The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium “Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future”, 25–30 June 2023, Florence, Italy

3D SURVEY TECHNOLOGIES TO DOCUMENT AND SUPPORT MICAELIC RUPESTRIAN ARCHITECTURE PRESERVATION. A CASE STUDY

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KEY WORDS: rupestrian architecture, micaelic architecture, heritage monitoring, heritage preservation, 3d survey technology

ABSTRACT:

The paper presents the actions conducted for the case study of the Hermitage of San Michele a le Grottelle, in Padula (Italy) in the framework of the scientific collaboration between the Urban\Eco Interdepartmental Research Centre and the Diocese of Teggiano-Policastro focused on the development of specific programmes of preventive conservation for the rupestrian heritage dedicated to the micaelic cult. In this context, the hermitage hosts precious wall paintings which show signs of advancing non-uniform degradation: some frescoes are completely lost, unlike others that, despite being spatially adjacent, are still intact.

The investigation was oriented towards understanding the reasons for this condition and articulated in 4 main actions: (i) digitisation of the site through the use of optical sensors, in order to obtain a digital model of the geometric and colour components of the asset; (ii) collection of external environmental data for the statistical characterisation of the site conducted considering multiple parameters recorded as observations from several meteorological stations; (iii) manipulation of the reflectance data for the informative characterisation from a material point of view of the most degraded frescoes, correlated to the colour information as well as to the geological classification of the site; (iv) virtual simulation of the incidence of external environmental parameters on the surfaces of the 3D model of the site, inserted in the real territorial context, in order to determine the relationship of causality and relative weight between the boundary conditions and the degradation phenomena found in order to direct preventive conservation actions.

1. INTRODUCTION

In the last two decades, increasing attention has been addressed to the knowledge and protection of rock-cut architecture and its related elements of artistic and historical value. The inclusion of many rock sites in the UNESCO World Heritage List has undoubtedly contributed to increasing the attention of the scientific community on these subjects. Suffice it to say that to date a great variety of rock sites are recognised as UNESCO World Heritage sites - about 67 - located all over the world. Among these are: Ḥimā Cultural Area (Saudi Arabia, 2021), Petroglyphs of Lake Onega and the White Sea (Russian Federation, 2019), Risco Caido and the Sacred Mountains of Gran Canaria Cultural Landscape (Spain, 2019), which have only been added to the list in the last four years.

This type of architecture is particularly significant for the evolutionary history of Mankind (Fonseca, 1972), an it is the result of long-lasting life choices, made in solitude or in community, with or without religious connotations. With respect to this last consideration, the cultic use of cave hypogea is a distinctive trait of certain confessions that have led Man to use caves for sacred purposes since archaic times (Ebanista, 2007; Kalby, 1975). Thus, over the years, real lines of research have developed around cave architectures with a religious matrix, which have initiated and consolidated, in parallel, pilgrimage and religious tourism phenomena. These are the pilgrimage routes related to the cult of certain Saints, such as the Via Francigena, the Via Micaelica, and so on.

All the examples of rock-cut architecture share their character of real Cultural Heritage, enriched by the varieties of art pieces, far beyond the motivation behind their erection and use,

In fact, the rock-cut cultural heritage consists of wall paintings, graffiti, sculptures and architectural elements that are often of great value and rare beauty (think about Valle Camonica and the City of Matera, declared European Capital of Culture 2019). However, it is at the same time a particularly fragile heritage because it is exposed to various deterioration factors, especially related to microclimatic conditions and their variations (Sileo et al., 2022). Unlike other hypogeal environments (e.g. catacombs, aqueducts), rupestrian hypogea are characterised by the presence of at least one open side. This condition makes these spaces particularly sensitive to external weather conditions, which influence the state of the interior space in a cause-effect relationship. For this reason, heritage conservation programmes, whether architectural or artistic and expecially the ones about rock-cut architecture, focus on preventive conservation actions formulated on the basis of careful monitoring of a series of physical parameters, including environmental ones (Cera, 2022; Bakalos et al., 2020; Camuffo, 2014).

Clearly, the monitoring of environmental parameters alone cannot explain the complex system of relationships that determines the state of degradation and deterioration that afflicts much of the rock-cut architecture. Therefore, a valid process of knowledge, restoration and protection of the heritage must correlate these environmental factors with the collection and analysis of additional data and cognitive elements such as the material consistency of the asset, its morpho-metric characteristics, colorimetric and structural components, and so on.

Thus, it is well known how 3D survey technologies based on the use of both active and passive optical sensors make it possible to obtain numerical models in the form of point clouds, which stand out as extremely refined and multi-purpose cognitive systems. In fact, the data acquisition and elaboration of three-dimensional models allows the extraction of useful data about the degenerative states of artefacts without carrying out destructive or anyhow invasive analysis to the architecture but rather direct subsequent in-depth studies in a target-oriented and heritage-friendly way (Cera, 2021; Clini et al.,2013; Meschini and Pelliccio, 2013; Zimbardo, 2011).

This contribution is part of this field of investigation by describing an experiment conducted on the case study of a rock hermitage dedicated to the cult of Saint Michael the Archangel. The research is oriented towards the manipulation of the digital model obtained from the survey and its correlation with environmental analysis and monitoring, in order to understand the state of health of the frescoed elements of the rock-cut architecture examined and to direct preventive conservation actions.

2. AIM OF THE WORK AND METHODOLOGY

The research presented herein is part of the scientific collaboration agreement between the Interdepartmental Research Centre Urban\Eco of the University of Naples Federico II and the Diocese of Teggiano-Policastro (Campania, Italy), signed with the aim of the systematising knowledge on the hermitages dedicated to the micaelic cult, located in Campania, through the cataloguing of the assets of this heritage and their networking and paths-connection (D'Agostino et al, 2019). The ultimate goal is the safeguard of the micaelic rupestrian heritage of Campania through the preparation of specific programmes of preventive conservation and restoration.
In this context, the contribution presents the actions conducted for the case study of the Hermitage of San Michele a le Grottelle, in Padula (Salerno, Italy), selected for its history and relevance in the area (Caffaro, 1996; Tortorella, 1983a).

2.1 The case study

The *Micaelion* of Padula is an ancient place of worship located in an isolated position outside the inhabited centre, on the eastern side of the steep rock face of Mount San Sepolcro. It is a typically rocky hermitage, carved out of a natural cave located at an altitude of 750 m a.s.l. and frequented since ancient times by the local Oenotrian populations, who practised the chthonic cult of the god Attis (ca. 8th century B.C.). The consecration of the pagan sanctuary to the Archangel, which was therefore converted into a Christian chapel, most probably dates back to the Constantinian Age (Tortorella, 1983b).
The architecture of the Padula hermitage (Fig.1) is remarkably natural: the entrance to the sacred place is secured by a gate, which was once next to a funerary stele (Cancellaro, 2016). Once through the gate, one finds on the left a first religious area, naturally protected by a recess in the rock. In the centre of the space is a bare altar from the end of the 14th century surrounded by walls frescoed with a cycle of Marian paintings dating from the early 14th century: it depicts the Nativity and the glorious Coronation of Mary. Opposite this first group of frescoes, to the right of the entrance, are some more recent rooms, possibly dating back to the 19th-20th centuries: a hut and a sacristy with an adjoining service. The grotto proper is dominated by an altar richly decorated with floral motifs, among which the design of the Carthusian coat of arms stands out on the rear face, evidence of the acquisition of the hermitage by the Charterhouse of San Lorenzo (Sacco, 2006). The altar, in its current form, is the result of a series of stratifications over the centuries that have also enriched the site with additional sacred elements. On the left side of the celebration hall of the grotto, for example, the tomb of Abbot Bernardino Brancaccio was placed in the 16th century, made of marble and bearing a low-relief bust of the deceased prelate. Between the 14th and 15th centuries, the perimeter of the chapel was decorated with a series of wall frescoes dedicated to various Saints and Martyrs. Behind the altar is a shrine dedicated to Saint James of Compostela, slightly shifted to the right in respect to the perpendicular axis of the small natural apse. The Saint is depicted enclosed in a trilobite, in the centre of a composition of miniatures inspired by his life and miracles. On the vault of the grotto that covers the altar, is the image of the Crucifix, to the left of which, proceeding clockwise, are depictions of: St Catherine of Alexandria martyr, with a cycle of scenes from her life; St Benedict; the figure of a saint identified as St Francis of Assisi, with a starry sky in the background, parts of a Crucifix and a representation of the Impression of the Stigmata; a Madonna and Child carried by angels, in a round shape (Fig.2). Today, the hermitage, despite its historical destination for pilgrimages related to the cult of Saint Michael, is closed to the public due to the need to carry out restoration work on the decorative apparatus and to secure the rock walls.

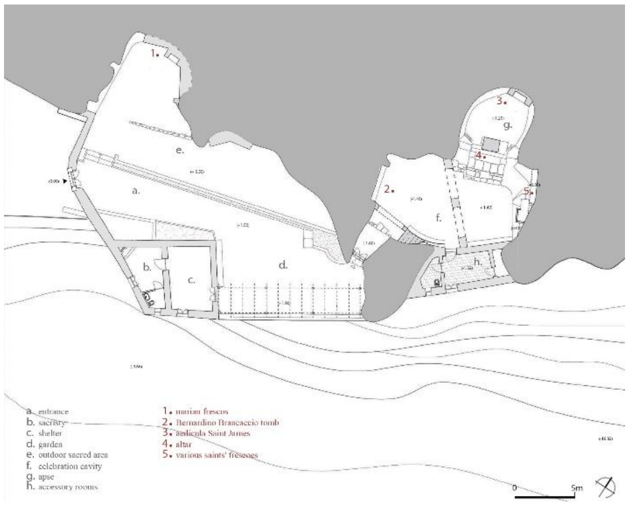

Figure 1. Hermitage of San Michele a le Grottelle (Padula, IT). Plant with indication of the decorative apparatus.

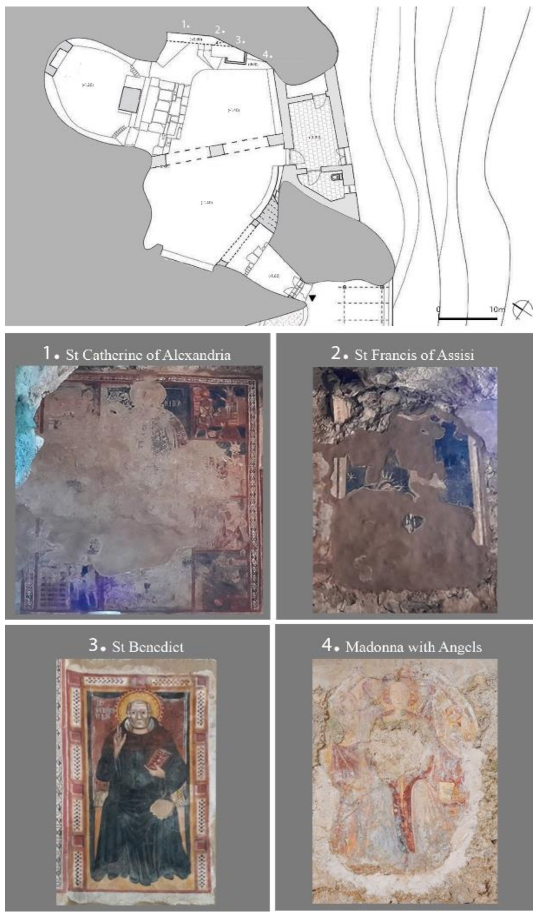

Figure 2. Frescos in the celebration hall. Detail of the most degraded depictions.

2.2 Methodological workflow

The wall paintings that constitute the decorative apparatus of the hermitage's celebration hall show the signs of advancing non-uniform degradation: some frescoes, in fact, are completely lost in contrast to others that, despite being spatially adjacent, are still fairly intact in their figurative and colour consistency.
For this reason, the investigation was oriented towards understanding the reasons for this condition and articulated in 4 main actions: (i) digitisation of the site through the use of optical sensors, both active and passive, in order to obtain an overall digital model, restitutive of the geometric and colour components; (ii) collection of external environmental data for the statistical characterisation of the site conducted considering the parameters of Temperature, Relative Humidity, Rainfall, Wind Direction and Speed, Sunshine and Solar Radiation, recorded as observations from multiple meteorological stations; (iii) manipulation of the reflectance data acquired with the range-based survey for the informative characterisation from a material point of view of the most degraded frescoes, correlated to the colour information recorded in the image-based survey as well as to the geological cataloguing of the site; (iv) virtual simulation of the impact of the external environmental parameters on the surfaces of the three-dimensional model of the site, inserted in the real three-dimensional territorial context, in order to determine the relationship of randomness and relative weight between the boundary conditions and the degradation phenomena found in order to direct preventive conservation actions.

(i) Both range-based and image-based optical sensors were used to *digitise the site*.
In particular, an initial collection of morphometric data was performed using a terrestrial laser scanner, the FARO Focus3D S120, with an acquisition mesh distribution consistent with the planimetric and altimetric development of the artefact. 7 scans were carried out for the open-air and external components of the hermitage, while 16 stations were positioned for the internal and celebratory areas, 2 of which were planned for the recording of information relating to the small elevated room. In relation to the conformation of the rocky bank that assumes the role of a wall, without interruption, of the hermitage, the scans were carried out at a rather close distance between the range maps acquired - a maximum of 2.5 metres. In fact, although the distributional characteristics of the architecture - substantially characterised by an almost free plan - are such as to suggest a scanning network with an even larger step between one station and the next, in fact the rupestrian nature of the architecture under examination imposed a survey design that took into consideration, as far as possible, the tangency planes and shadow zones for the blind projections of the surfaces. In light of these considerations, an average resolution of 6 mm at a distance of 10 m and an accuracy of 4x was then chosen, resulting in a range map infill step of approximately 1 mm at 1.5 m. Given the extremely naturalistic nature of the site, spherical targets were placed to facilitate the alignment process by locating artificial homologous points. Furthermore, the shape of the targets, the geometry of which differs significantly from the rock configuration of the hermitage, allowed for a rapid cleaning of the final data, of which no gaps were recorded having carefully planned the position of the targets so as not to occlude characteristic portions of the surface texture under examination. Finally, the alignment of the individual scans was performed with the instrument's proprietary processing and recording software in order to ensure the most correct rigid rototranslation procedure between the clouds with the smallest possible deviation values (Fig.3). The tension recorded between the different primitive elements on the individual scans is of the order of a millimetre.

The survey obtained by means of TLS was, as mentioned, integrated with a photogrammetric survey campaign carried out using a CANON Eos1300D Reflex camera. Since the focus of the research was on the cycle of frescoes that adorns the hermitage, the colour data is extremely important; therefore, by means of about one hundred photos taken with an average focal length of 24 mm, the colorimetric information was integrated into the TLS point cloud using well-known SfM algorithms implemented in the RealityCapture application. Finally, in order to obtain an overall model of the hermitage, representing both the internal characteristics of the rock-cut architecture but also its external features - closely related to the mountain ridge in which it is excavated - an aerial photogrammetric survey was also carried out. Using a DJI Spark drone, 55 frames were taken with a camera in a nadiral position and 15 frames with an oblique camera (60°) for the overhanging faces (Fig.4).

Figure 3. TLS point cloud.

Figure 4. Mesh SfM.

(ii) In relation to the *statistical environmental characterisation* of the site where the Hermitage of le Grottelle is located, some of the possible parameters considered most significant at this stage of the research were considered, such as: Temperature, Relative Humidity, Rainfall, Wind Direction and Speed, Sunshine and Solar Radiation. The information was collected from open source databases as observations from different databases and different meteorological stations active in the study area.
In particular, the meteorological dataset available at Climate.OneBuilding was used as the Typical Meteorological Year TMYx database from 2008 to 2021, containing Design Day DDY, EnergyPlus Weather EPW and Statistical Report STAT files. The meteorological stations in this database closest to the site of the Hermitage of le Grottelle are those of Potenza (inland) and Capo Palinuro (on the sea). Therefore, the meteorological database was expanded and integrated with the observations of two meteorological stations closer to the site of Padula, near Sala Consilina (a. Lat. 40.39; Lon.15.60; b. Lat.40.35; Lon.15.61) that are part of the MISTRAL project. Similarly, the collected observations were integrated and compared with the meteorological data available, again as open data, for a station located precisely in Padula (Lat.40.34; Lon.15.66) in the Pwsweather project in order to be able to use more accurate and specific information for the geographical area under investigation in the environmental assessment. In order to refine the statistical

characterisation of the asset, the COSMOS 5 model was also taken into consideration, which, for the latitudes in question, provides forecasting, with a resolution of about 5 km (corresponding to 0.045°) and a range of 72 hours, updated every 12 hours (run 00:00 UTC and run 12:00 UTC) and made available 5 hours after the run.

(iii) In order to *detail the body of information* from the material point of view of the investigated frescoes, the reflectance data acquired with the range-based survey were carefully manipulated.
Firstly, in order to avoid the compensations inherent in the overall cloud, related to the variability of the angle of inclination and the distance of the laser pulse from the surface of interest, the hue intensity maps were examined individually. Considering the type of pulse emitted - structured infrared light characterised by a wavelength of 1550nm - the percentage values of the detected reflectance were compared with laboratory spectra found in the literature in order to determine, as a first analysis, the type of material defining the most superficial layer of the frescoes.
The subsequent sampling of the colour palette of the pictorial cycles acquired in the image-based survey was then related to the reflectance values found, refining the material analysis and allowing for a somewhat more refined cataloguing of the materials, also considering the colorimetric parameter.
Lastly, in order to characterise the surfaces of interest in greater depth, the information gathered in this way was correlated with the geological and geolithological cataloguing of the site, deduced from the 1: 25,000 and 1: 5,000 maps respectively of the P.U.C. (Padula Municipal Urban Plan).

(iv) The *climatic analysis* of the hermitage, in the form of a virtual simulation of the incidence, on the surfaces of the three-dimensional model of the site, of the various external environmental parameters, previously collected, was conducted considering the artefact inserted in the real three-dimensional territorial context.

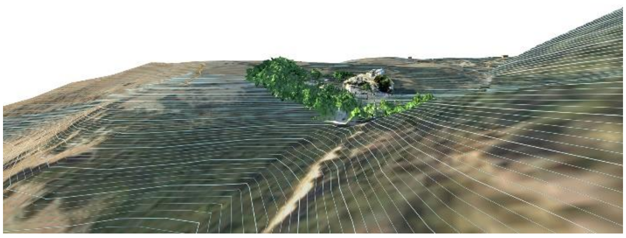

Figure 5. General verification of sunshine on a 3D spatial scale model.

In a first phase, the spatial data available, for the geographical area under examination, as open data were directly downloaded and processed in the Autodesk Infraworks software. In particular, (i) the orography of the terrain was assumed to be the DEM from SRTMGL1, Nasa's Shuttle Radar Topography Mission, with a 30-metre pitch for the project latitudes; (ii) the buildings, highways and railways were derived from the OpenStreetMap database; (iii) the raster images applied to the DEM were processed from Microsoft Bing Maps satellite images. Once the spatial model was defined, the digital model of the hermitage was imported into the same application in the form of a point cloud, previously acquired and processed. An initial check of the sunshine was carried out in order to obtain rough information regarding the level of solar exposure of the various fronts during the year and over the course of the different days (Fig.5).To further the analysis, the entire multiscalar model was exported and imported into the McNeel Rhinoceros software where, by exploiting the LadyBug plugin of Grasshopper, the climatic analysis was refined and detailed in relation to the various environmental parameters previously collected.

3. FIRST RESULTS AND DISCUSSION

The digital survey model shows an architecture articulated in two cavities, one of which is more like a slight recess in the rock, open to the sky, and the other like a real cave divided by a reinforcing arch into two main rooms, the largest of which is dominated by an altar. In the perimeter of the celebration hall, the wall frescoes show signs of major deterioration. In particular, the fresco depicting St Francis of Assisi - still visible in some images from the past decade - appears to be severely compromised in the possibility of grasping its original configuration, in spite of what has been recorded for the figurations immediately nearby in both space and date (Fig.6).

Figure 6. Fresco of St. Francis of Assisi, today (a) and in 2016 (b).

By cross-referencing spatial information with external environmental data, it emerges firstly that the site in general is located in an area characterised by considerable temperature variations throughout the day and the year. The average temperature in the winter months is around +8°C, with an average minimum value of -2.8°C and an average maximum of +19.9°C, and an average daily temperature range of 15°C. In the summer months, the average temperature is around +24°C, with an average minimum value of +10°C and an average maximum of +38.8°C, and an average daily temperature range of 25°C (Fig.7). Such large thermal variations certainly influence the behaviour and thermal state of the rock and could explain the degradation phenomena observed.

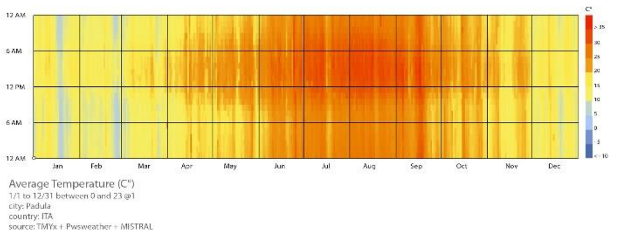

Figure 7. Average temperature for the geographical area of Padula (TMYx + MISTRAL + Pwsweather).

From a geological point of view, the hermitage lies on the side of a hillside formed as a gravitational deposit from a rotational landslide. From a geolithological point of view, the blanket of detrital material has a texture consisting of clasts of varying size immersed in and supported by a pelitic and/or sandy matrix (which may be altered by oxidation and pedogenesis), only locally stratified and/or cemented. This pelitic areanaceous formation, from scientific studies on its physical and mechanical characterisation, appears to be particularly sensitive to the effects of environmental conditions, showing, specifically, high susceptibility to climatic variations as well as to water absorption both by permeability and capillary rise.

This data is particularly significant if cross-referenced with the information relating to the site's rainfall, according to which the average rainfall in the period considered for the climatic characterization is around 150 mm. This could be interpreted so that, although the examined area is characterized by a medium-low rainfall (compared to other Italian cities), rainwater could be retained for longer by rock masses which are more permeable due to their nature.

However, the geological conditions and characterizations affect the entire frescoed wall and only partially explain the degradation conditions found, leaving the cause of the disparity in the level of degradation of the frescoes still unclear. Special climate analysis simulations were conducted to try to explain why, on the same wall, a fresco is degraded and the adjacent one, dating back to the same historical period of construction, does not show any deterioration.

Therefore, the punctual incidence of the environmental parameters on the individual external surfaces of the three-dimensional model of the site, inserted in the real territorial context, was verified and calculated. Examining in this case the values of solar radiation and the direction and speed of the wind, this time a punctual inhomogeneity was found in the amount of sunlight on the wall affected by the examined murals which could explain the situation in the first instance. In fact, due to the geographical location of the site as well as the conformation of the mountain complex that welcomes and surrounds the hermitage, it appears that the external wall corresponding to the internal surfaces of the celebratory hall where the representation in question is present - with NE orientation -, is subject to clearly different solar radiation values. Specifically, the deteriorated fresco is located on a portion of the wall in which the radiation parameter expressed in hours of sun exposure is close to the average value of 429.40, therefore very low considering that the immediately adjacent areas register an average value of 2147 (Fig.8).

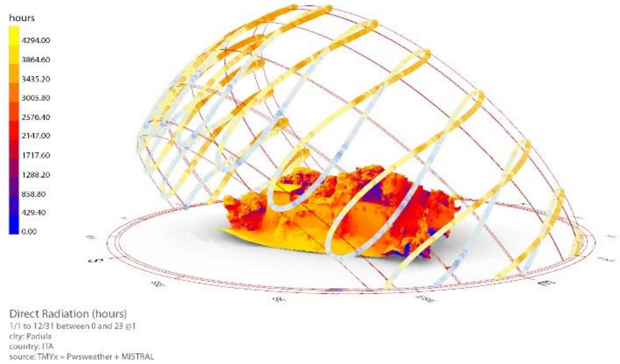

Figure 8. Sun path and solar radiaction for the geographical area of Padula (TMYx + MISTRAL + Pwsweather).

In addition, the wind rose shows a prevailing direction of the flows almost grazing the exposure of the affected wall (Fig.9) which, therefore, could potentially remain colder and more humid, especially on days of greater rainfall.

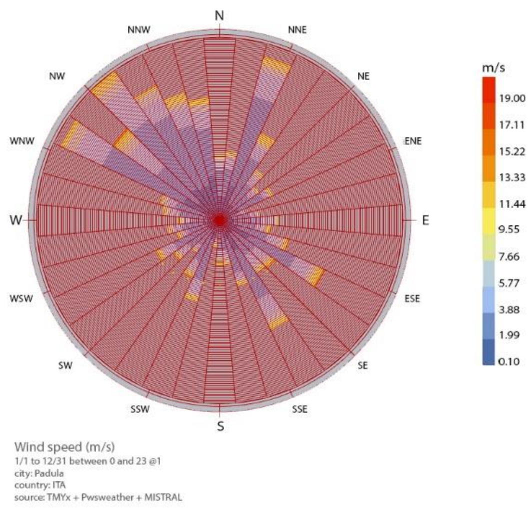

Figure 9. Wind speed and direction for the geographical area of Padula (TMYx + MISTRAL + Pwsweather).

Another significant fact is, as mentioned before, the loss in the last twenty years of some fresco fragments, which were still partially visible before. To investigate a possible course of detachment, hue intensity maps were manipulated. In the first place, the percentage values of reflectance found adhere to the behavior of the material classified in the literature as "plaster". Analyzing, then, the laboratory spectra present in the literature, the recorded reflectance variation is consistent with the colorimetric variation of the finishing pictorial layer. In particular, blue lime plaster, 30%; natural lime plaster, 60%; yellow ocher lime plaster, 70%; red ocher lime plaster, 65% (Fig.10a). Once again, these data are confirmed in the appropriate catalog of colors prepared and inferred from the photogrammetric survey (Fig.10b).

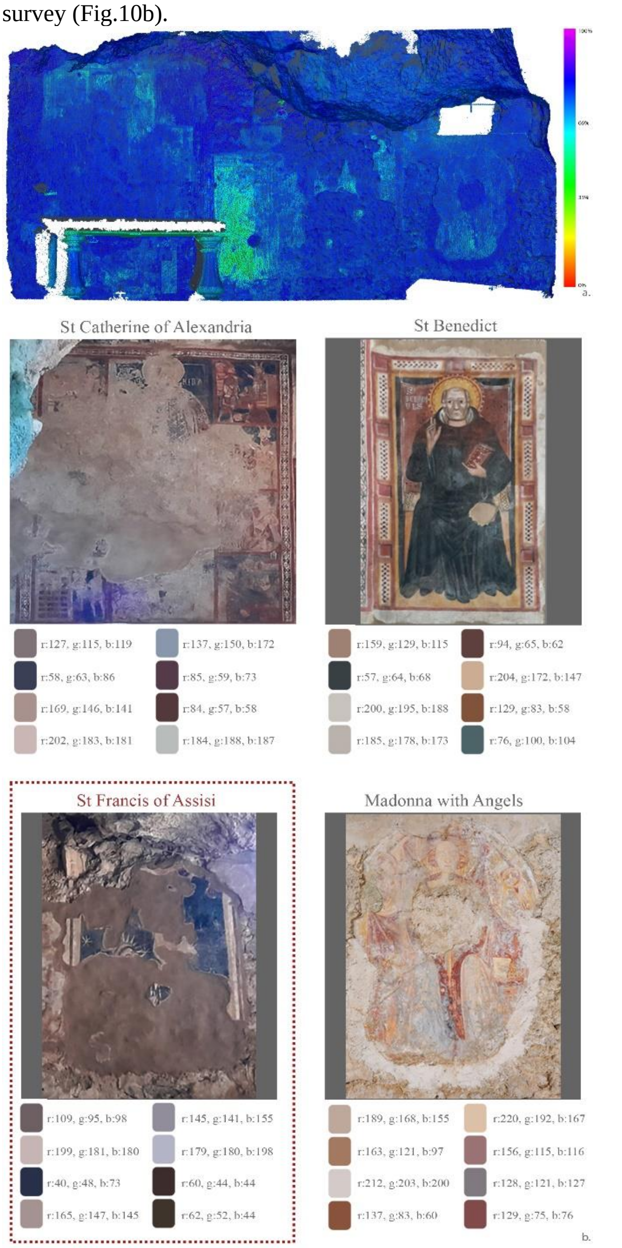

Figure 10. Hue Intensity Map (a) and colour palette (b) for the frescoes on the NNE wall.

Deepening the analysis, through the manipulation of the reflectance data of the TLS cloud, it emerged that some portions of the fresco of St Francis of Assisi, although no longer visible to the naked eye, are on the contrary distinguishable in the spectrum of the intensity values of the range maps (Fig.11). This datum could then be explained by a loss of the superficial pictorial layer and by the permanence of the lower anchoring layers for the colour.

4. FINAL DISCUSSION AND OUTLOOKS

To define the framework of the most appropriate actions to be pursued in the context of a preventive conservation program, there is no doubt that further investigations are necessary: among these, by way of example, the punctual analysis of the substrate, the study of the chemical-physical composition of the colors of the paints.

Further study of the environmental monitoring conducted also in indoor spaces, through the installation of specific sensors, will help to characterize the microclimate of the hermitage in thermo-hygrometric terms and better compare it with the surrounding environmental conditions. Considering the Diocese's desire to make the architecture of the hermitage increasingly accessible and usable to the public, in the future it will also be possible to envisage the analysis and interrelation of the data mentioned above, with information relating to the flow of visitors. The presence of visitors can in fact affect some indoor parameters such as the temperature and the amount of CO_2 present in the air. In line with these considerations, in the future, we also plan to enrich outdoor monitoring by including data of pollution (in particular CO_2, NO_x, etc., at 30 m resolution) as well as satellite information deriving from Sentinel 5 with reference to air quality, and ozone/surface UV applications.

For now, the first results of the research show the validity of the approach based on the correlation of digital models obtainable with current 3D survey techniques with monitoring actions of environmental parameters. Since the information is extracted on the one hand from open-source databases and on the other from the same architectural surveys, the system has the advantage of making the most of the survey outputs and open data. In this way it is possible to direct the most appropriate choices for diagnostic investigations - even with destructive tests - which, however, are carried out on more restricted and targeted areas, circumscribing the field of action and reducing waste and damage to the historical heritage. This scenario is particularly significant for fragile architectures such as rocky ones for which preventive conservation interventions cannot ignore the close relationship that such architectures have with the natural environment from which they originated.

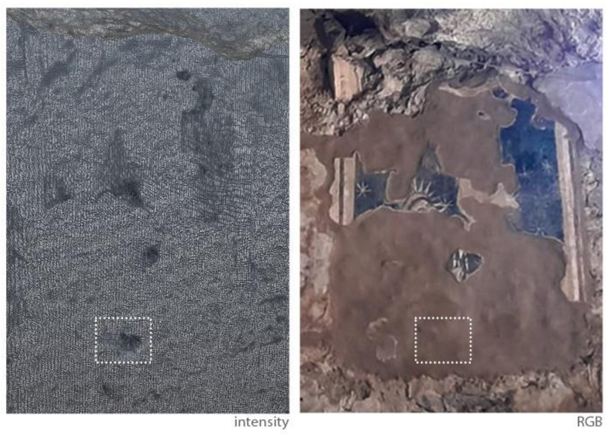

Figure 11. Comparison between the reflectance map (left) and a colour photo (right). An area of the fresco that is no longer visible is highlighted.

ACKNOWLEDGEMENTS

The study is part of the scientific cooperation agreement signed between the Interdepartmental Research Centre Urban/Eco of the University of Naples Federico II (Scientific Directors prof. Massimiliano and arch. Valeria Cera) and the Diocese of Teggiano-Policastro, in the person of the Vicar General, don Giuseppe Radesca. The author wishes to thank all the architects and researchers who contributed to the logistical and data collection phases, in particular arch. Alessandro Cancellaro and arch. Michele Sanseviero for their support.

REFERENCES

Bakalos, N., Doulamis, N., Doulamis, A., 2020. Multispectral Monitoring of Microclimate Conditions for Non-destructive Preservation of Cultural Heritage Assets. In A. Kavoura et al. (eds.), *Strategic Innovative Marketing and Tourism*, 641-646. Springer, Cham. https://doi.org/10.1007/978-3-030-36126-6_71.

Caffaro, A., 1996. *L’eremitismo e il monachesimo nel salernitano. Luoghi e strutture*. Salerno: Fondo per l'ambiente italiano, Delegazione di Salerno.

Camuffo, D., 2014. *Microclimate for cultural heritage. Conservation, restoration, and maintenance of indoor and outdoor monuments*. New York: Elsevier Science, 560 pages. ISBN: 9780444632982; https://doi.org/10.1016/C2013-0-00676-7.

Cancellaro, A., 2016. *L’eremo di San Michele a le Grottelle*, Padula: Comune di Padula.

Cera, V., 2022. Multisensor data fusion for Culture Heritage assets monitoring and preventive conservation. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVI-2/W1-2022, 151–157. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-151-2022, 2022.

Cera, V., 2021. La manipolazione di modelli discreti per orientare l'indagine diagnostica per il restauro. In R. A. Genovese (Ed.), *Il patrimonio culturale tra la transizione digitale, la sostenibilità ambientale e lo sviluppo umano. Cultural Heritage in digital transition, environmental sustainability and human development*, Napoli: Giannini Editore, 167-190. ISBN 978-88-6906-196-7.

Clini, P., Quattrini, R., Nespeca, R., 2013. Colore, geometria e riflettanza. Uso integrato dei dati Lidar per il rilievo e la diagnostica: il caso studio di Villa Trissino. In M. Rossi, A. Siniscalco (Eds.), *Colore e Colorimetria Contributi Multidisciplinari*, Rimini: Maggioli Editore, 185-192. ISBN 978-88-3876-241-3.

D’Agostino, P., Cera, V., Campi, M., 2019. I siti micaelici nel sud della Campania. Una rete di conoscenza. In S. Bertocci & S. Parrinello (Eds.), *Architettura Eremitica. Sistemi progettuali e paesaggi culturali*, Firenze: Edifir-Edizioni Firenze, 76-81. ISBN 978-88-9280-002-1.

Ebanista, C. 2007. L'utilizzo cultuale delle grotte campane nel Medioevo. *Atti I Convegno Regionale di Speleologia "Campania Speleologica"*, 127-150.

Fonseca, D., 1972. Civiltà rupestre in terra jonica. *Rivista di Storia della Chiesa in Italia*, XXVI, 492–496.

Kalby, G., 1975. Insediamenti rupestri della Campania. In C. D. Fonseca (Ed.), *La civiltà rupestre medioevale nel Mezzogiorno d’Italia. Ricerche e problemi*, 153-172.

Meschini, A., Pelliccio, A., 2013. Meschini, A., & Pelliccio, A. (2013). Il colore nel rilievo strumentale. Laser scanner, termografia e postprocessing dei dati in un sistema GIS. In M. Rossi, A. Siniscalco (Eds.), *Colore e Colorimetria Contributi Multidisciplinari*, Rimini: Maggioli Editore, 70-81. ISBN 978-88-3876-241-3.

Sacco, A., 2006. *La Certosa di Padula, designata, descritta e narrata da Mons.Sacco. Con special riguardo alla topografia, alla storia e all’arte della contrada*, Roma: Laveglia (Ed. Rist).

Sileo, M., Gizzi, F. T., Donvito, A., Lasaponara, R., Fiore, F., Masini, N., 2022. Multi-Scale Monitoring of Rupestrian Heritage: Methodological Approach and Application to a Case Study, *International Journal of Architectural Heritage*, 16:3, 469-484. https://doi./10.1080/15583058.2020.1799261.

Tortorella, A., 1983a. Tradizioni grecobizantine a Padula. *Lares*, 49 (4), 577-588.

Tortorella, A., 1983b. *Padula. Un insediamento medievale nella lucania bizantina*, Salerno.

Zimbardo, M., 2011. Valutazione dell’alterazione con laser scanner negli ammassi a struttura orientata e nella diagnostica dei beni monumentali. *Meccanica dei materiali e delle strutture*, 2:1, 41-51.