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A Top-Down, Multi-Method and Multi-Scale Approach to Studying the Byzantine–Umayyad Settlement of Umm ar-Rasas (Amman, Jordan)

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Abstract: The present study constitutes the latest in a series of investigations conducted between 2021 and 2023 as part of the ongoing, multidisciplinary research project at the UNESCO archaeological site of Umm ar-Rasas in Amman Governorate, Jordan, which began in 2013. Building on the foundations of previous studies, this latest research offers a comprehensive analysis of the region, with a special focus on pinpointing the boundaries of the Byzantine–Umayyad settlement. The delineation of these boundaries has hitherto been the subject of theoretical discourse only, thus rendering this study a significant addition to the field. An innovative multi-dimensional, multi-methodological, and multi-scalar approach has been adopted, incorporating the capabilities of remote sensing technologies, archaeological surveys, laser scans, and geophysical prospecting to facilitate a shared interpretation of the results. This approach has culminated in the establishment of a probable configuration of the northern limits, which is truly remarkable.

Keywords: Umm ar-Rasas; Byzantine–Umayyad settlement; remote sensing analysis; laser scanning; geophysical prospections

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1. Introduction

The Eastern Limes represents the defense system of the Roman East border, which connected Trapezunte, the historical city of Trapezus, situated on the Black Sea, with Eilat, the historical city of Aila, located on the Red Sea. It functions as a valuable laboratory for the investigation of the significant potential inherent in historical and recent remote sensing documentation for the identification and mapping of fortified centers along the eastern frontiers of the Roman and Byzantine Empires. The integration of historical aerial and space photography, and satellite imagery with contemporary surveying techniques and tools—such as geophysics, photogrammetry, and laser scanning—has resulted in substantial advancements in the identification, documentation, and study of ancient sites and communities [1–13]. Furthermore, these techniques have facilitated the establishment of programs focused on the protection and enhancement of archaeological sites, including the creation of both physical and virtual pathways to facilitate the access and appreciation

of these locations. Umm ar-Rasas in Amman Governorate, Jordan, serves as a prime illustration of this development.

Since 2013, Umm ar-Rasas has functioned as an authentic interdisciplinary and inter-institutional open-air laboratory, where archaeologists, engineers, architects, physicists, geophysicists, and restorers from various institutions and universities collaborate on research aimed at preserving and improving a World Heritage Site [14].

1.1. Historical-Topographical Background

Approximately 30 km south-east of Madaba, 24 km east of Diban and the ancient route of the Via Nova Traiana, the remains of Umm ar-Rasas (in Arabic 'mother of lead') lie (Figure 1a) [15,16].

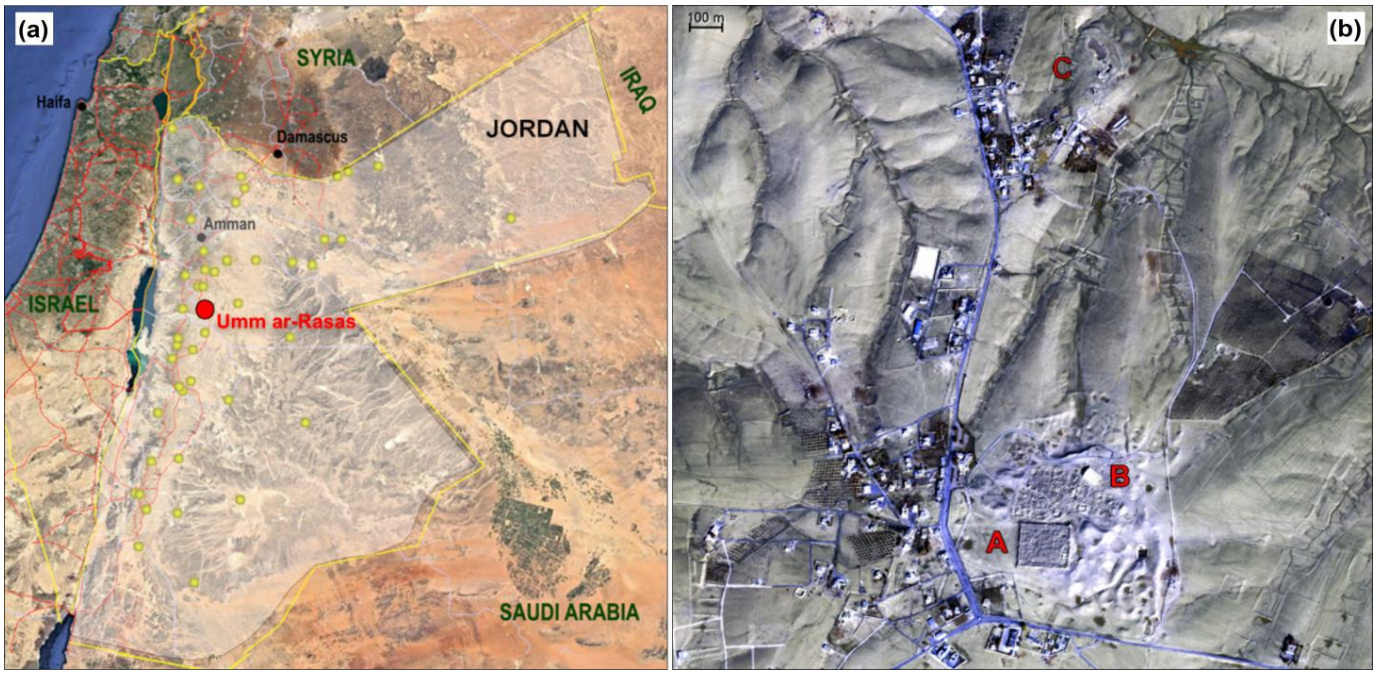


Figure 1. (**a**) Site location base map from Google Earth © (yellow dots highlight main cities and yellow line indicate the border of Jordan) and (**b**) detail of the archaeological area (Pléiades Neo satellite image taken on 25 January 2022, acquired from Sysdeco Company): castrum (A); Byzantine–Umayyad village (B); Stylite tower complex (C).

Three settlement cores characterize the site, starting from the south: the castrum from the Tetrarchic period (A in Figure 1b); immediately to the north, the Byzantine–Umayyad settlement (B in Figure 1b); 1 km to the north, the Byzantine–Umayyad complex of the Stylite Tower (C in Figure 1b)).

The castrum (A) has a square plan of 158 × 139 m (approx. 2 ha) characterized by the presence of three gates (north, east and south), four corner towers and, along the walls, four bastions on each side. Despite the discovery of a Nabataean inscription, which would attest to a pre-Roman occupation of the area, the castrum has been dated between the 3rd and 4th centuries A.D. The presence of dwellings and four churches within the walls would then testify a continuity of life until the Umayyad period. As for the Byzantine–Umayyad settlement (B) immediately north of the castrum, it is characterized by the presence of a series of dwellings and churches, whose beauty and wealth of mosaic floors have made the site famous. The Byzantine–Umayyad settlement of the Stylite Tower (C) is about 1 km further north, grouped around a tower, 2.5 m square on each side and 13.5 m high, and characterized by the presence of a church, an adjacent building and a 50 m^2 fort; about 300 m south, then, there is another church and another small fortified structure. Finally, the

area occupied by this third group is marked by several quarry fronts and cisterns dug into the rock.

1.2. State of Art

Umm ar-Rasas, which had been explored since 1800, was documented from above by Sir Marc Aurel Stein on 6 May 1939. The aerial reconnaissance took place in the last days of the mission and was, therefore, not accompanied by a ground survey, given the location of the site, more than 20 km to the east of the Via Nova Traiana, where the interest of the explorers was concentrated. Between the second half of the 1980s and the early 2000s, Umm ar-Rasas was the subject of a series of archaeological excavation campaigns carried out by the Studium Biblicum Franciscanum in Jerusalem and the Swiss Mission of the Max van Berchem Foundation. The Studium Biblicum's excavations focused mainly on the cult buildings, nine overall, which were uncovered between 1986 and 2006 [15–36]. The discovery of two inscriptions inside two of these buildings, the Church of the Lions and the Church of St. Stephen (Figure 2), led to the identification of the site as Kastron Mefa or Mefat, the biblical city of the tribe of Reuben [37,38]. It would also correspond to the φρούριον mentioned in Eusebius' Onomasticon and the Roman camp of the Equites Promoti Indigenae mentioned in the Notitia Dignitatum.



Figure 2. Umm ar-Rasas. (**I**) The mosaic images of Kastron Mefa in the Church of the Lions and (**II**) the Church of St. Stephen. Modified by [39]. Copyright © Studium Biblicum Franciscanum, permission obtained.

The Swiss Max van Berchem Foundation undertook an extensive program of excavations between 1988 and 1997, with a particular focus on the castrum [40–43]. This

encompassed the excavation of the two Twin Churches, situated within the walls in the quadrant to the southeast, and the gates of the fortified settlement. Concurrently, the Swiss researchers conducted a comprehensive survey of the castrum and the settlement to the north, resulting in the creation of a plan that continues to serve as a foundational reference for scholars of the site.

At the same time, the research conducted at Umm ar-Rasas has enabled the identification of sporadic traces of the area's frequentation as early as the Iron Age and its occupation until the 8th–9th century A.D. [44]. About the castrum, the extant plan, distinguished by the presence of three gates, is attributed to the 4th century A.D. [43,45,46]. However, the discovery of an inscription and material dating to the 2nd–3rd century A.D. would necessitate a re-evaluation of the original fortified structure, which is believed to have a single gate on the eastern side [43].

1.3. Kastrum Project: Innovative Methods, Research and Training Activities for the Conservation and Enhancement of Umm ar-Rasas

From 2013 to 2019, the CNR ISPC conducted a series of geophysical, topographic and 3D survey campaigns at several buildings [47–51] (Figures 3 and 4).

The archaeological area encompasses the churches of St. Stephen, Bishop Sergius and St. Paul, situated in the settlement to the north of the castrum, and the Stylites' Tower, located approximately 1.5 km north of the settlement. The measurements were conducted with the objective of documenting the state of preservation of the remains, with a particular focus on the intricate mosaic carpets and the walls of the Stylite Tower. The team also planned protection measures and designed visit routes that are easier for the able-bodied and accessible to the disabled.

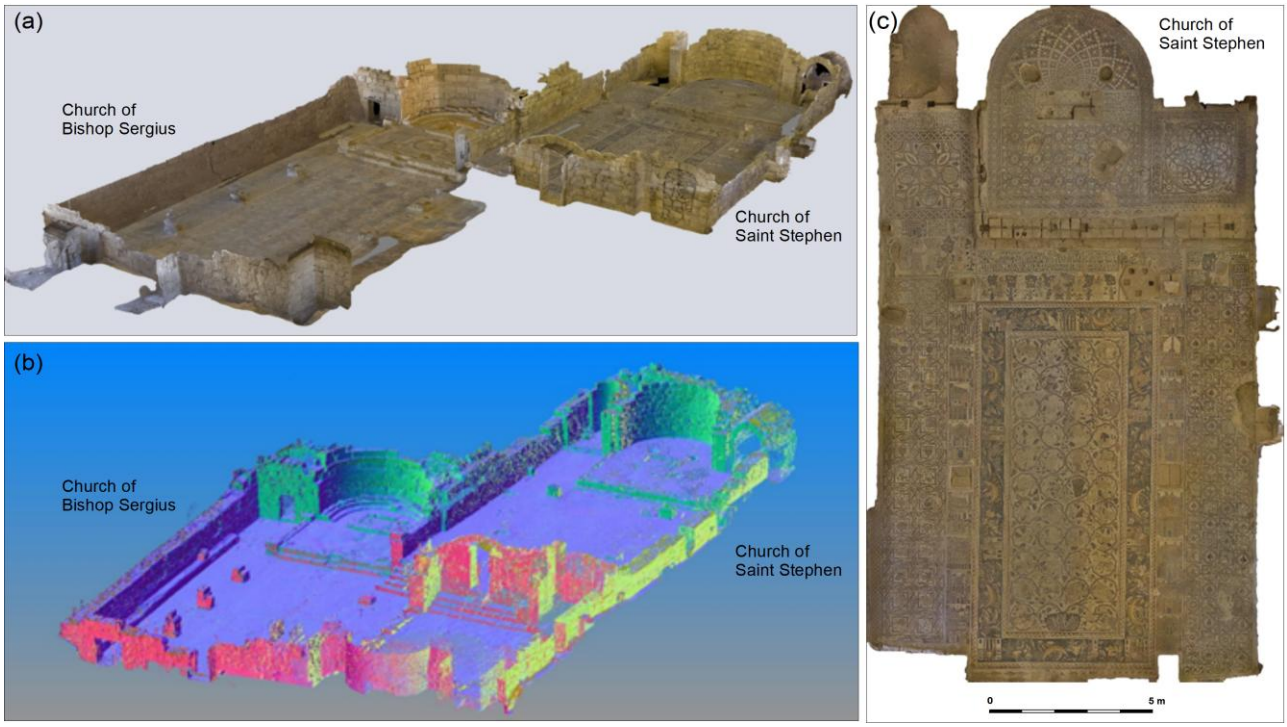


Figure 3. Byzantine churches: (**a**) 3D model of the two Churches in their actual spatial arrangement; (**b**) qualitative inclination map of walls where the colors indicate the direction of the surfaces; (**c**) High-resolution orthographic view of Saint Stephen's mosaic floor obtained by integration of photogrammetric and laser scanning techniques. Modified by [50], copyright by the authors.

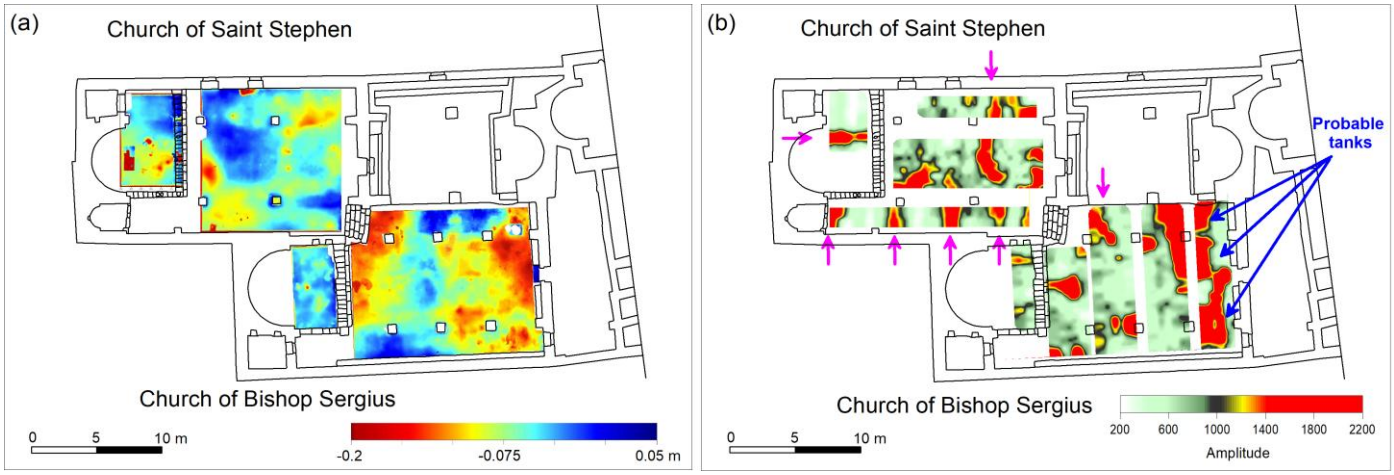


Figure 4. Byzantine churches: (**a**) Model of altitude variation in the floor of the churches; (**b**) Georadar slices related to the depth window of 0.5–0.7 m overlapped on the map of the churches: the blue arrows indicate the location of probable tanks, while the pink arrows highlight probable buried archaeological structures. Modified by [50], copyright by the authors.

Since 2021, with the addition of new research objectives, the CNR's investigations have been extended to the castrum, the Byzantine–Omayyad settlement as a whole, and the surrounding area [52–54]. A series of topographical and architectural survey campaigns were started in order to verify a series of anomalies revealed by the analysis of historical remote sensing images. These campaigns also facilitated the documentation of the construction phases of the fortification. Wall sections have been identified that are clearly from the Teterarchic fortification or even predate it, and are probably from the Severan phase [53,54].

1.4. Research Questions and Objectives

In this paper, the results of a top-down, multi-method and multi-scale approach to studying the Byzantine–Umayyad settlement of Umm ar-Rasas (Figures 1b and 5, B) are presented with the aim to summarize the main results of the scientific activities achieved adding new data. For this area, previous studies had hypothesized the existence of a fortified wall circuit or at least a boundary [39], but this had never been identified. The analysis of historical satellite images, in particular a 1974 Hexagon KH-9 cosmic photo (Figure 5), as well as the analysis and processing of the most recent high- and very-high-resolution satellite images, in particular a 2022 Pléiades Neo, have allowed to identify micro-relief traces that probably belong to a section of the northern boundary of the settlement under investigation. Guided by the results of the analysis and processing of remote sensing data, two areas were identified. Thus, the following workflow was considered:

- Archaeological surveys in order to collect information about the presence of material dispersed on the surface or remains of structures and possibly evaluate their distribution and location;
- Logistic, environmental and geological analysis of the site in order to choose the most suitable investigation methodologies and consequent choice of the research approach;
- Laser scanner survey of the identified and potentially interesting surfaces for the analysis of micro variations in height;
- Geophysical surveys in a focused area in order to verify the presence of buried structures.

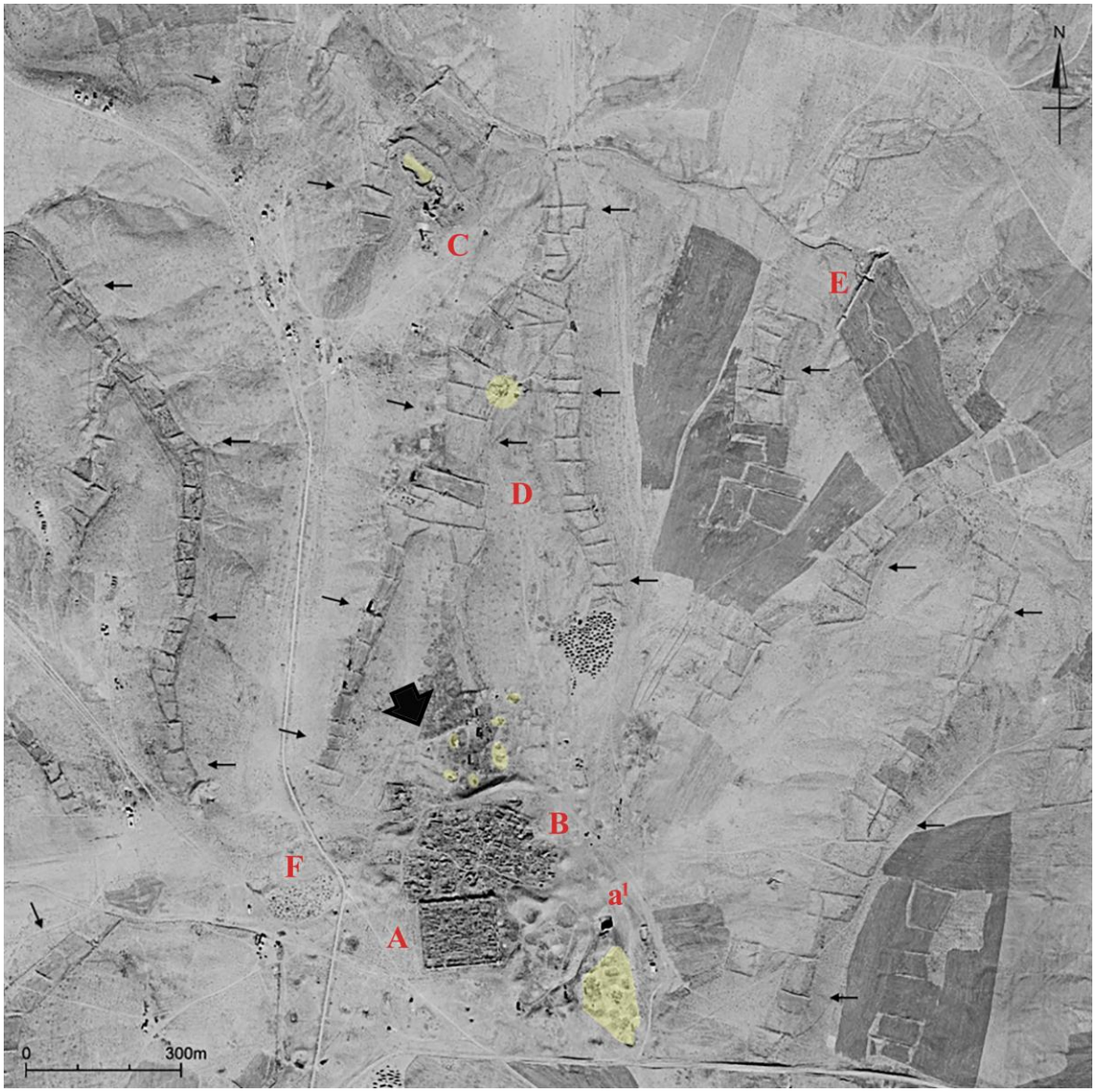


Figure 5. Umm ar-Rasas. Hexagon KH-9 space photo taken on 1974/12/01, ground resolution: 1.20–0.60 m (acquired from United States Geological Survey). Featured: (A) Roman castrum; (a^1) hydraulic reserve; (B) Byzantine and Umayyad settlement; (C) Stylite tower complex; (D) System of irrigated plots (channels and dams); (E) the dam; (F) the Byzantine cemetery. Quarries and stone material extraction sites are highlighted in yellow, while arrows indicate hydraulic channeling systems. Finally, the large black arrow indicates the northern limit of the settlement.

According to the planned work, the surveys were organized during the executive phases of the intervention with the following aims:

- Verify the hypothesis formulated through the remote sensing analysis about the presence of the northern boundary of the settlement;
- Evaluation of the potential risk of presence of archaeological remains, and consequently their hazard of destruction in future interventions;
- Increase the knowledge of the site through the study of an area never systematically investigated so far;
- Show the validity and efficiency from a scientific point of view of the research approach used in the particular archaeological context;
- Highlight the potential of non-invasive techniques in archaeological research.

2. Material and Methods

Since 2021, detailed analyses and processing have been conducted on both historical and recent remote sensing data across three distinct scales: the castrum, the Byzantine–Umayyad settlement, and the historical landscape [54]. These analyses have been followed by targeted field surveys, which allowed for the verification and identification of the features highlighted by the interpretation of historical and recent satellite imagery. Preliminary data concerning the castrum and the fossilized historical landscape are in [53], while the results of the aerotopographical analysis of the Byzantine–Umayyad settlement are examined and reported here. In 2023, archaeological surveys, laser scanning surveys and geophysical prospections, were carried out [52–54] in order to verify the hypothesis formulated in the first steps of the researches. In the following sections, a brief description of materials and methods used during the field works is given.

2.1. Remote Sensing

The research presented herein is founded upon a comprehensive analysis of historical images acquired by American spy satellites during the Cold War, with a particular emphasis on the series of Hexagon KH-9 cosmic high-resolution photographs (1971–1986). These photos, which were declassified in 2011 but only recently made available, represent a significant source of data for the archaeological studies [55–58]. The images exhibit adequate geometric resolution (1.20–0.60 m) and facilitate the documentation of archaeological contexts that have either been transformed or have completely vanished. By analyzing and processing this historical documentation through the application of filters, it has been possible to highlight and identify traces that are no longer readily visible. At the same time, more recent experiments involving image enhancement, deep learning, and statistical methods applied to historical satellite images—which are, by naturegrey scale panchromatic images—have been undertaken by the authors. In addition to the analysis of historical satellite images, the use of recent multispectral images, characterized by high and very high resolution (ground resolution ranging of 0.50–0.30 m), has been incorporated. The capacity to operate across multiple bands within the visible spectrum and the near-infrared has facilitated an initial remote verification of archaeological traces identified in the cosmic photographs and, concurrently, the discovery of new traces, facilitated by calculations conducted using spectral indices to enhance and analyze the characteristics of the Earth's surface in each area of interest. As is well understood, a spectral index is a mathematical formula that combines reflectance values from various spectral bands to emphasize specific properties of the surface [59]. In the context of multispectral satellite images, the efficacy of spectral indices in identifying and analyzing specific elements and materials, including vegetation, bodies of water, and diverse soil types, is well-documented. These indices serve to enhance the reflectance of targeted materials, thereby facilitating their more accurate identification in imagery. Specifically, for the case study of Umm ar-Rasas, two multispectral images have been analyzed: one from Pléiades-1A captured on 30 October 2020 and another from Pléiades Neo taken on 25 January 2022 (Table 1).

Table 1. Dataset of analyzed satellite images.

Satellite Images	ID	Dates	Spatial Resolution	Sensors
Hexagon KH-9	1209-200214F019	11 December 1974	1.20–0.60 m	Panchromatic
Pléiades-1A	202010300836510	30 October 2020	0.50 m	Multispectral
Pléiades Neo	202201250826144	25 January 2022	0.30 m	Multispectral

These images were initially processed using Envi 4.5 (Boulder, CO, USA) [52,53] and eCognition 10.5 (Munich, Germany) software. The most recent processing have focused particularly on the Pléiades Neo satellite imagery and were conducted using eCognition 10.5, employing seven spectral indices (Table 2) calculated by combining the six bands of the satellite image. These indices have been essential for extracting key information about the landscape and enhancing data interpretation for archaeological analysis (Figure 6).

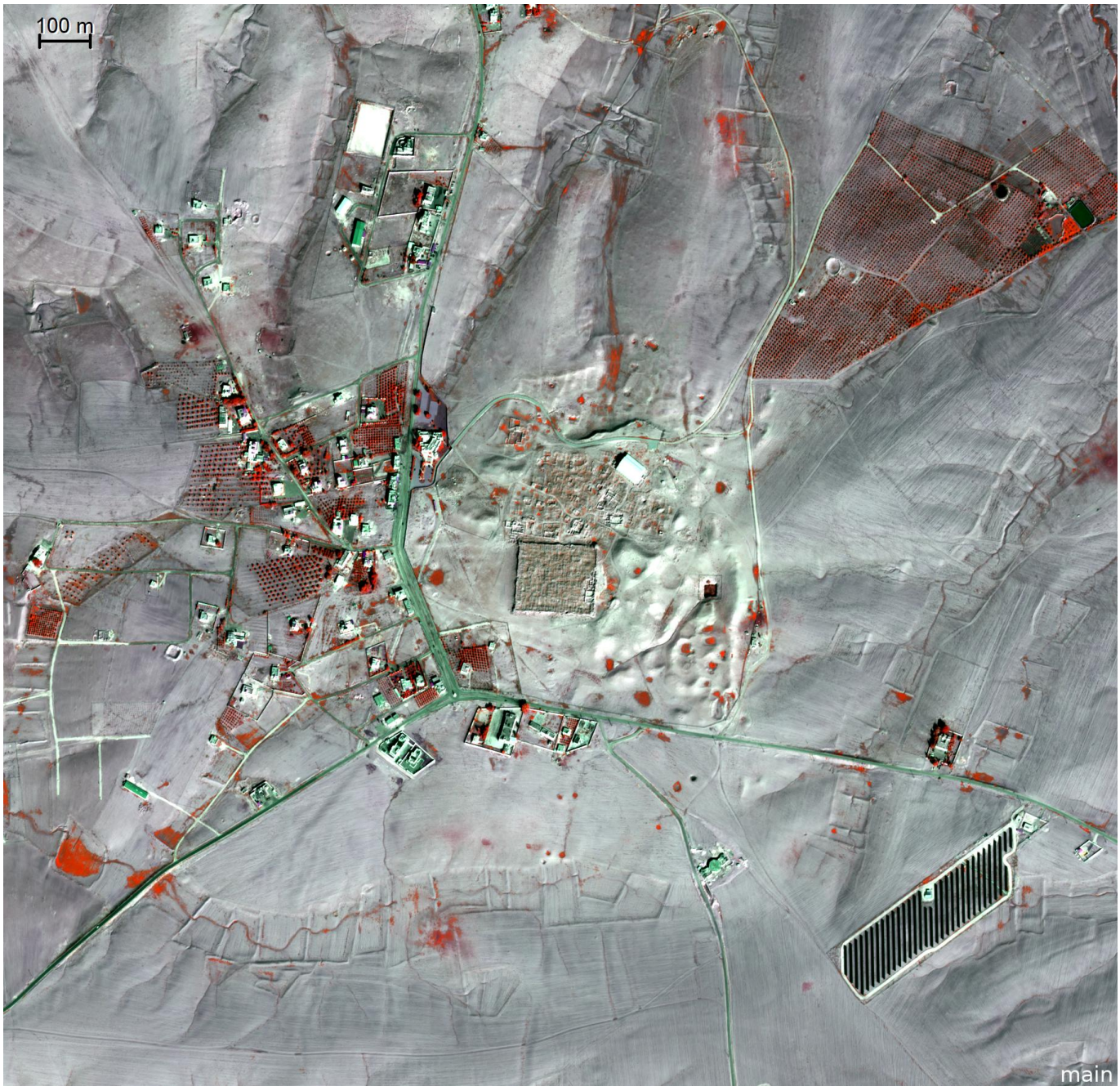


Figure 6. Umm ar-Rasas. False color composite Pléiades Neo image taken on 25 January 2022 (processed in eCognition Developer). The color red is employed to denote areas of elevated humidity.

Specifically, the application of an arithmetic function to the bands, notably by combining the panchromatic band (PAN) with the Normalised Difference Water Index (NDWI) and/or with the Principal Component Analysis (PCA) determined on the variance conditioned on the bands, as well as the Near-Infrared (NIR), has allowed to distinctly highlight

all the raised features and traces of micro-relief, thereby further emphasizing the remains already identified through the interpretation of the cosmic photographs.

Table 2. The seven spectral indices used, with their respective references.

Spectral Indices	Description	Formula	References
NDWI	Normalized Difference Water Index	(Green − NIR)/(Green + NIR)	[60]
NDVI	Normalized Difference Vegetation Index	(NIR − Red)/(NIR + Red)	[61]
NDSI	Normalized Difference Soil Index	(Red − Blue)/(Red + Blue)	[62]
SAVI	Soil-adjusted vegetation	((NIR − Red)/(NIR + Red + L)) ∗ (1 + L)	[63]
EVI	Enhanced vegetation	G ∗ ((NIR − Red)/(NIR + C1 ∗ Red − C2 ∗ Blue + L))	[64]
VrNIRBI	Visible Red based built-up index	(Red − NIR)/(Red + NIR)	[65]
VgNIRBI	Visible Green based built-up index	(Green − NIR)/(Green + NIR)	[65]

2.2. Terrestrial Laser Scanner (TLS)

Nowadays, the use of Terrestrial Laser Scanner is a common component in surveying activities for archaeological purposes allowing to measure 3D cloud points directly and automatically. Specifically, a laser works on the following principle: an electromagnetic pulse is sent into the area to be detected, and the wave that is reflected from a spot on a surface that is within the instrument's operational range is measured. The time interval between the emission time (t0) and the reflected beam's reading time (t1) is used to calculate the beam's journey distance [66,67].

The laser beam from the scanner's center is redirected into the surrounding area by oscillating mirrors and rotational movements, for the emitter/receiver sensor. The device may illuminate (in a figurative sense) every surface within its operational range in a number of adjacent locations by adjusting the azimuth and zenith angles.

The azimuth angle, zenith angle, inclination distance, and reflectance value are measured for every single point that is obtained. An acquisition grid that represents the detected object is used to arrange these data. The regular movement of the laser beam, which can detect up to one million points per second in the surrounding environment, determines the grid. The acquisition grid makes it feasible to arrange the reflectance data into a two-dimensional picture that makes the survey item easier to understand. A point cloud, which includes a two-dimensional reflectance image (RGB or grayscale) and the coordinates of each measured point (x, y, z) in a Cartesian reference system with its center firmly at the instrument's center, is available during the post-processing stage. In order to improve the fidelity of the three-dimensional model and make scan registration processes easier, the integrated camera enables you to obtain and associate the colorimetric information with each detected point.

In this work, the phase-difference laser scanner FARO 3D X330 (Faro Company, Lake Mary, FL, USA) was utilized for data acquisition with the aim to detect surface inhomogeneity. Sixteen scans were performed with a resolution of one point every 7 mm obtaining a cloud of about 70,452,142 points. The volume of data generated was processed in accordance with generally accepted methods for point cloud maintenance and restoration across many application domains [68]. JRC 3D Reconstructor 4.4.1 (Brescia, Italy) and Cloud Compare 2.13.2 (Paris, France) software were used for point cloud conversion and subsampling with uniform point spacing of 1 cm, obtaining a total of 65,687,769 points with a resolution of 6 mm, for Digital Elevation Model (DEM) and orthophoto generation (Figure 7). All data were imported in a QGIS Geographic Information System (QGIS Development Team (2024), Open Source Geospatial Foundation Project, http://qgis.osgeo.org, accessed on 15 December 2024).

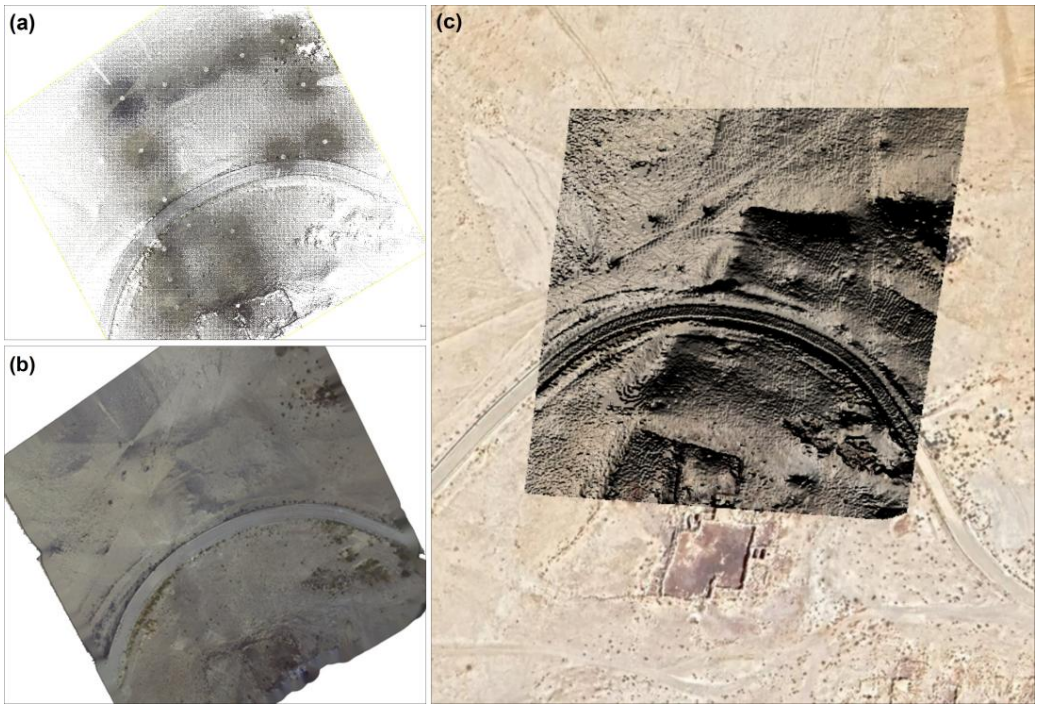


Figure 7. (**a**) Resampled point cloud with location of the 16 scanning stations, (**b**) orthophoto generation from point cloud, (**c**) DEM import into QGIS Geographic Information System through the hillshade view.

2.3. Geophysical Prospections: Electrical Resistivity Tomography (ERT)

Geophysical prospections are frequently employed to detect buried archaeological features, especially ground-penetrating radar (GPR) [69–71] and magnetometric (MAG) [72–74] surveys because of their complete non-intrusiveness, excellent resolution, and reasonably deep exploration. Additionally, electrical resistivity [75–77] and electromagnetic methodologies [78–80] can be used in situations where the features of the site limit the use of GPR and MAG, such as the presence of conductive soils, rough surfaces or anthropic noise [81].

In this case, considering the surface on which to operate, the features of the site, the typology of searched targets, and their supposed depth, the electrical resistivity tomography (ERT) was applied. Two metal probes are used to inject an electrical current into the ground, while the other two probes are used to measure the potential drops. Electrical deviations that might be connected to potential ancient structures can be found by examining the electrical behavior of the soil. Despite having longer acquisition periods than other techniques, the resistivity approach works well because it yields findings that are simple to understand, is very adaptable to different soil types, and is perfect for finding relatively deep structures.

Two areas were investigated, one located to the north to the road that joins the visitor center to the complex of S. Stefano Churches (Area 1) and another to the south close to the remains of one of the most NNO dwellings in the ancient settlement (Area 2) (Figure 8a). Areas 1 and 2 were surveyed using 85 and 14 lines of investigation, respectively, with equal spacing of 1.5 m. In each line, 16 electrodes were located at a mutual distance of 1 m.

A dipole–dipole (DD) array, which is more sensitive to surface inhomogeneities and may locate anomaly sources laterally, was used for the ERT survey [82]. The apparent resistivity $r_{a,n}$ is, therefore, determined as $r_{a,n} = \pi k\,(k+1)\,(k+2)\,a\,(V_n/I_n)$ for a generic nth measurement with the current electrodes in positions A_n and B_n and the potential electrodes in positions M_n and N_n. In this calculation, I_n represents the intensity of the direct current

injected into the ground from the active dipole, and V_n represents the potential drop across the passive dipole.

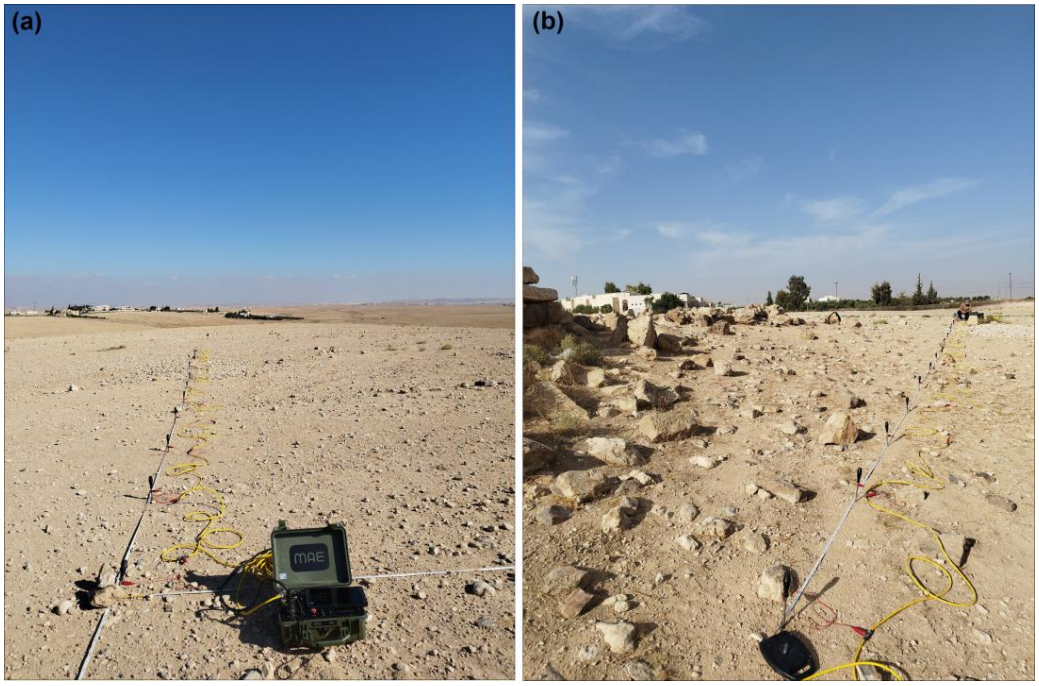


Figure 8. Data acquisition using the multi-channel resistivity meter M.A.E. ET300 in (**a**) Area 1 and (**b**) Area 2.

Data acquisition was performed through the multi-channel M.A.E. ET300 resistivity meter (M.A.E. s.r.l., Frosolone, Italy, www.mae-srl.it, accessed on 20 January 2025). Because of the dry terrain, a high voltage up to 800 V, 1600 V peak to peak, was employed to boost the resistivity contact between the electrodes and ground. Additionally, the voltage at the receiving dipole was stacked, and up to ten samples of the input voltage were averaged until a stable average value was reached in order to control the quality of the obtained data.

In this research, archaeological buried features have been imaged using the Extended data-adaptive Probability-based Electrical Resistivity Tomography Inversion (E-PERTI) [83]. It represents the most recent advancement in the probability tomography methodology specially designed for geoelectric techniques. First developed for the self-potential method [84], the theory was later modified for the resistivity approach [85]. By taking into account a reference background resistivity, the primary technique was able to differentiate between high and low resistivities in the field datasets; however, it did not estimate the intrinsic resistivities of the source bodies. The technique has been effectively applied to map buried ancient structures [86] and to detect faults [87].

The true resistivities were then estimated using a data-adaptive probability-based ERT inversion approach (PERTI) [88], which was directly derived from the principles of probability tomography. The algorithm, which is a nonlinear approach, finds the most likely solution that is compatible with the dataset collection strategy among the set of potential solutions from a probabilistic perspective. Numerous applications of the PERTI technique to near-surface prospecting to address archaeological research concerns have been documented in the literature [89,90].

Finally, the E-PERTI approach was created to optimize resistivity estimates and improve robustness to noise with respect to the original PERTI. Many distinct subsets of data are recovered from the apparent resistivity dataset using the PERTI algorithm, both randomly and through sequential vertical scanning and horizontal windowing within the

datum space [83]. In the end, an intrinsic linear regression model using ordinary least squares techniques is used to predict the best prediction of the most likely resistivity in the same point, which is a more or less dense cluster of resistivity values in each point of the surveyed region. The characterization of a buried ditch [91] and a fortification wall [92] are the first use of the E-PERTI scheme.

Since the method does not involve a priori information or iterative processes, calculating the Root Mean Squared Error between the observed and modeled apparent resistivity values is not helpful in this situation. Consequently, comparing the outcomes with those of other deterministic inversion algorithms is one method of assessing the modeling capability of E-PERTI, as demonstrated in [88].

3. Results

In the context of the research focused on the topographical study of the Byzantine–Umayyad settlement, which develops to the north of the castrum, it is essential to begin with a review of the current state of the site and the archaeological excavations conducted by the Studium Biblicum Franciscanum in Jerusalem [15–36] and the Swiss Max van Berchem Foundation mission [39–42]. These excavations have exerted a substantial influence on the site, providing a comprehensive survey. The settlement is notable for the presence of a total of 16 churches (of which 14 buildings, including churches and chapels, have been excavated), which provide evidence for an important phenomenon of Christianization that characterized the Jordanian rural settlements between the 5th and 8th centuries A.D., such as Umm ar-Rasas, under the control of the bishops of Madaba, as attested by the dedicatory inscriptions found on the mosaic floors of the cult buildings of Umm ar-Rasas (for a comprehensive overview of the pivotal role of bishops in the suburban topography of the territory of Madaba between the 5th and 8th centuries A.D., see [93]). The study proceeded to investigate the organization of the site, the articulation of road axes and blocks, and the presence of any additional structures in the strip to the north of St. Stephen's Church, where remote sensing documentation has revealed numerous semi-outcropping remains, as well as in the areas to the east and west. In addition, among the open questions regarding the ancient topography of the settlement is that of the possible presence of a city walls generally unidentified [42,94], but recently proposed [54] thanks to the examination of remote sensing traces and the mosaic representation of Kastron Mefa present in the Church of the Lions (I) and the Church of St. Stephen (II) (Figure 2). In this regard, the historical satellite images, specifically Corona KH-4B cosmic photos from 1967 to 1970, and two Hexagon KH-9 photos from 1974 were analyzed with the objective of identifying and positioning additional archaeological traces. To this end, two recent high- and very high-resolution satellite images were selected for analysis: Pléiades 1B from 2020 and Pleiades Neo from 2022. These images underwent a series of processing, georeferencing, and orthorectification procedures to serve as a cartographic foundation for locating buried or semi-buried structures. This analysis culminated in the identification of a section of the northern boundary of the Byzantine settlement. This, in turn, has further highlighted the traces already delineated by cosmic photographs, which appear to define the northern limit of the Byzantine settlement, particularly with regard to the location of the Byzantine necropolis (Figures 4 and 9). The topographic features under investigation were distinguished by two different sections, the first of which, measuring approximately 29 m in length, exhibited a north-easterly to south-westerly orientation, while the second, spanning approximately 150 m, demonstrated an east–west alignment (Figure 9).

A systematic surface reconnaissance approach was adopted, entailing a thorough examination of the area using remote sensing data. Due to their inherent variability, these data could not always be readily interpreted on the ground. Furthermore, the investigations

were expanded beyond the initial limits, resulting in the documentation of a more or less frequent concentration of ceramic fragments, primarily of Umayyad age, recorded within a maximum distance of 500 m to the north of the St. Stephen's complex.



Figure 9. Umm ar-Rasas. The result of Pléiades Neo processing combines the panchromatic band (PAN) with the Normalized Difference Water Index (NDWI) and the Near-Infrared (NIR) band. (A) Roman castrum; (B) Byzantine and Umayyad settlement; (F) remains of Byzanthine cemetery. Black arrows indicate traces of the north-western boundary of the Byzantine and Umayyad settlement.

Figure 10 shows a Google Earth™ satellite image of the investigated area, the indication of traces with black dotted lines and the digital elevation model achieved through the laser scanner. The elevation varies between 716 and 724 m above sea level. The analysis of the model clearly highlights some ridges in continuity with the Byzantine structures in their northern part in an area not affected by archaeological excavations.

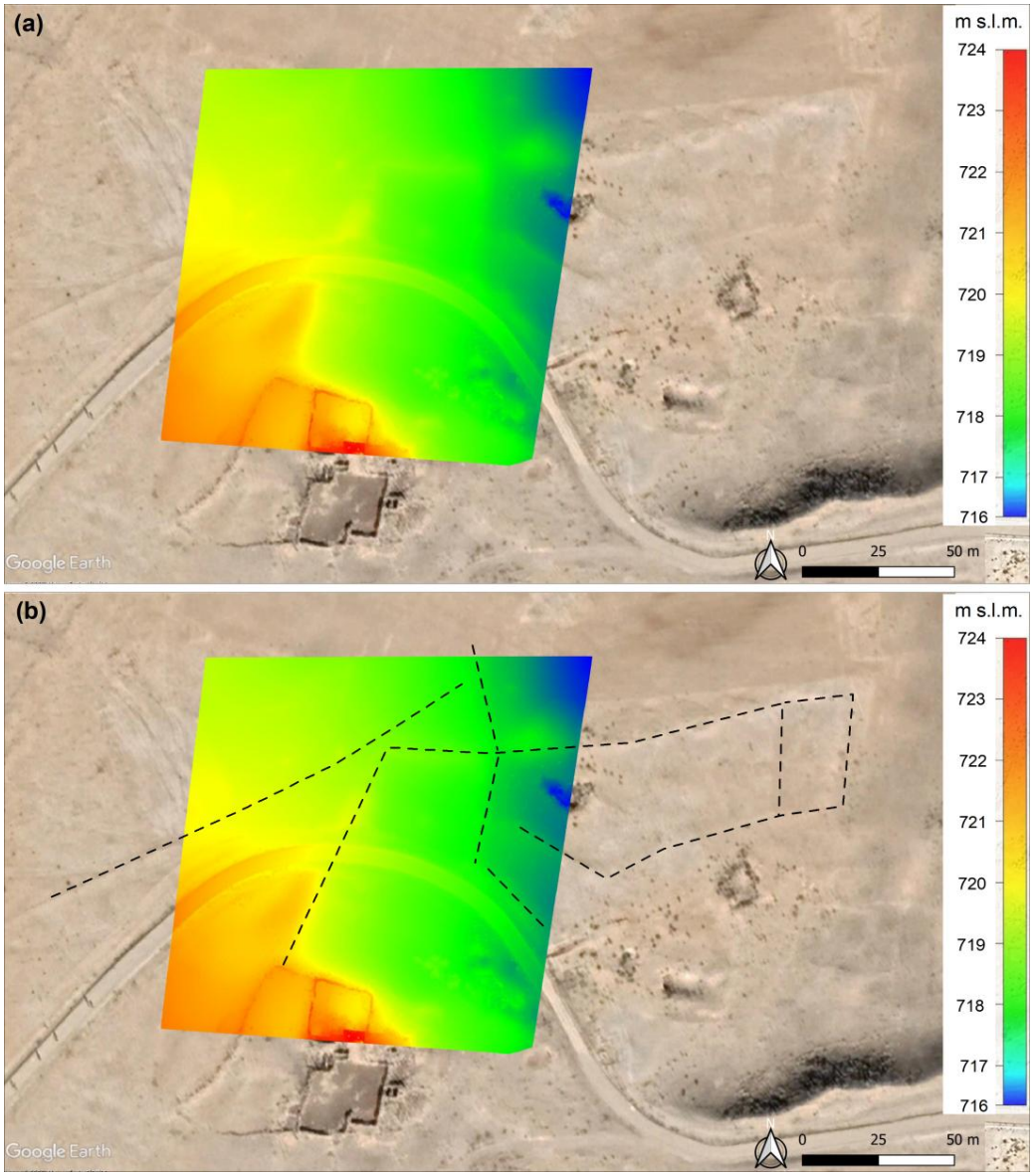


Figure 10. Google Earth™ satellite image of the investigated area with (**a**) the overlapping of the DEM obtained through the laser scanner and (**b**) the superposition of the traces with dotted lines.

Figure 11a reports the horizontal slice obtained at a depth of 1.5 m beneath the ground level. It is extracted from the 3D ERT model, the E-PERTI solution of the complete apparent resistivity dataset by merging all DD profiles. The map shows the resistivity variations in a wide range with very resistive nuclei (red in the adopted chromatic scale). They present well-defined geometries perfectly in agreement with the results of the analysis of the traces identified by satellite images and by the analysis of the elevation variations (Figure 11b). It is likely that the resistivity anomalies highlight the presence of collapsed structures, of which internal divisions can be imaged, belonging to the Byzantine settlement, defining its northern limit.

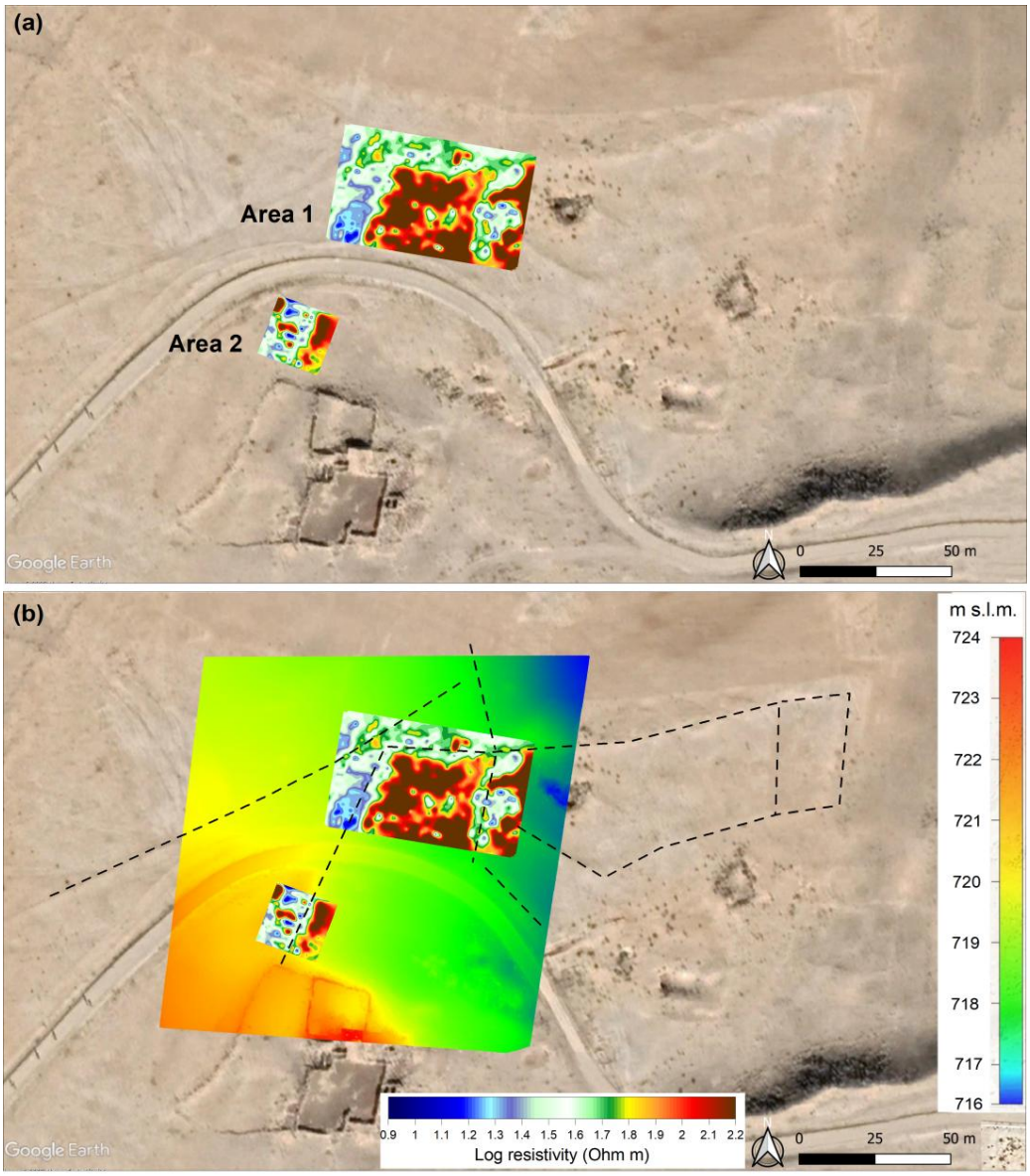


Figure 11. (**a**) Horizontal slice relative to 1.5 m in depth and (**b**) its overlapping with the DEM and traces (dotted lines) reported in Figure 10b.

Surface archaeological surveys facilitated exploration and learning about the settlement, including the checking, mapping, and positioning of water reservoirs, structures, and alignments. Special attention was paid to the traces located immediately north of the castrum. However, with regard to the ancient road system, a number of difficulties were encountered in ground verification. Indeed, to date, the analysis of the road routes that characterized the settlement is better understood through the examination of historical remote sensing data. Extensive field investigations were conducted to the NNW of the Church of St Stephen, where a series of wall alignments were traced, some of which had already been partially identified by Swiss scholars. In the same area, a hypogeum, characterized by side seats and a perforated ceiling, was discovered, which is probably comparable to one of the Bronze Age tombs found in the archaeological area of the Citadel of Amman. However, the continuous use of the site, which had become a shelter for animals and Bedouin shepherds at least until the expropriation of the area following its nomination as a UNESCO site, as well as the presence of a considerable layer of recent rubbish, makes it impossible to verify this information today.

4. Discussion

In this work, the results of the application of non-invasive imaging methods applied to the extensive study of a world-class archaeological site such as the UNESCO site of Umm ar-Rasas have been shown. Until recently, large-scale implementation and data collecting were hampered by expensive costs and technological difficulties. The latest advances in artificial intelligence, deep imaging, drones, imaging and instrumental technology have enhanced the quantity and quality of data gathered and analyzed while lowering costs. Individual survey methodologies' potential and limitations have long been recognized, in part because of the growing amount of academic research on the subject [81,95,96]. The limitations of geophysical and remote sensing techniques are still evident, both operationally (because the use of these techniques depends on land use and occasionally geology) and interpretively (because they do not provide direct information on the type and chronology of the evidence detected).

In this case, the experimental approach involved a synergic use of multi- and cross-disciplinary methods in order to obtain more robust technical information on the distribution of physical properties of the subsurface. It is crucial to emphasize that in archaeological prospecting, a single technical method is rarely, if ever, the optimum option for diagnosis. Due to the often ill-posed and implicitly probabilistic nature of the results derived from reconstruction problems, a multi-methodological approach enables the acquisition of high-quality information by means of a global evaluation of the convergence of data subject to various physical factors. Thanks to the integration of multiple techniques, it is possible to find the same anomalies that, although having been detected through different physical behaviors, have identified the same buried object. Such a theoretical framework is also perfectly in synergy with the general policies of cultural heritage management (see, for example, the Malta Convention [97]) that recommend the use of non-invasive methods to try to solve archaeological research problems without interfering with stratigraphic systems. Such a modern study approach is aimed at a proper preservation, conservation and management of the archaeological heritage encouraging a physical protection of the archaeological heritage of the elements that according to an old custom are often not uncovered or left exposed during or after excavation without provision being made for their safety. Our work fully respects this school of thought.

Starting with a hypothesis, the application of remote sensing technologies, archaeological surveys, laser scans, and geophysical prospecting led to the identification of what can be considered the northern boundary of the Byzantine–Umayyad settlement of Umm ar-Rasas. Qualitative and quantitative analysis of the datasets was conducted using geographic information management systems that integrated location data with various types of descriptive information. The exact fitting of these datasets serves as the validation element for the proposed boundary. While the results are to be confirmed through direct archaeological verification, they have significantly increased our understanding of the investigated site.

The archaeological evidence from Umm ar-Rasas (Kastron Mefa'a) offers important insights into the urban organization and spatial dynamics of Byzantine and Umayyad settlements in the Eastern Mediterranean. Located in southeastern Jordan, the site is characterized by distinct demarcations between military and civilian zones, with fortifications such as walls and towers marking the urban boundaries. These fortifications not only served defensive purposes but were also integral to the internal organization of the settlement, reflecting the strategic and administrative needs of the period [39,98,99].

Previous research, notably the work of Claudine Dauphin [39,98,99], has suggested that the physical boundaries of Umm ar-Rasas could be inferred from a combination of mosaics, textual evidence, and topographical surveys. Mosaics from the Churches of the Lions (575 A.D.) and St. Stephen (785 A.D.) are particularly significant, as they provide

visual representations of urban landscapes that likely correspond to real-world spatial limits within the settlement. Dauphin, along with other scholars, proposed that these mosaics, in conjunction with other sources, reveal the existence of distinct functional zones within the city—military, residential, and religious areas—each governed by its own spatial logic and organization [98,99]. The scholar hypothesized that the northernmost boundary of the settlement was at the level of the Church of St. Stephen.

The study presented here builds on earlier hypotheses by integrating modern remote sensing techniques, machine learning, and geophysical surveys to more accurately map the physical boundaries of Umm ar-Rasas. By combining multiple datasets, including satellite imagery and survey data, a more precise and comprehensive representation of the settlement's layout has been achieved. The results indicate that the northern boundary of the settlement, confirmed through geoelectric surveys, extends further north than previously suggested by scholars.

The articulation of settlement boundaries was not uniform across Byzantine and Umayyad sites. At Umm ar-Rasas, photointerpretation has revealed a likely fortified boundary. However, at neighboring sites such as Al-Jumayyil and Khirbet Samra, similarities in settlement organization are observable, with identifiable Byzantine walls at Khirbet Samra. Sites such as Umm al-Jimal exhibit well-defined boundaries. This variation suggests urban planning during the Byzantine and Umayyad periods was adaptable, influenced by local factors such as topography, available resources, and the specific function of each settlement. Our efforts to identify the physical boundary were guided by iconographic sources, particularly mosaics, which provided key visual clues essential for defining the boundaries of Umm ar-Rasas.

The integration of advanced technologies in the present study represents a significant advancement in archaeological practice, enabling a more nuanced and non-invasive approach to understanding ancient urban landscapes. The application of remote sensing, geoelectric surveys, and machine learning not only enhances the accuracy of boundary identification but also aligns with contemporary best practices in cultural heritage management. This ensures the preservation and non-destructive study of archaeological sites. While further archaeological excavation will be necessary to directly verify these results, the work presented here contributes to a deeper understanding of the complexities of urbanization in the late antique period. It also highlights the growing potential of technological innovations in archaeological research.

5. Conclusions

The interdisciplinary nature of the Umm ar-Rasas collaboration serves as a compelling example of how interdisciplinary approaches can significantly enhance the study and preservation of cultural heritage. By bringing together experts from archaeology, physics, geophysics, engineering, architecture and technology, the project not only advances the understanding of ancient settlements but also showcases innovative methodologies.

The integration of different expertise allows for a more comprehensive analysis of the archaeological landscape, facilitating the identification and mapping of key features that may have otherwise gone unnoticed. For instance, the use of cutting-edge technologies such as remote sensing analysis and machine learning application, 3D modeling, and geophysics and geospatial analysis enables researchers to visualize and interpret the spatial relationships within the site.

This paper presents the research results related to the Byzantine Umayyad settlement of Umm ar-Rasas. It focuses on non-invasive investigation methods, including remote sensing analysis and machine learning, which have been employed as authentic guiding tools to identify archaeological traces. These traces have been verified on the ground

through surface surveys and geophysical investigations. The present paper presents the research results related to the Byzantine Umayyad settlement of Umm ar-Rasas. Through a combination of traditional and innovative remote sensing analysis techniques, a physical boundary of the settlement has been identified. This feature was previously only hypothesized. The field research conducted in 2023 has ultimately confirmed the actual existence of a physical boundary, currently validated by geoelectrical surveys.

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References

1. Quattrone, G. Integrated Approach of Historical Landscape Characterisation Techniques and Remote Sensing for the Definition of Predictive Models and Scenario Analysis in the Planning of Archaeological Areas. *Heritage* **2024**, *7*, 2444–2457. [CrossRef]
2. Brancato, R.; Ferrari, V.; Ditaranto, I.; Merrola, P.; Rossi, I. Investigating resilient Roman agricultural landscapes in southern Italy. An integrated and open IT approach to modeling centuriation. *Archeol. E Calcolatori* **2024**, *35*, 387–400.
3. Calisi, D.; Botta, S.; Cannata, A. Integrated Surveying, from Laser Scanning to UAV Systems, for Detailed Documentation of Architectural and Archeological Heritage. *Drones* **2023**, *7*, 568. [CrossRef]
4. Bondar, K.; Petrauskas, O.; Mostovyi, D.; Didenko, S.; Reida, R. Combining remote sensing and geophysical data to determine Roman structures at Buzovytsia-1 settlement in Ukraine, in: Advances in on and Offshore Archaeological Prospection. In Proceedings of the 15th International Conference on Archaeological Prospection, Kiel, Germany, 28 March–1 April 2023; Universitätsverlag Kiel | Kiel University Publishing: Kiel, Germany, 2023; pp. 91–94. [CrossRef]

5. Zhurbin, I.; Borisov, A. Non-destructive approach for studying medieval settlements destroyed by ploughing: Combining aerial photography, geophysical and soil surveys. *Archaeol. Prospect.* **2020**, *27*, 343–360. [CrossRef]
6. Deiana, R.; Leucci, G.; Martorana, R. New Perspectives on Geophysics for Archaeology: A Special Issue. *Surv. Geophys.* **2018**, *39*, 1035–1038. [CrossRef]
7. Scardozzi, G. Il contributo dell'aerotopografia archeologica e del telerilevamento da satellite per la conoscenza dell'urbanistica di Hatra. *Archeol. Aerea* **2014**, *8*, 75–83.
8. Scardozzi, G. The contribution of historical aerial and satellite photos to archaeological and geo-archaeological research: Case studies in Italy and Turkey. *Adv. Geosci.* **2010**, *24*, 111–123. [CrossRef]
9. Keay, S.; Parcak, S.; Strutt, K. High resolution space and ground-based remote sensing and implications for landscape archaeology: The case from Portus, Italy. *J. Archaeol. Sci.* **2014**, *52*, 277–292. [CrossRef]
10. Hill, A.; Rowan, Y.; Kersel, M. Mapping with Aerial Photographs: Recording the Past, the Present, and the Invisible at Marj Rabba, Israel. *Near East. Archaeol.* **2014**, *77*, 182–186. [CrossRef]
11. Leucci, G.; Di Giacomo, G.; Ditaranto, I.; Miccoli, I.; Scardozzi, G. ntegrated ground-penetrating radar and archaeological surveys in the Ancient City of hierapolis of phrygia (Turkey). *Archaeol. Prospect.* **2013**, *20*, 285–301. [CrossRef]
12. Sarris, A.; Papadopoulos, N.; Agapiou, A.; Salvi, M.; Hadjimitsis, D.; Parkinson, W.; Yerkes, R.; Gyucha, A.; Duffy, P. Integration of geophysical surveys, ground hyperspectral measurements, aerial and satellite imagery for archaeological prospection of prehistoric sites: The case study of Vésztő-Mágor Tell, Hungary. *J. Archaeol. Sci.* **2013**, *40*, 1454–1470. [CrossRef]
13. Ciminale, M.; Gallo, D.; Lasaponara, R.; Masini, N. A multiscale approach for reconstructing archaeological landscapes: Applications in Northern Apulia (Italy). *Archaeol. Prospect.* **2009**, *16*, 143–153. [CrossRef]
14. Abu Dayyeh, A.S. Nomination of the old city of Um er-Rasas (Kastrum Mefa'a) for the World Heritage List (Feb. 2002). Amman. 2002. Available online: https://whc.unesco.org/document/168869 (accessed on 10 December 2024).
15. Piccirillo, M. Excavation at Mount Nebo-Umm Er-Rasas 1989. In *DoA: Registration and Documentation Section*; Unpublished Report; Department of Antiquities of Jordan Archive: Amman, Jordan, 1989.
16. Piccirillo, M.; Alliata, E. *Umm al-Rasas Mayfa'ah. Vol. I. Gli scavi del Complesso di Santo Stefano*; SBF Maior, 28: Jerusalem, Israel, 1994.
17. Abela, J.; Acconci, A. Umm al-Rasas Kastron Mefa'a. Excavation Campaign 1997. Church of St. Paul: Northern and southern flanks. *Liber Annus* **1997**, *47*, 484–488.
18. Abela, J.; Pappalardo, C. Umm al-Rasas, Church of St. Paul: Southeastern flank. *Liber Annus* **1998**, *48*, 542–546.
19. Abela, J.; Pappalardo, C. Umm al-Rasas—Kastron Mefaa Archaeological Campaign 2002. *Liber Annus* **2002**, *52*, 475–478.
20. Abela, J.; Pappalardo, C. Umm al-Rasas 2004, Excavation Report. *Liber Annus* **2004**, *54*, 419–424.
21. Piccirillo, M. Prima campagna di scavo a Um er-Rasas. *Liber Annus* **1986**, *36*, 351–354.
22. Piccirillo, M. Le iscrizioni di Um er-Rasas—Kastron Mefaa in Giordania I (1986–1987). *Liber Annus* **1987**, *37*, 177–240.
23. Piccirillo, M. Um er-Rasas—Kastron Mefaa. Terza campagna, 1988. *Liber Annus* **1988**, *38*, 459–468.
24. Piccirillo, M. Sesta campagna a Umm er-Rasas—Kastron Mefaa. *Liber Annus* **1991**, *41*, 522–526.
25. Piccirillo, M. Settima Campagna di scavi a Umm al-Rasas 1992. *Liber Annus* **1992**, *42*, 366–369.
26. Piccirillo, M. Archaeological Campaign at Umm al-Rasas. *Liber Annus* **1995**, *45*, 513–515.
27. Piccirillo, M. A New Church amongst the ruins of Umm al-Rasas—Kastron Mefa'a in Jordan. *Liber Annus* **1996**, *46*, 409–413.
28. Piccirillo, M. La chiesa di San Paolo a Umm al—Rasas-Kastron Mefaa. *Liber Annus* **1997**, *47*, 375–394.
29. Piccirillo, M. Excavation Report on the Tombs of the Lion's and St. Paul Churches at Um Er-rasas. In *DoA: Registration and Documentation Section*; Unpublished Report; Department of Antiquities of Jordan Archive: Amman, Jordan, 1999.
30. Piccirillo, M. Um Er-rasas archaeological campaign. In *DoA: Registration and Documentation Section*; Unpublished Report; Department of Antiquities of Jordan Archive: Amman, Jordan, 2001.
31. Piccirillo, M. Um Er-Rasas archaeological campaign. In *DoA: Registration and Documentation Section*; Unpublished Report; Department of Antiquities of Jordan Archive: Amman, Jordan, 2002.
32. Piccirillo, M. La Chiesa della Tabula Ansata a Umm al-Rasas. *Liber Annus* **2003**, *53*, 285–302. [CrossRef]
33. Piccirillo, M. La Chiesa del Reliquiario a Umm al-Rasas. *Liber Annus* **2006**, *56*, 375–388. [CrossRef]
34. Piccirillo, M.; Attiyat, T. The complex of Saint Stephen at Umm er-Rasas—Kastron Mefaa. *Annu. Dep. Antiq. Jordan* **1986**, *30*, 341–351.
35. Piccirillo, M.; Abela, J.; Pappalardo, C. Umm al-Rasas 2005, Excavation Report. *Liber Annus* **2005**, *55*, 494–498.
36. Piccirillo, M.; Abela, J.; Pappalardo, C. Umm al-Rasas—Campagna 2007. Rapporto di scavo. *Liber Annus* **2007**, *57*, 660–668.
37. Elitzur, Y. The Identification of Mefa'at in View of the Discoveries from Kh. Umm er-Raṣāṣ. *Isr. Explor. J.* **1989**, *38*, 267–277.
38. Piccirillo, M. L'identificazione storica delle rovine di Umm al-Rasas—Kastron Mefaa in Giordania. *Biblica* **1990**, *71*, 527–541.
39. Dauphin, C. The Garden of the Lord: Works and Days in the Byzantine Agricultural Landscape of Mefaa (Ummar-Rasas), Jordan. In *Holy Land. Archaeology on Either Side. Archaeological Essays in Honour of Eugenio Alliata ofm*; Coniglio, A., Ricco, A., Eds.; Studium Biblicum Franciscanum: Jerusalem, Israel, 2020; Collectio Major 57; pp. 33–72.

40. Bujard, J.; Haldimann, M.A. Fouilles de la mission archéologique Suisse (fondation Max van Berchem) a Umm er-Rasas et Umm al-Walid en 1988. *Annu. Dep. Antiq. Jordan* **1988**, *32*, 291–301.
41. Bujard, J. Les Églises Géminées D'Umm Er-Rasas, Fouilles de la mission archéologique Suisse (fondation Max van Berchem). *Annu. Dep. Antiq. Jordan* **1992**, *36*, 291–301.
42. Bujard, J.; Joguin, M. La fortification de Kastron Mayfa'a/Umm ar-Rasas. *Stud. Hist. Archaeol. Jordan* **1995**, *5*, 241–249.
43. Bujard, J. Kastron Mefaa, Un Bourg à l'époque Byzantine: Travaux de la Mission archéologique de la Fondation Max van Berchem à Umm al-Rasas, Jordanie (1988–1997). Ph.D. Dissertation, University of Fribourg, Fribourg, Switzerland, 2008.
44. Benedettucci, F.M. Ceramica del Ferro IIC. In *Umm al-Rasas Mayfa'ah. Vol. I. Gli scavi del Complesso di Santo Stefano*; Piccirilo, M., Alliata, E., Eds.; Studium Biblicum Franciscanum: Jerusalem, Israel, 1994; pp. 272–274.
45. Scarpati, D. Un'iscrizione latina da Umm al Rasas". *Liber Annus* **1991**, *41*, 363–364.
46. Lewin, A.S. Kastron Mefaa, the equites promoti indigenae and the creation of a late Roman frontier. *Liber Annus* **2001**, *51*, 293–304. [CrossRef]
47. Gabrielli, R.; Salvatori, A.; Lazzari, A.; Portarena, D. Il sito di Umm ar-Rasas—Kastron Mefaa—Giordania. In *Scavare Documentare Conservare, Viaggio Nella Ricerca Archeologica del CNR*; CNR Edizioni: Roma, Italy, 2016; pp. 236–240.
48. Gabrielli, R.; Portarena, D.; Franceschinis, M. Tecniche di documentazione dei tappeti musivi del sito archeologico di Umm al-Rasas Kastron Mefaa (Giordania). *Archeol. E Calcolatori* **2017**, *28*, 201–218. [CrossRef]
49. Malinverni, E.S.; Pierdicca, R.; Di Stefano, F.; Gabrielli, R.; Albiero, A. Virtual Museum enriched by GIS data to share science and culture. Church of Saint Stephen in Umm ar-Rasas (Jordan). *Virtual Archaelogy Rev.* **2019**, *10*, 31–39. [CrossRef]
50. Angelini, A.; Cozzolino, M.; Gabrielli, R.; Gentile, V.; Mauriello, P. Geophysical and Geomatic Methods for the Knowledge, Conservation, and Management of Jordanian Cultural Heritage. *Geosciences* **2023**, *13*, 349. [CrossRef]
51. Intrigila, C.; Giannetti, I.; Eramo, E.; Gabrielli, R.; Caruso, G. HBIM for conservation and valorization of structural heritage: The Stylite Tower at Umm ar-Rasas, Jordan. *J. Cult. Herit.* **2024**, *70*, 397–407. [CrossRef]
52. Di Palma, F.; Gabrielli, R.; Miccoli, I.; Scardozzi, G. The study of Limes Arabicus using aerial and satellite remote sensing documentation. The case of Umm ar-Rasas (Amman, Jordan). In Proceedings of the IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage, Rome, Italy, 19–21 October 2023; pp. 316–319. Available online: https://www.imeko.org/publications/tc4-Archaeo-2023/IMEKO-MetroArchaeo-2023-060.pdf (accessed on 10 January 2025).
53. Di Palma, F.; Gabrielli, R.; Merola, P.; Miccoli, I.; Scardozzi, G. Study and enhancement of the heritage value of a fortified settlement along the Limes Arabicus. Umm ar-Rasas (Amman, Jordan) between remote sensing analysis, photogrammetry and laser scanner surveys. In Proceedings of the CAA 2023, Amsterdam, The Netherlands, 3–6 April 2023. (in press 2025). [CrossRef]
54. Di Palma, F. Dal Laboratorio Sperimentale del Limes Orientale al Laboratorio Interdisciplinare di Umm ar-Rasas (Amman, Giordania). In Infrastrutture e Strutture di Confine. Lo Studio Aerotopografico del Limes Orientale Tra Iraq e Giordania: Dalle Foto Aeree di Sir Aurel Stein alle Immagini Satellitari Storiche e Recenti. Ph.D. Dissertation, University of Bari 'Aldo Moro', Bari, Italy, 5 February 2025.
55. Hammer, E.; Fitzpatrick, E.; Ur, J. Succeeding CORONA: Declassified HEXAGON intelligence imagery for archaeological and historical research. *Antiquity* **2022**, *96*, 679–695. [CrossRef]
56. Di Palma, F.; Scardozzi, G. Le ricognizioni aeree di Sir Marc Aurel Stein in Iraq e Giordania settentrionale: Il contributo allo studio del Limes orientale. *Archeol. Aerea* **2022**, *14*, 100–140.
57. Di Palma, F. Aseikhim (Giordania): Da tell a qasr. Studio aerotopografico di un insediamento di frontiera. *Archeol. Aerea* **2023**, *16*, 253–261.
58. Casana, J.; Goodman, D.; Ferwerda, C. A wall or a road? A remote sensing-based investigation of fortifications on Rome's eastern frontier. *Antiquity* **2023**, *97*, 1516–1533. [CrossRef]
59. Argyrou, A.; Agapiou, A. A Review of Artificial Intelligence and Remote Sensing for Archaeological Research. *Remote Sens.* **2022**, *14*, 6000. [CrossRef]
60. McFeeters, S.K. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *Int. J. Remote Sens.* **1996**, *17*, 1425–1432. [CrossRef]
61. Rouse, J.W.; Haas, R.H.; Schell, J.A.; Deering, D.W. *Monitoring the Vernal Advancement and Retrogradation (Green Wave Effect) of Natural Vegetation*; NASA/GSFCT Type III Final Report; NASA: Greenbelt, MD, USA, 1974.
62. Deng, Y.; Wu, C.; Li, M.; Chen, R. RNDSI: A Ratio Normalized Difference Soil Index for Remote Sensing of Urban/Suburban Environments. *Int. J. Appl. Earth Obs. Geoinf.* **2015**, *39*, 40–48. [CrossRef]
63. Huete, A.R. A Soil Vegetation Adjusted Index (SAVI). *Remote Sens. Environ.* **1988**, *25*, 295–309. [CrossRef]
64. Huete, A.; Didan, K.; Miura, T.; Rodriguez, E.P.; Gao, X.; Ferreira, L.G. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sens. Environ.* **2002**, *83*, 195–213. [CrossRef]
65. Estoque, R.C.; Murayama, Y. Intensity and Spatial Pattern of Urban Land Changes in the Megacities of Southeast Asia. *Land Use Policy* **2015**, *48*, 213–222. [CrossRef]
66. Vosselman, G.; Maas, H.G. *Airborne and Terrestrial Laser Scanning*; Whittles: Caithness, UK, 2010.

67. Remondino, F.; Campana, S. (Eds.) *3D Recording and Modelling in Archaeology and Cultural Heritage—Theory and Best Practices*; BAR International Series 2598; BAR Publishing: Oxford, UK, 2014.
68. Remondino, F.; Guarnieri, A.; Vettore, A. *3D Modeling of Close-Range Objects: Photogrammetry or Laser Scanning?* SPIE-IS&T Electronic Imaging: San Jose, CA, USA, 2005; Volume 5665, pp. 216–225.
69. Booth, A.D.; Szpakowska, K.; Pischikova, E.; Griffin, K. Structure of an ancient Egyptian tomb inferred from ground-penetrating radar imaging of deflected overburden horizons. *Archaeol. Prospect.* **2015**, *22*, 33–44. [CrossRef]
70. Coolen, J.; Wallner, M.; Trausmuth, T.; Konig, A. New Insights into a Romanesque Basilica Church in the Deserted Town of Corvey, Germany, Based on a High-Resolution GPR Survey. *ArcheoSciences* **2021**, *45*, 35–38. [CrossRef]
71. Urban, T.M.; Murray, C.A.; Vella, C.; Lahikainen, A. Ground-penetrating radar survey on the island of Pantelleria (Italy) reveals an ancient architectural complex with likely Punic and Roman components. *J. Appl. Geophys.* **2015**, *123*, 164–169. [CrossRef]
72. Gaffney, V.; Neubauer, W.; Garwood, P.; Gaffney, C.; Locker, K.; Bates, R.; De Smedt, P.; Baldwin, E.; Chapman, H.; Hinterleitner, A.; et al. Durrington walls and the Stonehenge Hidden Landscape Project 2010–2016. *Archaeol. Prospect.* **2018**, *25*, 255–269. [CrossRef]
73. Barta, J.; Belov, T.; Frolik, J.; Jirků, J. Applications of Geophysical Surveys for Archaeological Studies in Urban and Rural Areas in Czech Republic and Armenia. *Geosciences* **2020**, *10*, 356. [CrossRef]
74. Fitton, T.; Contreras, D.A.; Gidna, A.O.; Mabulla, A.Z.; Prendergast, M.E.; Grillo, K.M. Detecting and mapping the 'ephemeral': Magnetometric survey of a Pastoral Neolithic settlement at Luxmanda, Tanzania. *Antiquity* **2022**, *96*, 298–318. [CrossRef]
75. Yi, M.J.; Kim, J.H.; Song, Y.; Cho, S.J.; Chung, S.H.; Suh, J.H. Three-dimensional imaging of subsurface structures using resistivity data. *Geophys. Prospect.* **2001**, *49*, 483–497. [CrossRef]
76. Al-Saadi, O.S.; Schmidt, V.; Becken, M.; Fritsch, T. Very-high-resolution electrical resistivity imaging of buried foundations of a Roman villa near Nonnweiler, Germany. *Archaeol. Prospect.* **2018**, *25*, 209–218. [CrossRef]
77. Tsourlos, P.; Papadopoulos, N.; Yi, M.J.; Kim, J.H.; Tsokas, G. Comparison of measuring strategies for the 3-D electrical resistivity imaging of tumuli. *J. Appl. Geophys.* **2014**, *101*, 77–85. [CrossRef]
78. Simpson, D.; Lehouck, A.; Van Meirvenne, M.; Bourgeois, J.; Thoen, E.; Vervloet, J. Geoarchaeological prospection of a medieval manor in the Dutch Polders using an electromagnetic induction sensor in combination with soil augerings. *Geoarchaeology* **2008**, *23*, 305–319. [CrossRef]
79. Simpson, D.; Lehouck, A.; Verdonck, L.; Vermeersch, H.; Van Meirvenne, M.; Bourgeois, J.; Thoen, E.; Docter, R. Comparison between electromagnetic induction and fluxgate gradiometer measurements on the buried remains of a 17th century castle. *J. Appl. Geophys.* **2009**, *68*, 294–300. [CrossRef]
80. De Smedt, P.; Saey, T.; Lehouck, A.; Stichelbaut, B.; Meerschman, E.; Islam, M.M.; Van De Vijver, E.; Van Meirvenne, M. Exploring the potential of multi-receiver EMI survey for geoarchaeological prospection: A 90 ha dataset. *Geoderma* **2013**, *199*, 30–36. [CrossRef]
81. Piroddi, L.; Abu Zeid, N.; Calcina, S.V.; Capizzi, P.; Capozzoli, L.; Catapano, I.; Cozzolino, M.; D'Amico, S.; Lasaponara, R.; Tapete, D. Imaging Cultural Heritage at Different Scales: Part II, the Meso-Scale (Sites). *Remote Sens.* **2025**, *17*, 598. [CrossRef]
82. Ward, S.H. Resistivity and induced polarization methods. In *Geotechnical and Environmental Geophysics, Vol. I, Review and Tutorials*; Ward, S.H., Ed.; Investigations in Geophysics No. 5; Society of Exploration Geophysicists: Tulsa, OK, USA, 1990; pp. 147–189.
83. Cozzolino, M.; Mauriello, P.; Patella, D. An Extension of the Data-Adaptive Probability-Based Electrical Resistivity Tomography Inversion Method (E-PERTI). *Geosciences* **2020**, *10*, 380. [CrossRef]
84. Patella, D. Introduction to ground surface self-potential tomography. *Geophys. Prospect.* **1997**, *45*, 653–681. [CrossRef]
85. Mauriello, P.; Patella, D. Resistivity anomaly imaging by probability tomography. *Geophys. Prospect.* **1999**, *47*, 411–429. [CrossRef]
86. Minelli, A.; Cozzolino, M.; Di Nucci, A.; Guglielmi, S.; Giannantonio, M.; D'Amore, D.; Pittoni, E.; Groot, A.M. The prehistory of the Colombian territory: The results of the Italian archaeological investigation on the Checua site (Municipality of Nemocòn, Cundinamarca Department). *J. Biol. Res.* **2012**, *85*, 94–97. [CrossRef]
87. Valente, E.; Ascione, A.; Ciotoli, G.; Cozzolino, M.; Porfido, S.; Sciarra, A. Do moderate magnitude earthquakes generate seismically induced ground effects? The case study of the M_w = 5.16, 29th December 2013 Matese earthquake (southern Apennines, Italy). *Int. J. Eart. Sci* **2013**, *107*, 517–537. [CrossRef]
88. Mauriello, P.; Patella, D. A data-adaptive probability-based fast ERT inversion method. *Prog. Electromagn. Res.* **2009**, *97*, 275–290. [CrossRef]
89. Cozzolino, M.; Baković, M.; Borovinić, N.; Galli, G.; Gentile, V.; Jabučanin, M.; Mauriello, P.; Merola, P.; Živanović, M. The contribution of geophysics to the knowledge of the hidden archaeological heritage of Montenegro. *Geoscience* **2020**, *10*, 187. [CrossRef]
90. Cozzolino, M.; Gentile, V.; Mauriello, P.; Peditrou, A. Non-Destructive Techniques for Building Evaluation in Urban Areas: The Case Study of the Redesigning Project of Eleftheria Square (Nicosia, Cyprus). *Appl. Sci.* **2020**, *10*, 4296. [CrossRef]

91. Cozzolino, M.; Mauriello, P.; Patella, D. The Extended Data-Adaptive Probability-Based Electrical Resistivity Tomography Inversion Method (E-PERTI) for the Characterization of the Buried Ditch of the Ancient Egnazia (Puglia, Italy). *Appl. Sci.* **2022**, *12*, 2690. [CrossRef]
92. Balossi Restelli, F.; Cozzolino, M.; Manuelli, F.; Mauriello, P. The Characterization of the Lower Town of the UNESCO Archaeological Site of Arslantepe (Malatya, Türkiye) Using the Geophysical E-PERTI Method (Extended Data-Adaptive Probability-Based Electrical Resistivity Tomography Inversion Method). *Heritage* **2025**, *8*, 37. [CrossRef]
93. Hamarneh, B. The Role of the Bishop in the Suburban Topography and Territory of Modern Jordan, 5th–8th Centuries. In Proceedings of the XV International Congress of Christian Archaeology: Episcopo, Civitas, Territorium—Toledo, Toledo, Spain, 8–12 September 2008; pp. 415–430.
94. Pappalardo, C. Hydraulic system of water harvesting and distribution in Umm al-Rasas/Kastron Mefa'a. In Proceedings of the International Conference Precious Water. Paths of Jordanian Civilizations as Seen in the Italian Archaeological Excavation, Amman, Jordan, 18 October 2016; pp. 55–66.
95. Luo, L.; Wang, X.; Guo, H.; Lasaponara, R.; Zong, X.; Masini, N.; Wang, G.; Shi, P.; Khatteli, H.; Chen, F.; et al. Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: A review of the century (1907–2017). *Remote Sens. Environ.* **2019**, *232*, 111280. [CrossRef]
96. Piroddi, L.; Abu Zeid, N.; Calcina, S.V.; Capizzi, P.; Capozzoli, L.; Catapano, I.; Cozzolino, M.; D'Amico, S.; Lasaponara, R.; Tapete, D. Imaging Cultural Heritage at Different Scales: Part I, the Micro-Scale (Manufacts). *Remote Sens.* **2023**, *15*, 2586. [CrossRef]
97. Council of Europe. European Convention on the Protection of the Archaeological Heritage (Revised) (ETS No. 143), Valletta 01/16/1992—Treaty Open for Signature by the Member States and the Other States Parties to the European Cultural Convention and for Accession by the Other Non-Member States and by the EU. 1992. Available online: https://www.coe.int/en/web/culture-andheritage/Valletta-Convention (accessed on 5 February 2025).
98. Dauphin, C. *Les Mosaïques de la Jordanie*; CNRS: Paris, France, 1985; Volume 1.
99. Dauphin, C. *L'urbanisme de la Jordanie Byzantine*; CNRS: Paris, France, 1996.

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