Archaeological digital anastylosis. From survey to lighting analysis

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ABSTRACT

The operational context is that of the ancient city of Stabiae, today not fully known and scarcely appreciated, and in particular of the complex of Villa San Marco and its representative spaces, in which there are figurative apparatuses both in wall paintings of the peristyle and in the stuccoes of the exedra at the bottom of the pool. The aim is to analyze the artifact in relation to the perceptive characterization - qualitative and quantitative - of its external and internal spaces, documenting some stages, related to the most thorough investigations with the targeted use of laser scanning techniques, to the analysis of photometric and colorimetric characteristics, and to the perceptive study of decorative apparatuses. Precisely this artistic repertoire, is believed to have characterized the use of the environments and, to date, it connotes spatial qualities. The focus is mainly on the area of the nymphaeum, characterized by a swimming pool and a bottom-closing exedra: for the two larger sides it is defined by suggestive arcades with decorated walls in the IV Style in which a figurative solution is adopted to subsequent panels. On this environment, the diaetae appear on opposite sides. They show, despite the structural symmetry, disparity in the chromatic and figurative treatment, presumably due to the different destination: representation on the east side, a more "domestic" use than the one located on the west side. The intention to test the variation of the simulated perception, within a digital reconstruction process, required a preliminary survey campaign, both for the metric acquisition of the artefact and the contextual lighting characteristics. In this preliminary study on a cultural heritage artefact with its own historical past we have highlighted the need for a concerted, multidisciplinary effort; these partial results should ensure future developments.

KEYWORDS Survey, Three-dimensional simulation, Lighting analysis

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1. Introduction

The study was carried out in the ancient city of Stabiae, still not fully explored and only marginally enhanced. Its objective was to analyse the Villa San Marco complex and the figurative decorations in its reception rooms: the wall paintings in the peristyle and the stuccoes in the exedra at the end of the swimming pool.

In addition, the study meticulously examined the characteristics of the building and qualitative and quantitative features of its external and internal spaces; it also documented several stages of a more in-depth assessment which included the use of laser scanning techniques, an analysis of its photometric and colourmetric characteristics, and a perceptive evaluation of its decorations.

The artistic repertoire is believed to have determined the use of the rooms and currently conveys its spatial qualities. Testing the changes in simulated perception as part of a digital reconstruction process required a preliminary surveying campaign and acquisition of the measurements of the building and lighting characteristics of the context.

2. The reference framework

Enhancement of archaeological artefacts is an extremely topical subject.

It has led to a merger between traditional enhancement methods and the most modern cognitive and communicative tools, appreciated by increasingly informed users especially when it is impossible to fully enjoy the sites included in national and international tourist itineraries.

The archaeological site of Stabiae is a case in point: the cognitive support tools present on site (primarily concise panels positioned near the most important excavated domus) fall short of visitors' expectations and the cultural interests perceptively sparked by the context (Fig. 1). All the villas brought to light so far were originally decorated and elegantly embellished with extremely expensive furnishings; unfortunately, ever since the initial eighteenth-century excavations they have been systematically removed in order to protect them (Papa et al. 2013, Papa et al. 2014). This raises two sets of problems: the first involves the difficulties inherent in the study of changes in local and territorial scenarios; the second is how to define and integrate the most effective cognitive and communicative strategies in order to generate greater fruition.

The experimentation illustrated in this contribution and presented as a progress report of the study in question chose Villa San Marco as a case study; it is one of the biggest architectural complexes in the Stabia area (a total of 49 hectares) located in the hilly south-east part of the Castellamare di Stabia municipality (Fig. 2).

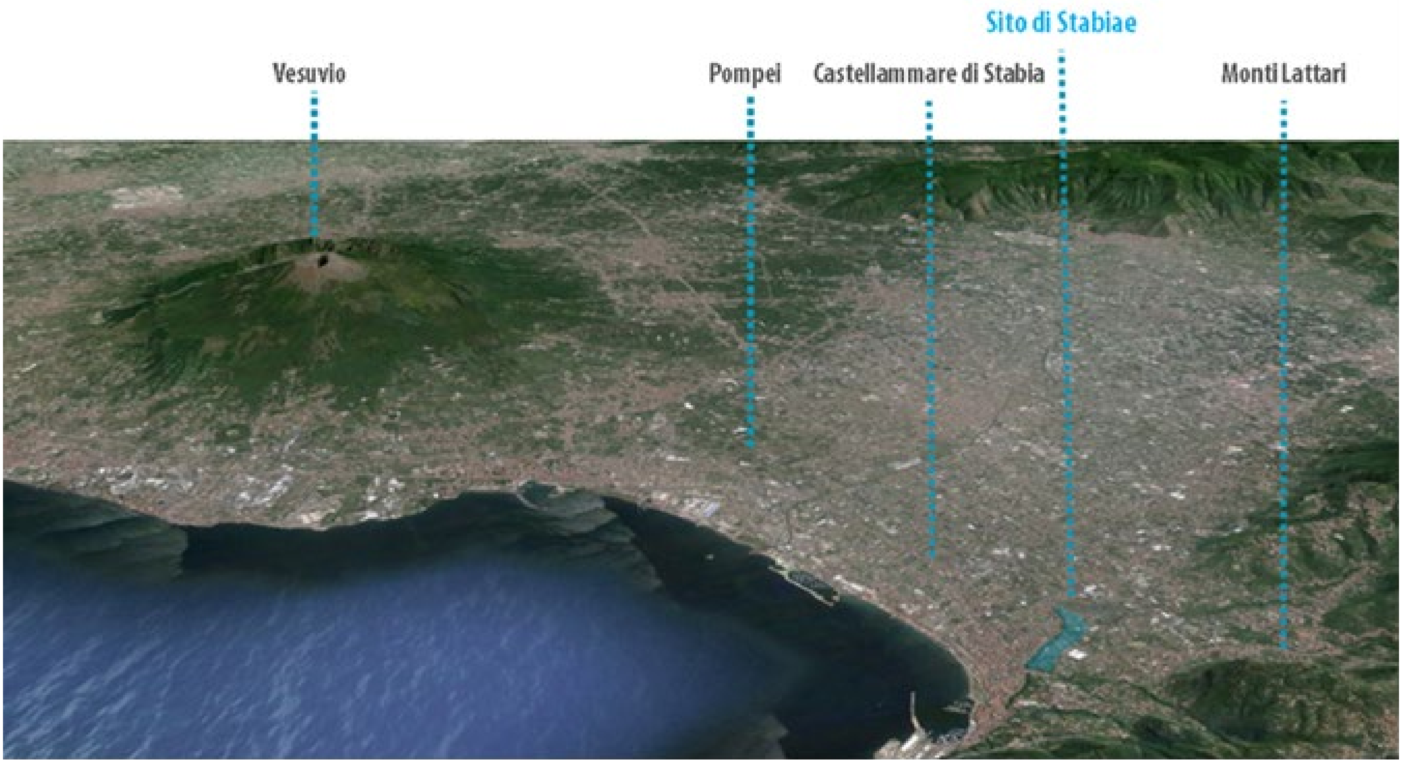

Fig. 1. The area of the otium villas

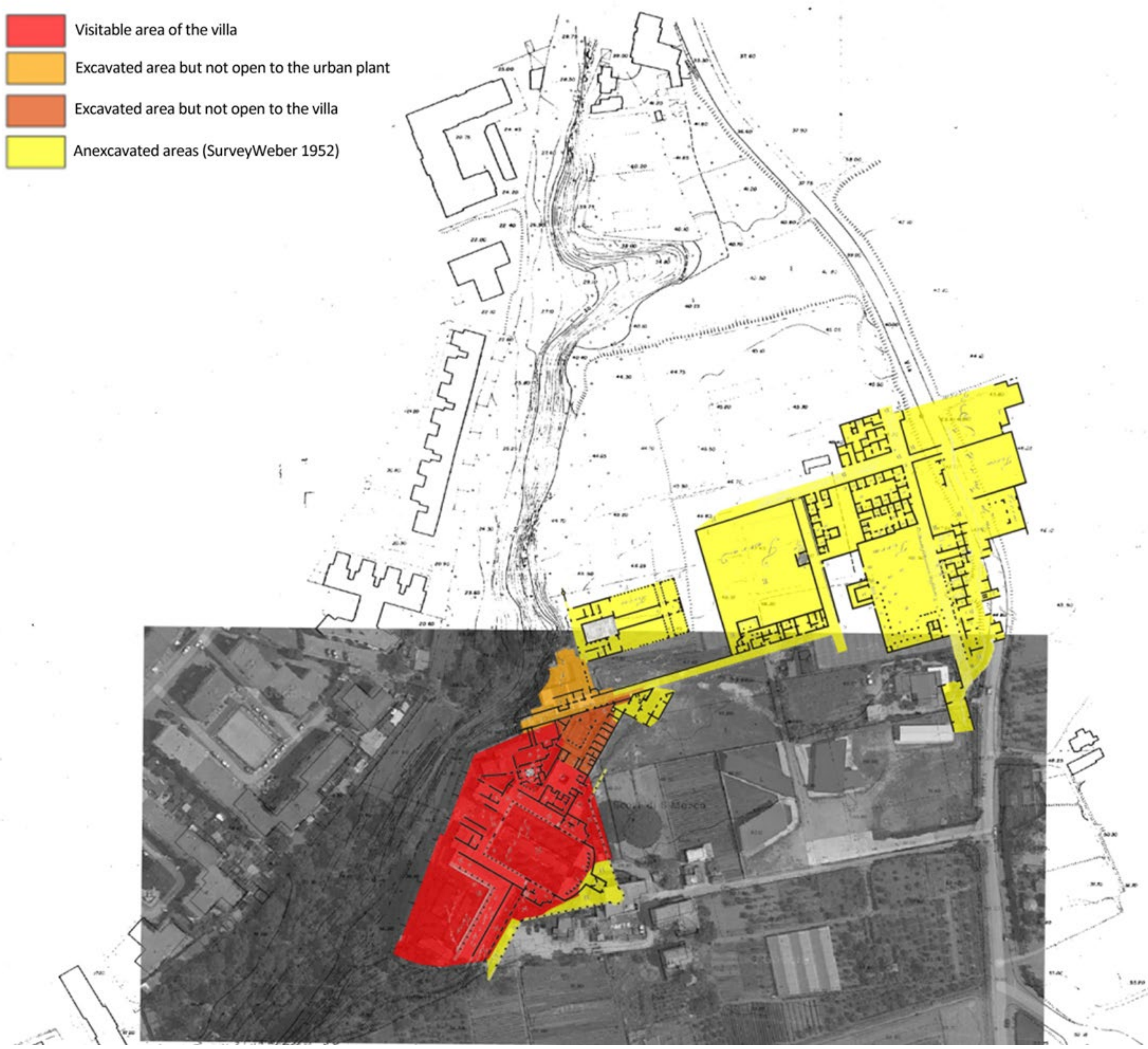

Fig. 2. Plan of old Stabiae showing Villa San Marco

The oldest part of the Villa was built under Augustus (from 27 BC to 14 AD), but the complex was enlarged under Claudius (41-54 AD). A spa area was built between the entrance to the complex and the edge of the hill as well as a big, shady garden and a decorated nymphaeum between the swimming pool and the hillside; the dietae panoramically opened onto the swimming pool. Most areas in the layout of the complex are positioned so as to adapt to the relief of the hillside on which it was built; the most representative rooms were originally positioned panoramically towards the sea. Instead the spa complex follows the orientation of the urban layout, as illustrated in the surveys performed by Karl Weber in 1759; these surveys will be compared with the results of the surveys we were necessarily required to perform to verify the position and extension of the buildings previously surveyed and later integrated.

3. Real space ad illusory space

The layout of the rooms in the Villa follows the privileged directions of the "San Marco terrace"; its conformation required the construction of imposing structures not only to solve the problem of the extremely steep slope between the terrace and the countryside below, but also to position the rooms in an east-west direction so that the design enhanced its panoramic position.

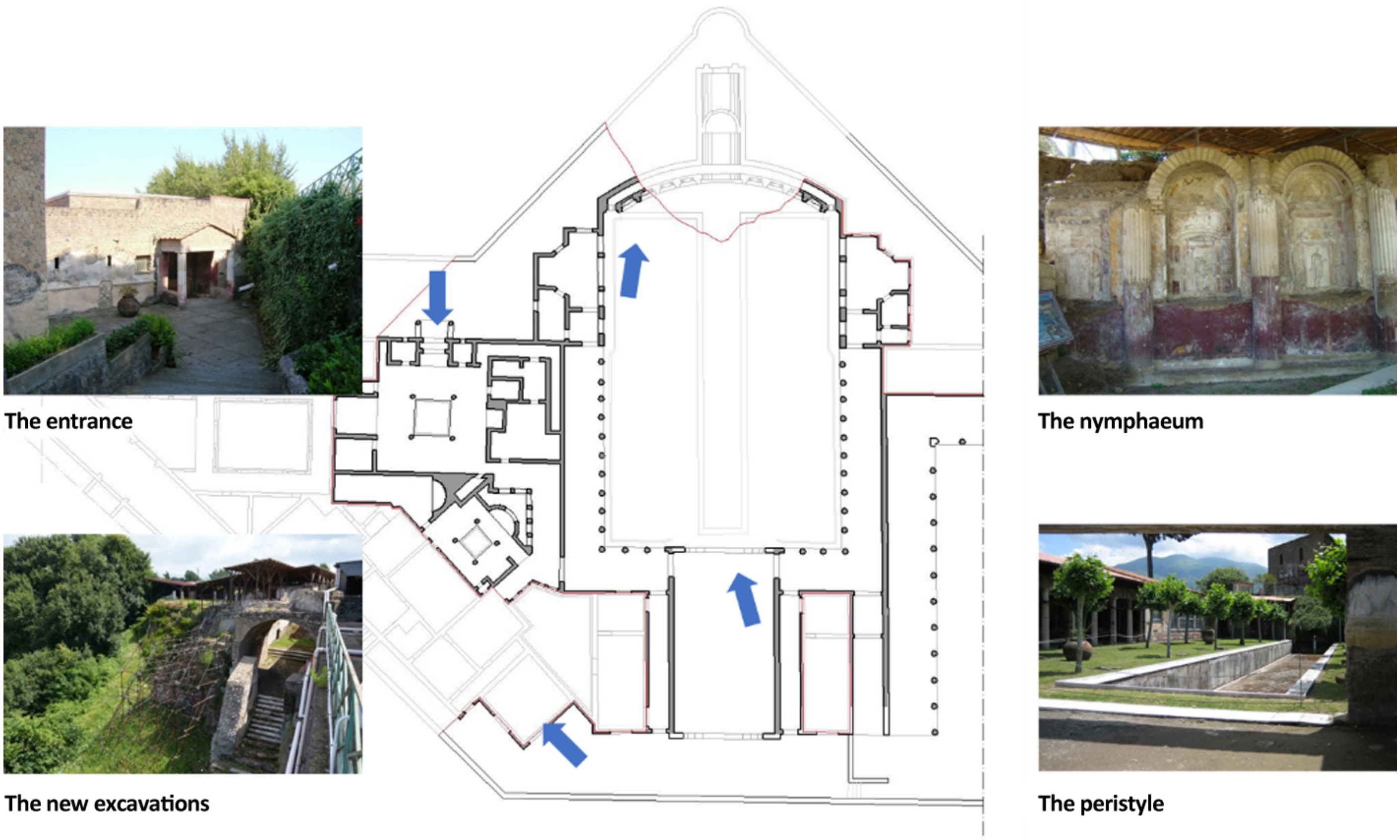

Fig. 3. Entrances to the villa: surveys and areas currently open to visitors

The villa's architecture and infrastructure influenced the decorations which, on the one hand, appear similar to the ones in other buildings in old Stabiae and, on the other, enable identification of the several construction phases of the Villa (Fig. 3). The built area developed around an older, initial layout that was reorganised during the first century CE. Evidence shows that the third rebuilding and reorganisation phase took place more or less when Vesuvius erupted in 79 CE.

The coherently executed decorations follow the logic of the temporal progression of the restructuring, but they also clearly characterise the rooms in which they are present. It is therefore possible to talk of a "decorative space" in which the use of unusual solutions boosts the quality of the architectural space by linking the rooms and turning them into an organic figurative narrative.

The oldest wall paintings are the ones in the spa rooms and hallway where the idea behind the albeit different decorations on the walls and floor was nevertheless similar; the tetrastyle hallway of Villa San Marco and the nymphaeum were particularly enhanced by decoratively varying the cabled white plaster coating and 8grooved plaster (also white). This was a common for open spaces in the alternation of lights and colors (Papa et al. 2014).

The nymphaeum, positioned along a longitudinal axis, faces the plain below where in the past the coastline was much closer to the hill, so much so that the water in the pool seemed to stretch seamlessly to the sea. The walls along its two longer sides have beautiful porticoes with IV Style of of Pompeiian wall-painting (datable to the second half of the first century) in successive panels. The main scene has a white background with small, framed figurative panels between the yellow and red painted areas. This pattern was quite common in the IV Style; due to its paratactic structure it was well-suited to decorations along long surfaces such as porticoes (Fig. 4a). The decorative effect is achieved by the studied, regular repetition of motifs and colours; the material continuity of the wall is only ostensibly broken insofar as the ensuing image is not fragmented but recomposed on a plane where colours, light and shadows create an illusory *continuum*.

4. The on-site architectural survey

The architectural survey campaign was performed using laser scanning techniques; it envisaged a series of recordings for a total of twenty-two stations covering approximately 2400 m^2, equal to roughly a third of the total excavated area.

This study was carried out on a relatively small portion of the Villa that was nevertheless emblematic for the articulation of the archaeological rests that were brought to light until then. Operating on the basis of a well-planned topographic framework, the scans were set up with the purpose of correlating the current survey campaign with future ones. In particular, a clear line of sight between current survey stations and potential future ones, to be located in other rooms, has been ensured. The ambulatory, the baths district and the kitchens are indeed adjacent to the scanned zones.

Thanks to this survey campaign, the overall perspective, offered by the processing of the obtained point cloud, led to some significant results since the very first observations. Once the campaign was finished, the images produced after processing the points clouds led to several initial results and observations. For example, the structural symmetry and chromatic and figurative differences of the dietae facing each side along the long sides of the garden are presumably due to their diverse function: the ones on the east side (Figs. 4b & 5) had a more representative function while the one on the west side played a more “domestic” role.

Fig. 4. Left (a), central view of the west wing of the major peristyle of the Villa; right (b), corner of the entrance of the west dietae towards the domestic area of the Villa.

Fig. 5. Points cloud from the laser scansion of the peristyle and east dietae

Moreover, the structures in the former were drawn in perspective which, unlike the ones in the more famous sites of Pompeii and Herculaneum, appear to have less figurative embellishments but are in some cases more interesting due to their unusual position at the corners of the walls rather than in the middle of the walls which are, nevertheless, present. Likewise, the surveys of the exedra next to the pool and at the end of the partially inaccessible ambulacrum at the rear are equally fascinating from a disciplinary point of view. The perceptive study of the decorative devices is integrated with the in-depth analysis of the photometric and colorimetric characteristics to investigate the variation of the simulated perception, within a digital reconstruction process.

4.1. *Photometric and spectroradiometric surveys*

Lighting in the Villa is currently provided only by daylight and during the surveys it presented significant spatial and temporal variability. These differences are generally due not only to the daylight variability during time, but also to the different daylight availability in the rooms due to their architectural features, i.e. the presence or absence of openings, their orientation, the presence of external obstructions, etc. (Balocco and Calzolari 2008). The on-site survey, aimed at collecting illuminance and luminance measurements along the visit route, made it possible to evaluate the gradients occurring both in spatial and temporal dimensions (Bellia et al. 2018) (Fig. 6). In addition, by measuring the spectral reflectance of the building surfaces (both painted and non-painted) it will be possible to insert the measured data into a lighting simulation software in order to obtain useful information not only about light scenarios, but also about the annual (day)light exposure of the painted surfaces, necessary for evaluating the risk of damage (Cuttle 2000). Spectral reflectance values are also useful for performing the proper choices of the light sources' spectral power distribution so as to enhance the correct fruition of the spaces. Finally, by measuring spectral irradiance it was possible to assess how the intensity and spectrum of natural light is modified by the materials on the walls (especially the colored ones) inside the rooms.

The first survey campaign was performed on February the 28th 2018, starting from 14:20 to 15:00. The relatively short period of time and the fact that the sky was cloudy allowed us to acquire data in the rooms with the same outdoor lighting conditions; as a result, measured data for all the rooms were comparable. We focused in particular on the two dietae. We measured luminance and spectral irradiance, as well as the spectral reflectance of the interior surfaces. From the measurements of spectral irradiance, performed in several points and different orientations, it was possible to calculate illuminances and colour temperature of the incident radiation. Specifically, both interior and exterior horizontal surfaces were considered, in order to obtain information on how daylight entrance is at today controlled by the presence of the current window systems. Vertical illuminances at the eye level (1.60 m from the floor), in several points of view along the visit route were also collected. In this way it was possible to detect if the visual conditions along the visit route are affected or not by strong gradients.

In fig.7 the points where measurements were performed are reported. It's important to notice that the illuminance value at the eye's level can be assumed as proportional to the average luminance in the field of view of the observer, by applying the relationship Lav= E/π. The average luminance, in its turn, can be considered as the "adaptation luminance", i.e. the luminance value corresponding to a specific condition of adaptation by the visual system. Consequently, when illuminance values at the eyes' level are affected by strong variations along the visit route, it means that visitors will not be able to adapt their visual system to the changing levels of lighting. The result will be an incorrect visual fruition of the spaces, especially in perceiving colors when passing from brighter to darker conditions.

Table 1 reports the results obtained by processing the spectral irradiance values. As it can be inferred by analyzing the vertical illuminances and the corresponding average luminances, even in the same room, values are strongly different. For example, in the "Pavilion left", average luminance ranges from 20 to 590 cd/m^2, whereas in both the cubicula illuminance assumes insufficient values in order to allow a proper environmental perception. This effect is enhanced by the fact that visitors reach the cubicula by previously passing through much more bright rooms (the pavillons). Given the overcast sky conditions during the survey, it is possible to assume that in general, even in other days or hours, illuminance and luminance distributions attain similar values than the measured ones, proportional to the outdoor external values on horizontal surfaces. In table 1, correlated colour temperatures (Tc) related to the spectral irradiances are also reported. They represent the "colour" of the light striking on the considered planes. As it can be noticed, outdoor values are always higher than the indoor ones. In particular, considering that outdoor values are around 6000K (6282K and 5866K in the points EXT/1 and EXT/2 respectively), in rooms as the cubicula, these values are much lower, reaching the minimum at around 3700K (3718K in the "Cubiculum left" and 3741K in the "Cubiculum right").

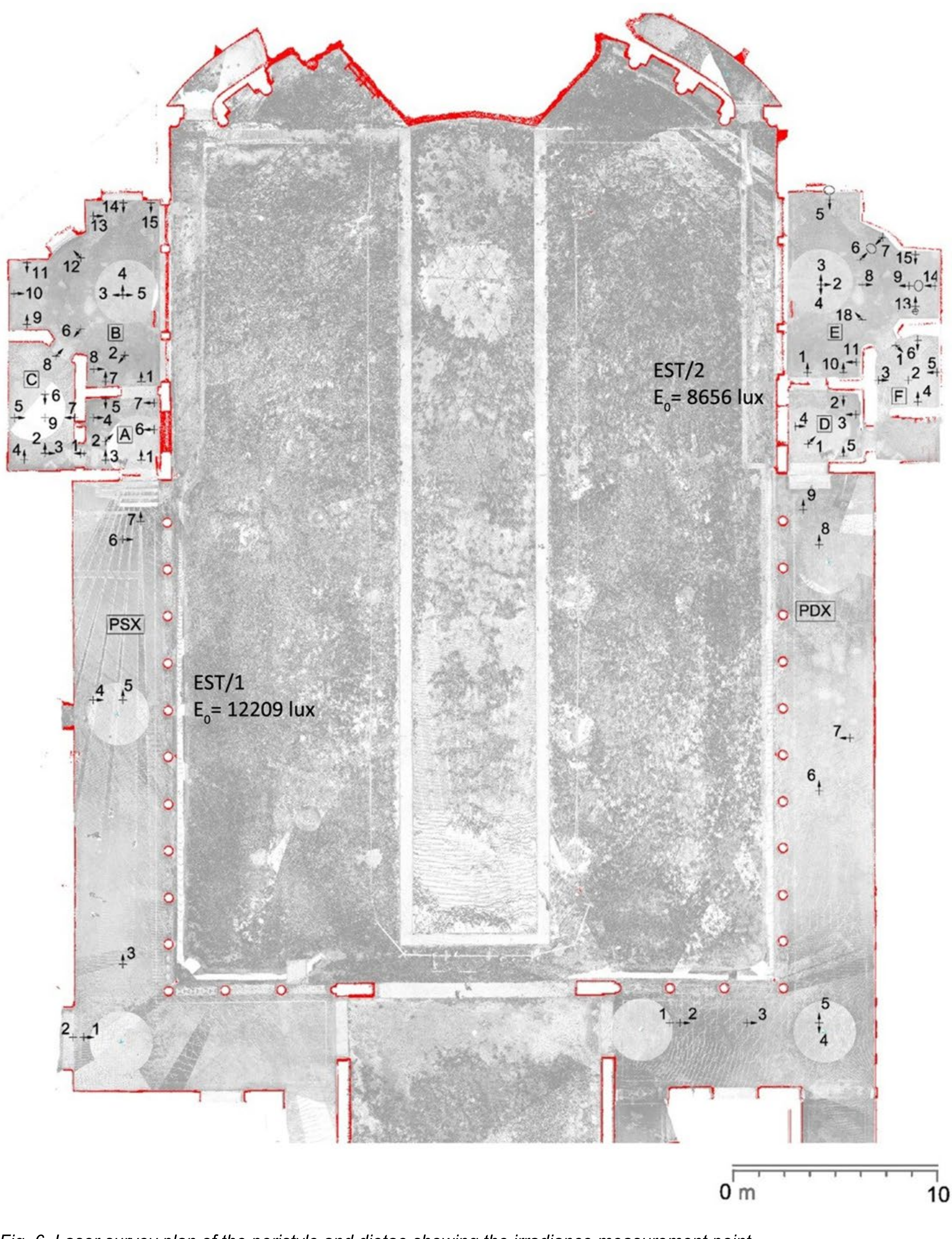

Fig. 6. Laser survey plan of the peristyle and dietae showing the irradiance measurement point

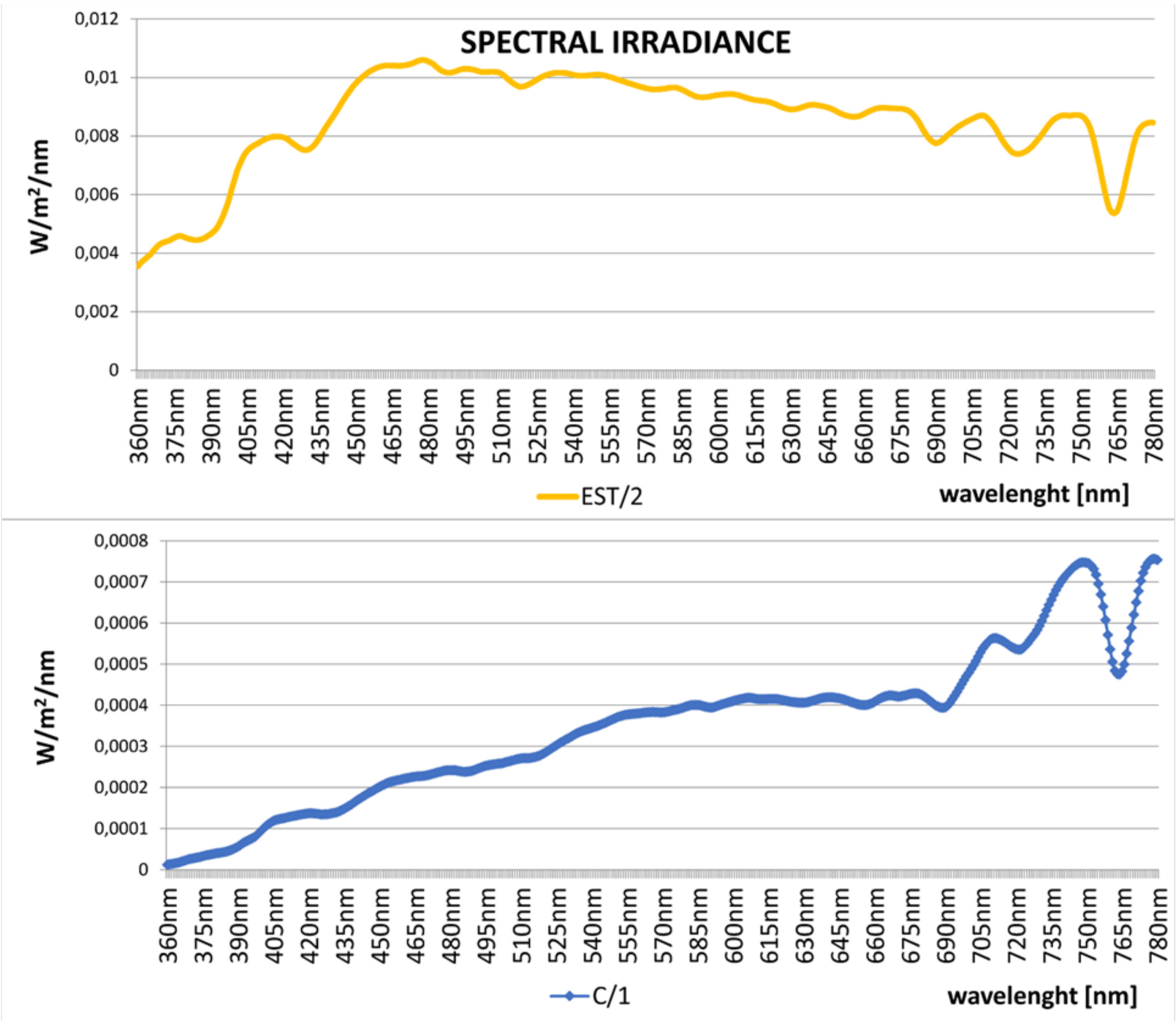

Fig. 7. Daylight spectral irradiance of the two extreme cases, EXT/2 (outdoor) and C/1 (indoor) regarding colour temperature.

Code	Position	E [lux]	L_{av} [cd/m^2]	Tc [K]	Code	Position	E [lux]	L_{eq} [cd/m^2]	Tc [K]
		OUTSIDE					OUTSIDE		
EXT/1	horizontal	12209..4		**5866**	**EXT/2**	horizontal	8656.0		**6282**
		PORCH LEFT					PORCH RIGHT		
PSX/1	vertical	711.6	226.6	5645	**PDX/1**	horizontal	1239.5		5024
PSX/2	vertical	375.8	119.7	4515	**PDX/2**	vertical	576.8	183.7	4923
PSX/3	vertical	1209.9	385.3	4775	**PDX/3**	vertical	255.7	81.4	5288
PSX/4	vertical	991.1	315.6	4719	**PDX/4**	vertical	626.7	199.6	5035
PSX/5	vertical	1106.2	352.3	4853	**PDX/5**	vertical	859.9	273.9	5078
PSX/6	vertical	3016.8	960.8	5295	**PDX/6**	vertical	1158.0	368.8	5206
PSX/7	vertical	1006.3	320.5	5086	**PDX/7**	vertical	808.3	257.4	5311
		ENTRANCE LEFT			**PDX/8**	vertical	706.8	225.1	5419
A/1	vertical	264.1	84.1	4762	**PDX/9**	vertical	85.6	27.3	4467
A/2	vertical	192.2	61.2	4638			ENTRANCE RIGHT		
A/3	vertical	139.5	44.4	4475	**D/1**	vertical	203.6	64.8	4908
A/4	vertical	226.5	72.1	4765	**D/2**	vertical	300.1	95.6	5069
A/5	vertical	155.0	49.4	4537	**D/3**	vertical	100.3	31.9	4710
A/6	vertical	91.3	29.1	3916	**D/4**	vertical	77.9	24.8	4281
A/7	vertical	118.4	37.7	4042	**D/5**	vertical	206.2	65.7	5592
		PAVILION LEFT					PAVILION RIGHT		
B/1	vertical	801.1	255.1	5076	**E/1**	vertical	674.3	214.8	5985
B/2	vertical	165.9	52.8	3942	**E/2**	vertical	124.2	39.5	4721
B/3	vertical	205.0	65.3	4587	**E/3**	vertical	167.2	53.2	5134
B/4	vertical	665.3	211.9	5023	**E/4**	vertical	938.9	299.0	5564
B/5	vertical	1845.8	587.8	5317	**E/5**	vertical	294.4	93.8	5418
B/6	vertical	115.1	36.7	4858	**E/6**	vertical	170.5	54.3	5226

B/7	vertical	661.0	210.5	5045	**E/7**	vertical	248.7	79.2	5237
B/8	vertical	816.0	259.9	5297	**E/8**	vertical	347.4	110.6	5100
B/9	vertical	143.9	45.8	4596	**E/9**	vertical	257.9	82.1	5178
B/10	vertical	229.4	73.1	4984	**E/10**	vertical	131.0	41.7	5094
B/11	vertical	62.9	20.0	4111	**E/11**	vertical	238.5	76.0	5348
B/12	vertical	324.1	103.2	5128	**E/12**	vertical	217.3	69.2	5146
B/13	vertical	625.3	199.2	5492	**E/13**	vertical	104.5	33.3	4879
B/14	vertical	461.1	146.8	5253	**E/14**	vertical	186.0	59.3	5077
B/15	vertical	600.0	191.1	5514	**E/15**	vertical	112.6	35.8	4817
CUBICULUM LEFT					CUBICULUM RIGHT				
C/1	vertical	26.1	8.3	**3718**	**F/1**	vertical	78.1	24.9	5059
C/2	vertical	32.2	10.2	4129	**F/2**	horizontal.	22.5		3677
C/3	vertical	31.9	10.2	4104	**F/3**	vertical	269.2	85.7	5004
C/4	vertical	25.0	8.0	4021	**F/4**	vertical	29.7	9.4	4072
C/5	vertical	34.5	11.0	4033	**F/5**	vertical	48.2	15.4	4546
C/6	vertical	32.4	10.3	4088	**F/6**	vertical	20.4	6.5	**3741**
C/7	vertical	141.0	44.9	5376					
C/8	vertical	407.3	129.7	4969					
C/9	horiziontal	28.7		4256					

Table 1. Illuminance, equivalent luminance and colour temperature of spectral irradiance measurements points

This effect is due to the optical properties of the painted indoor surfaces and precisely to their spectral reflectance. In order to evaluate how daylight spectral distribution is modified by the spectral reflectance of the surfaces, in Fig.7, diagrams of spectral irradiances measured in the two extreme cases are reported. So, in order to better investigate about this effect, by means of the spectrophotometer CM-2600d (Konica Minolta) the spectral reflectance of 16 samples including plasters, floors, coatings and decorations were collected, so as to describe the optical behaviour of nearly all the materials and pigments characterizing the surfaces. In Fig.8 the considered samples are shown, and in Fig.9 the spectral reflectance diagrams for eight of the sixteen samples are reported. As it can be observed, for all materials, spectral reflectance diagrams show an increasing trend with the wavelength, confirming that shorter wavelengths are generally absorbed more than longer wavelengths. This explains the fact that indoor daylight is characterized by lower correlated colour temperatures values (warmer light) rather than outdoor daylight. By processing spectral reflectance, it was possible to obtain the total reflectance under the Standard Illuminants A and D65. These are reported in Table 2. It is interesting to notice that, for all the samples, the reflectance related to the Illuminant. A always assume higher or equal values than those related to the illuminant D65. Equal values are attained for black surfaces (almost neutral). This is due to the already mentioned characteristic of all the analysed surfaces to absorb mostly short wavelengths of the visible range. The survey included luminance measurements as well. By means of a video luminance meter (Bellia et.al 2002; Bellia et al. 2003), luminance maps were obtained in correspondence of several points of view. Indeed, besides the already mentioned gradients of the adaptation luminance along the visit route, it must be noticed that, especially in presence of windows, for most of the considered positions of the observer, very high luminance contrasts occur. These conditions produce visual discomfort. Specifically, 21 luminance maps were analysed, the results of 12 of which are reported in Figs. 10 and 11. For each luminance pattern, the average luminance Lav was calculated by weighting the measured values according to the apparent areas; then the maximum value Lmax was considered and the ratio Lmax/Lav. This ratio is particularly significant because it represents how much the maximum luminance value, in the visual field, exceeds the average one, considering that, on increasing this ratio, the discomfort effects increase.

Fig.8. Pictures of the samples taken into consideration

Num.	Sample Name	ρ(A)	ρ(D65)
1	YELLOW 1	37	33
2	RED 1	10	9
3	BLACK 1	10	9
4	WHITE	65	63
5	BROWN	17	16
6	BLACK 2	5	5
7	RED 2	12	11
8	BLACK 3	8	8
9	PINK	21	19
10	RED 3	14	12
11	YELLOW 2	24	21
12	RED 4	12	10
13	WHITE FLOOR	43	42
14	RED DECORATION	19	16
15	BLACK FLOOR	13	13
16	WHITE COLUMN CLADDING	56	54

Table 2. Total reflectance factors

Assuming that in indoor spaces, for comfort purposes it is generally suggested not to exceed luminance ratio of 10:1, from the analyses reported in Figs. 10 and 11, it appears evident how most of the values are higher than 30 and in five cases they are higher than 100, demonstrating the presence of very critical visual conditions. Figure 12 shows the detailed luminance maps, represented in false colours, for the main room of the left dieta (view 1) and one of its cubicula (view 4). Both of them present an excessive luminance range and reveal the necessity of specific interventions for a correct and comfortable perception.

5. Discussion and Conclusions

This contribution was written to illustrate the methodological approach used to enhance the archaeological site of Villa San Marco in Castellammare di Stabia. From the photometric and spectroradiometric surveys it came out that currently, without any lighting installation in this archeological site, many problems occur. Indeed, the main issues are related to the illuminance and luminance gradients that, in many cases assume excessive values and compromise the correct perception of the spaces and their work of arts. More in detail, it can be observed that some rooms, as the cubicula, receive insufficient daylight whereas other spaces, as in the porches and in the dietae, are characterized by excessive illuminance values and contrasts.

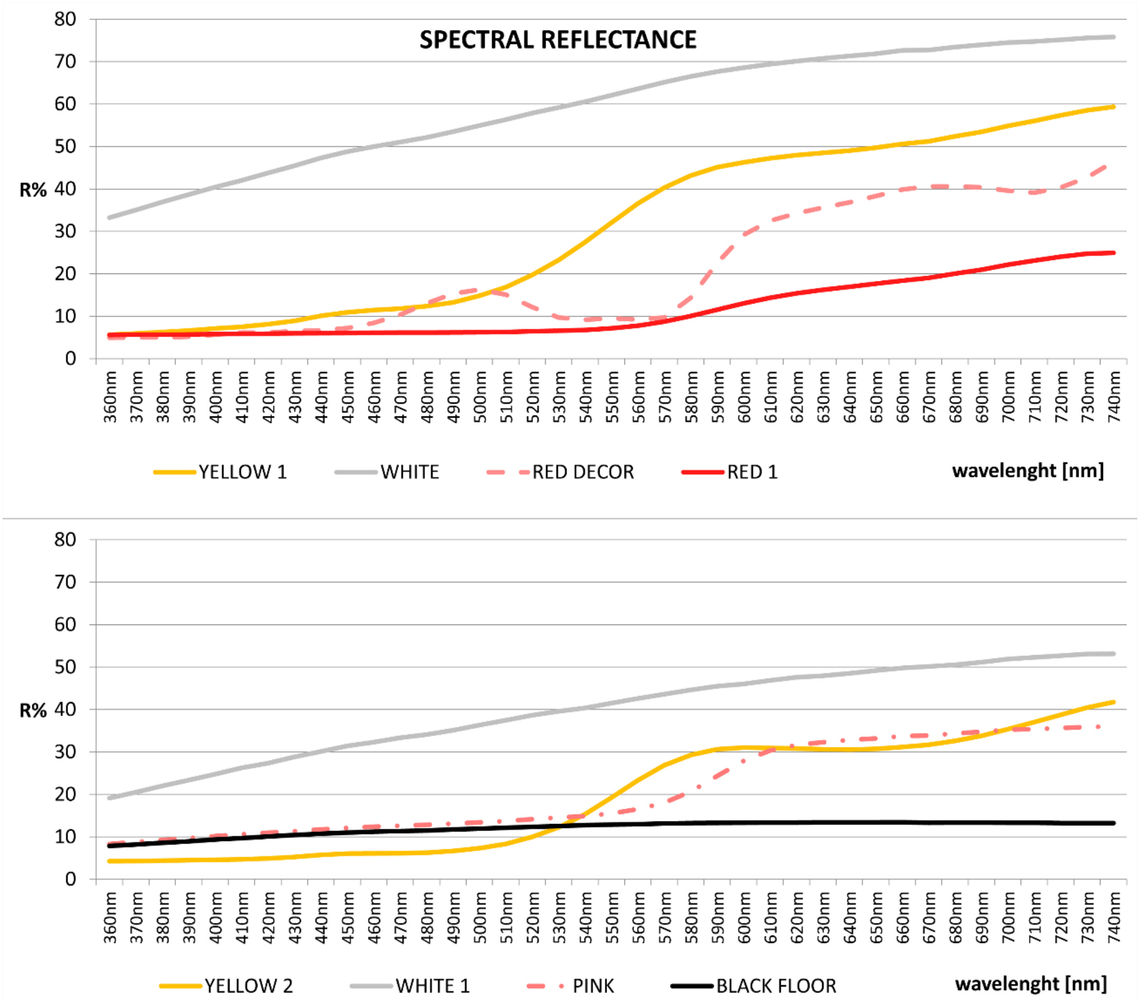

Fig. 9. Spectral reflectances of eight of the sixteen samples

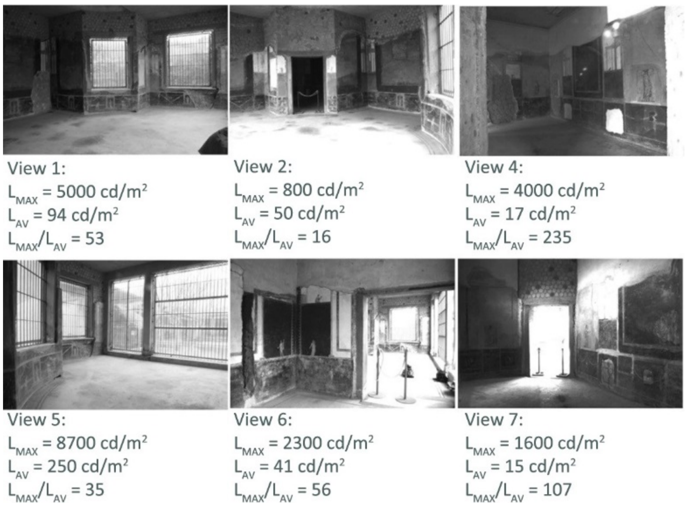

Fig. 10. Images of some views with luminance data and ratios (left spaces)

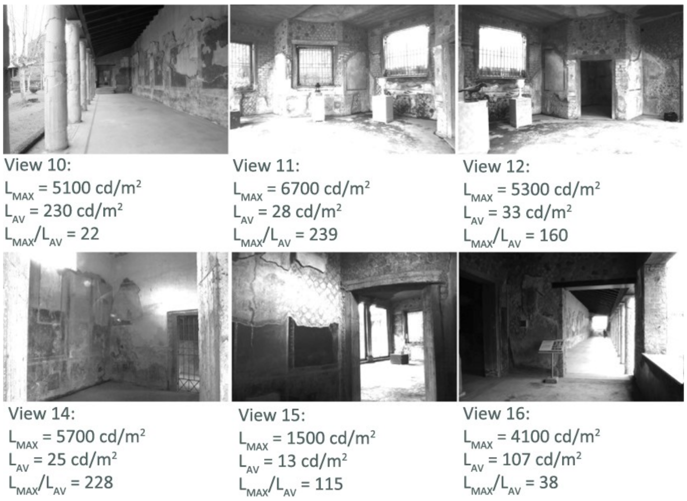

Fig. 11. Images of some views with luminance data and ratios (right spaces)

From the obtained results, the necessity of a proposal of intervention outcomes, both for limiting the daylight access in some spaces and for integrating the insufficient light in others. The former aim can be addressed by installing proper shading systems, while the latter by installing proper lighting systems. Both of them should be removable, flexible and well-integrated in the archeological context.

However, considering the daylight variability during time, in order to propose the most effective solution, further research is required. Indeed results obtained by the measurements survey will be useful to calibrate input parameters for lighting calculation software and to validate the model, in order to perform dynamic and static daylight simulations (Reinhart et al, 2006; Nabil and Mardaljevich, 2006). Results from dynamic daylight simulation will be useful for the assessment of the potential damage to the paintings produced by radiation (especially the direct sunlight), for the choice of the most effective light control strategies (lighting and shading fixtures) and also for the evaluation of energy consumption due to electric light. On the other hand, static simulations, performed in different typical conditions will be useful to help light designers in making the most proper choices in integrating daylight and electric light for a perfect fruition of the site. Furthermore, spectral reflectance of materials will be necessary for the design of the most appropriate Spectral Power Distribution of the light sources, considering also the daylight contribution when present (Schanda et al. 2015; Di Salvo S., 2014).

In conclusion, our dual goal was to not only enhance the heritage of frescoes and improve perception and fruition by tourists, but also safeguard the original chromatic features and ultimately protect them from direct sunlight, where necessary. After this experimental study on part of the site and the acquisition of data from just one instrumental lighting survey – which obviously requires further research – any further developments will provide visitors with a variety of scenarios in an archaeological context which, although ready to be compared with contemporary, adjacent sites and situations, presents its own unique characteristics that deserve a much broader cultural focus based on solid technical and scientific knowledge.

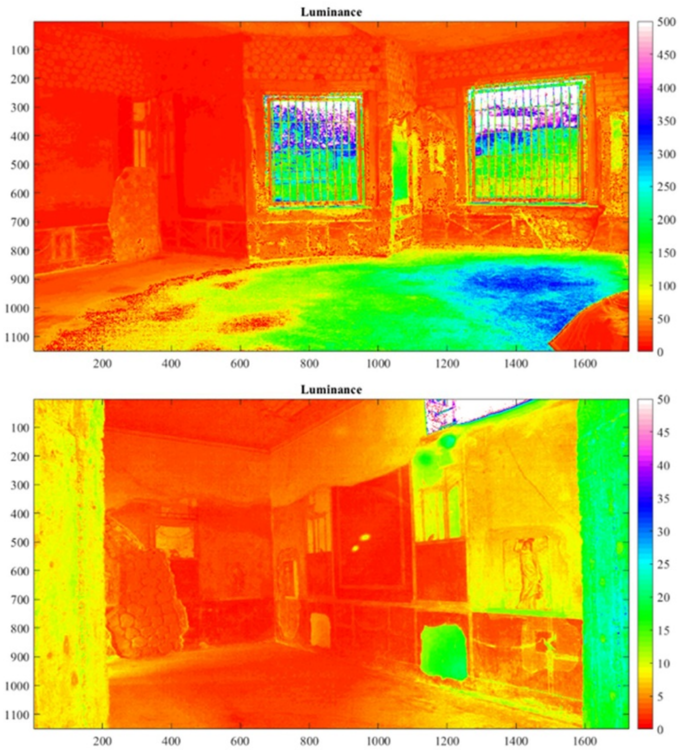

Fig. 12. Luminance maps in false colours referring to view 1 (above) and view 4 (below)

6. Conflict of interest declaration

The authors declare that there is no conflict of interest with other people or organizations.

7. Funding source declaration

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8. Short biography of the author(s)

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Laura Bellia - MSc, PhD is full professor of Lighting and Building Physics at the University of Naples Federico II, Italy. Her research's topics and interests include lighting, daylighting, smart lighting systems and automatic controls, lighting quality, visual comfort, glare, non-visual effects of lighting as circadian effects, LED sources. She leads national research programs about indoor lighting quality and daylight harvesting. She cooperates with European Universities both for research and students' exchange purposes.

Pierpaolo D'Agostino - Engineer, is associate professor at University of Naples Federico II, involved in investigations concerning design, survey and digital representation in architectural, urban and environmental issues. He is author of over forty scientific papers, many of which signed, often autonomously, in several national and international editorial publishers. He is also author of monographic work about, above all, solar shading design in architecture and railway stations.

Gennaro Spada - MSc in Mechanical Engineering on 27/11/2000, PhD in Thermal-Mechanical Systems in 2004, his final dissertation dealt with videography applied to luminance measurements. At present he is technical responsible of the Photometry and Lighting Laboratory at the Department of Industrial Engineering of the University of Naples Federico II. He performs scientific and educational activities related to lighting.

Giuseppe Antuono - Engineer, PhD in History, Design and Restoration of Architecture (XXX Ciclo, Curriculum Design, SSD ICAR/17), carries out research at the Department of Civil, Construction and Environmental Engineering in the field of architectural survey and documentation complex of historical, urban and environmental interest, with integrated methodologies and with attention to the management and implementation of geographic information systems. Participate in national and international conferences with written contributions and communications.

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