://dx.doi.org/10.4995/HEDIT2024.2024.17727
46. DFG—Deutsche Forschungsgemeinschaft. Digitale 3D-Rekonstruktionen als Werkzeuge der architekturgeschichtlichen Forschung. Available online: https://gepris.dfg.de/gepris/projekt/395536813 (accessed on 13 August 2024). (In German)
47. DFG—Deutsche Forschungsgemeinschaft. DFG-Viewer 3D—Infrastruktur für Digitale 3D-Rekonstruktionen. Available online: https://gepris.dfg.de/gepris/projekt/439948010 (accessed on 20 August 2024). (In German)
48. Münster, S. Advancements in 3D Heritage Data Aggregation and Enrichment in Europe: Implications for Designing the Jena Experimental Repository for the DFG 3D Viewer. *Appl. Sci.* **2023**, *13*, 9781. https://doi.org/10.3390/app13179781
49. Maietti, F.; Medici, M.; Ferrari, F.; Ziri, A.E.; Bonsma, P. Digital Cultural Heritage: Semantic Enrichment and Modelling in BIM Environment. In *Digital Cultural Heritage;* Ioannides, M., Ed.; Springer International Publishing: Cham, Switzerland, 2018; Lecture Notes in Computer Science vol 10605, pp. 104–118. https://doi.org/10.1007/978-3-319-75826-8_9
50. Inclusive Cultural Heritage in Europe through 3D semantic modelling—INCEPTION. Available online: https://www.inception-project.eu/en (accessed on 13 August 2024).
51. De Luca L. n-Dame_Heritage project. Available online: http://www.ndameheritage.map.cnrs.fr/ (accessed on 20 August 2024).
52. Kuroczyński, P.; Apollonio, F.I.; Bajena, I.P.; Cazzaro, I. Scientific Reference Model—Defining standards, methodology and implementation of serious 3d models in archaeology, art and architectural history. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2023**, *48*, 895–902. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-895-2023

53. Apollonio, F.I.; Fallavollita, F.; Foschi, R. The Critical Digital Model for the Study of Unbuilt Architecture. In Research and Education in Urban History in the Age of Digital Libraries. UHDL 201; Niebling, F., Münster, S., Messemer, H., Eds.; Springer International Publishing: Cham, Switzerland, 2021; Communications in Computer and Information Science, vol 1501, pp. 3–24. https://doi.org/10.1007/978-3-030-93186-5_1
54. Demetrescu, E. Virtual Reconstruction as a Scientific Tool: The Extended Matrix and Source-Based Modelling Approach. In Digital Research and Education in Architectural Heritage. UHDL 2017, DECH 2017; Münster, S., Friedrichs, K., Niebling, F., Seidel-Grzesińska, A., Eds.; Springer: Berlin/Heidelberg, Germany; 2018; Communications in Computer and Information Science, vol 817, pp. 102–116. https://doi.org/10.1007/978-3-319-76992-9_7
55. Demetrescu, E.; Ferdani, D. From Field Archaeology to Virtual Reconstruction: A Five Steps Method Using the Extended Matrix. *Appl. Sci.* **2021**, *11*, 5206. https://doi.org/10.3390/app11115206
56. Westphalen, S. The Byzantine Basilica at Priene. *Dumbart. Oaks Pap.* **2000**, *54*, 275–280. https://doi.org/10.2307/1291846
57. Rabinowitz, A.; Shaw, R.; Golden, P. Period O. Available online: https://perio.do/en/ (accessed on 5 August 2024).
58. Galeano, A.; Sanseverino, A.; Berto, S.; Demetrescu, E.; Limongiello, M. Extended BIM: A proposed workflow for the integration of the HBIM and EM approaches. In Proceedings of the 2023 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Rome, Italy, 19–21 October 2023; pp. 115–120. https://dx.doi.org/10.21014/tc4-arc-2023.023
59. Giovannini, E.C.; Demetrescu, E. Extending the Extended Matrix with CIDOC-CRM. Paradata for Virtual Reconstruction Processes & Beyond. Presented at 2nd Webinar on Paradata, Metadata and Data in the 2D/3D Data Acquisition in Cultural Heritage, Online, 8 April 2024. Available online: https://zenodo.org/doi/10.5281/zenodo.11210424 (accessed on 20 August 2024).
60. Dörpfeld, W. *Das Theater von Priene und Die Griechische Bühne*; Archäologisches Institut: Berlin, Germany, 1924; Volume 49, pp. 50–101. https://doi.org/10.11588/diglit.29493.8
61. The Ancient Theatre Archive: A Virtual Reality Tour of Greek and Roman Theatre Architecture. Theatre at Priene. Available online: https://www.whitman.edu/theatre/theatretour/priene/priene.htm (accessed on 5 August 2024).
62. Champion, E.; Rahaman, H. Survey of 3D digital heritage repositories and platforms. *Virtual Archaeol. Rev.* **2020**, *11*, 1–15. https://doi.org/10.4995/var.2020.13226
63. Potenziani, M.; Callieri, M.; Dellepiane, M.; Corsini, M.; Ponchio, F.; Scopigno, R. 3DHOP: 3D Heritage Online Presenter. *Comput. Graph*. **2015**, *52*, 129–141. https://doi.org/10.1016/j.cag.2015.07.001
64. Champion, E.; Rahaman, H. 3D Digital Heritage Models as Sustainable Scholarly Resources. *Sustainability* **2019**, *11*, 2425. https://doi.org/10.3390/su11082425
65. Demetrescu, E.; Fanini, B.; Cocca, E. An Online Dissemination Workflow for the Scientific Process in CH through Semantic 3D: EMtools and EMviq Open Source Tools. *Heritage* **2023**, *6*, 1264–1276. https://doi.org/10.3390/heritage6020069
66. Menconero, S.; Fanini, B.; Pietroni, E. The e-Archeo 3D Project, an Innovative and Sustainable Cultural Proposal Based on XR Technologies. In *Advances in Representation: New AI-and XR-Driven Transdisciplinarity*. In Giordano, A., Russo, M., Spallone, R., Eds.; Springer Nature: Cham, Switzerland, 2024; pp. 201–216. https://doi.org/10.1007/978-3-031-62963-1_12
67. Fanini, B.; Ferdani, D.; Demetrescu, E.; Berto, S.; d'Annibale, E. ATON: An Open-Source Framework for Creating Immersive, Collaborative and Liquid Web-Apps for Cultural Heritage. *Appl. Sci.* **2021**, *11*, 11062. https://doi.org/10.3390/app112211062
68. Grellert, M.; Wacker, M.; Bruschke, J.; Stille, W.; Beck, D. Documentation and Evaluation of Virtual Reconstructions. In Proceedings of the 2023 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Rome, Italy, 19–21 October 2023; pp. 653–658. https://doi.org/10.21014/tc4-ARC-2023.122
69. Scholz, M.; Goerz, G. WissKI: A virtual research environment for cultural heritage. In *ECAI 2012*; IOS Press: Amsterdam, The Netherlands, 2012; Volume 242, pp. 1017–1018. https://doi.org/10.3233/978-1-61499-098-7-1017
70. WISSKI Infrastructure. Available online: https://wiss-ki.eu/ (accessed on 13 August 2024).
71. DFG 3D-Viewer. Available online: https://dfg-viewer.de/en/dfg-3d-viewer (accessed on 13 August 2024).
72. Semantic Kompakkt. Available online: https://nfdi4culture.de/services/details/semantic-kompakkt.html (accessed on 13 August 2024).
73. Myers, D.; Dalgity, A.; Avramides, I. The Arches heritage inventory and management system: A platform for the heritage field. *J. Cult. Herit. Manag. Sustain. Dev.* **2016**, *6*, 213–224. https://doi.org/10.1108/JCHMSD-02-2016-0010
74. Oldman, D.; Tanase, D.; Santschi, S. The problem of distance in digital art history: A ResearchSpace case study on sequencing Hokusai print impressions to form a human curated network of knowledge. *Int. J. Digit. Art Hist.* **2019**, *29*, 5.29–5.45. https://doi.org/10.11588/dah.2019.4.72071
75. Giovannini, E.C.; Bono, J. Creating virtual reality using a Social Virtual Environment: Phygital Exhibition at the Museum Passion in Sordevolo. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2023**, *48*, 669–676. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-669-2023
76. Giovannini, E. Social Virtual Environments: Opportunities and Workflows in Cultural Heritage and Education in Architecture. In *Proceedings of the 16th International Conference on Computer Supported Education CSEDU, Angers, France, 1–4 May 2024*; SCITEPRESS—Science and Technology Publications: Setúbal, Portugal, 2024; Volume 1: ERSeGEL, pp. 772–783. http://dx.doi.org/10.5220/0012758500003693