The "ID card" of ancient materials: spectral signature, colour and thermal analysis. A tool for the monitoring and conservation of the archaeological heritage

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This work introduces a methodology for characterising and representing the properties of ancient materials and structures. The results achieved are here presented for the artefacts of the archaeological site of Ancient Ostia, near Rome, which is the first case study on which the implementation of our study on the properties of ancient materials begun. The measurement techniques are non-destructive techniques for "in situ" measurements, and are based on a portable spectroradiometer and a portable infrared camera. Collected data are then processed to produce the appropriate tabs for describing the optical-visual properties of materials investigated. The final aim of this work is to produce an atlas of the properties of ancient materials, whose aim is to fill a gap of knowledge, but also to create a system for the detection and control of any kind of degradation that such materials may have in time owing to natural and/or incidental causes, and for assessing the quality and durability of the interventions of conservation in archaeological sites as well. The tabs describing the properties of materials could also be considered an useful tool for an approach to the design of lighting systems, design that should be "conscious" of the reality of the archaeological sites, on one side, and of the needs for security and safety, on the other side.

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Introduction

The characterisation and the classification of the state of conservation of ancient materials have recently gained some relevance, especially in relation to the possibility of studying and monitoring their state of conservation and degradation.

The analysis of the state of degradation of ancient materials is often performed by experts at "naked eye", through a careful but exterior observation that permits to describe the state of conservation of the object, limiting the study of the type of damage and accessibility of the surface of the material to what is visible. This approach is generally linked to the lack of instruments and economical resources, or to the pressing necessity for works of conservation required by the objects, or more in general by the site.

One of the major problems in this field is to document the condition of an asset testing its changes over the time [1]. The definition of a methodology that allows to detect and to follow over time the state of conservation and any kind of evolution of the degradation is an increasing need for archaeologists and experts. And this is especially true if we think to the great relevance of our cultural heritage, and to the lack of financial measures available. These needs are leading to fast diagnostic monitoring activities, as economically sustainable solutions that help in realizing the plans for programmed maintenance inside archaeological areas [2].

The (visible and non visible to the eye) techniques for the survey of degradation and the identification of its causes are the necessary terms of reference for a correct planning and for the organization of the intervention of programmed maintenance and recovery.

The causes of the degradation of materials are of multiple nature, like the natural aging of the constructive materials, the poor maintenance, the incongruity of the physic-chemical, qualitative and resistance properties of the materials [3-5].

It is believed that the spectral reflection factor is a good indicator of the state of conservation of an asset [1]. In this context, in fact, the colour and spectral reflection measurements carried out with “portable” tristimulus colorimeters, spectrophotometers and spectroradiometers can represent a good solution and a help for the diagnosis and the study of the evolution of the degradation of historical and artistic materials [6,7].

Generally, however, the features of colorimeters and spectrophotometers are defined to satisfy the needs of most of the measurements required in the industrial field. But the use of these instruments is excluded when the object cannot be touched, and especially when the surface of the object is not uniform and sufficiently extended. Measurements anyway can be easily developed especially in the case of delicate surfaces with a spectroradiometer, without any direct contact between the surface and the instrument. In particular, from this point of view the spectroradiometer offers other interesting and practical advantages, such as:

- The opportunity to change the controlled area, that in the traditional portable spectrophotometers is generally fixed: this feature allows to perform measurements on very small areas (up to 0.45 mm of section with the macro optical group).
- The possibility to control the exact point where the measurement is performed, by implementing a correct and repeatable positioning of the instrument, thanks to the reflex system of the instrument [6].

In literature, some results have been shown, and they appear to be reliable especially if compared with the measures taken by traditional colorimeters. This is why nowadays the spectroradiometer is considered an optimal alternative to the traditional instruments [2] for “in site” measuring.

Another important and generally used non-invasive diagnostic method is represented by the infrared thermography, which allows the acquisition of information through the survey of the energy irradiated in a specific field of the electromagnetic spectrum, characterized by wavelengths between 3 and 14 μm. The thermography is a already established technique in the field of archaeometry and of the study of monumental architecture, although the acquired data by thermal cameras are not always of immediate interpretation [8].

An integrated methodology of analysis, supported by a careful philological and critical analysis of the asset, may be able to put in evidence not only the essential information to the practical operating of the experts of restoration, but it can also represent the basis for introducing a tool for a knowledge based approach to ancient materials, capable of making possible an “aware” design of lighting installations of archaeological sites, with the aim of making them accessible to the public during the night (for cultural events or just for visits) [9,10], while preserving them from damage.

The present work has the aim to implement a methodology for the preservation and restoration of the cultural heritage which is able to produce informative cards for the ancient materials, starting from the elaboration of the graphical and numerical information obtained through experimental spectral optical techniques. The capabilities and the feasibility of the proposed methodology is also discussed. These cards are of simple consultation by the experts, but also by non-experts in this field as well. The proposed cards shall be a support to the identification of any degradation that may be caused over time for natural or accidental causes, and for the evaluation of the quality and durability of the measures taken for conservation [9-11].

Materials and Methods

In this paper, we examined different types of materials located in the ancient archaeological site of Ostia Antica: tuff, brick, plastering, travertine, marble and basalt. The spectral and visual characterization of these materials was obtained by using a portable spectroradiometer together with a infrared camera, and by mixing the collected data.

The spectroradiometry allows to study numerically the relation between the incident radiation and the optical properties of materials by measuring their reflective properties (reflectance). The values of reflectance are obtained as a function of wavelength (λ), and their trends, in a determined range (the visible interval) of wavelengths. The energy detected by the instrument is converted into a digital signal that is processed to define the spectral signature and the chromaticity (Figure 1) of a particular material [12].

When considering ancient materials, this aspect becomes still more complex, because the analyzed areas are highly irregular and corrupted. And thus reflection parameters too are highly variable from point to point on the same type of material and surface.

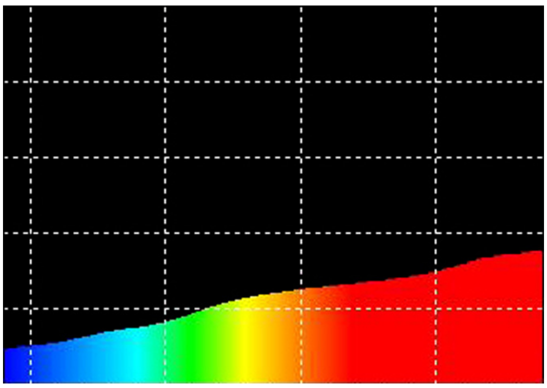


Figure 1: The spectral signature of a piece of brick.

The thermography acts in a different way: it is based on the principle that anybody, with temperatures higher than 0 K, emits radiations in the infrared band. In accordance with the Wien's law, the wavelength is closely related to the absolute temperature of the radiating source and its emissivity.

The energy emitted by the source, is the evidence of the energetic state of the material, and it can be detected at a distance and used in order to define its thermal distribution. The information of this survey method are expressed by a "thermal image", that is a thermal photograph of the tested material obtained through the elaboration of optical signals captured by devices sensitive to the infrared radiation (Figure 2).

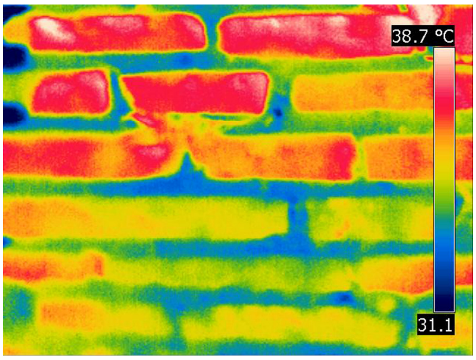


Figure 2: The thermal image.

The comeback images are in black and white or in false colours, where the scale of gray or the shading of colour are closely correlated to the temperatures of the examined objects.

The here proposed methodology is based on the development of a series of steps for the definition and characterisation of the materials:

- the study of the provenance, composition and processing of the materials;
- the selection of both the original and restored parts of the material suitable to be measured (operated with the help of archaeologists);
- the selection of the most accurate grid of measurement points.

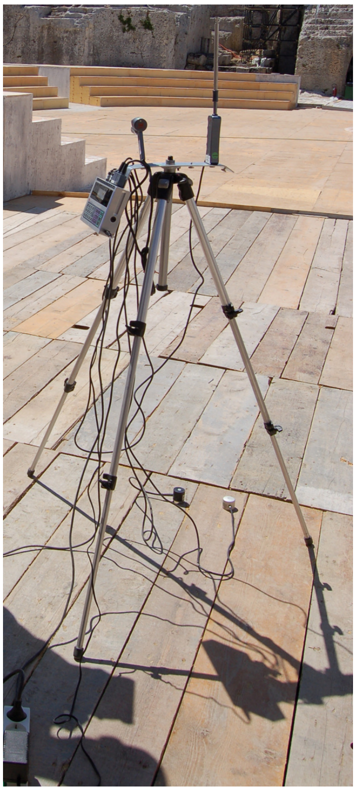


Figure 3: The BABUC acquisition system.

This phase has been supported with photo images with reference shoot points in order to accurately report all the data for every single sample and point examined. To have a complete description of the measurement conditions, the environmental data too were collected through the BABUC acquisition system (Figure 3). The system recorded global and diffuse irradiance data, global and diffuse illuminance data, wet and dry bulb temperatures, air speed and relative humidity.

The measurements on materials have been carried out with a portable spectroradiometer CS 1000 A Konica Minolta (Figure 4) with a 50mm macro lens specifically dedicated to the shooting of very small areas with a 0.45 mm diameter, able to assure reliable data at a distance that varies from a minimum of 40 cm to a maximum of 2 meters from the surface. The reference illuminating setting is the natural light, classified as CIE D65 (daylight 65, approximate colour temperature, 6500 K). All measures have been carried out after the instrument calibration for each type of material, by the use of the appropriate calibration plate placed perpendicular to the lens of the spectroradiometer. For every sample studied, measures have been repeated a sufficient number of times in order to reduce possible errors due to the variation of lighting conditions, as well as random errors made during the execution of the measures.

The properties of materials in the field of infrared wavelengths were determined with a thermocamera FLYR (Figure 5).

Figure 4: The spectroradiometer Minolta CS-1000A (left).
Figure 5: The thermal camera FLYR (right).

Results

The reconstruction of the spectral signature of every single material was possible thanks to the use of a special calculation software from which we obtained information about the reflection properties of materials in function of the wavelength of the incident radiation and basing on the CIE standard observer (2°) 1931 colorimetric functions. The average coefficient of spectral reflectance of each material has been then evaluated by analytical calculations. Finally, all the data obtained have been collected and organized in a ID card of the material (Table 1), characterized by a series of descriptive and technical information. An ID card of the material presents the following form and information, useful to technicians, archaeologists and people in general:

a. photographic images indicating a grid of measure and the points of measure, in particular on the single material and in general terms on the whole portion taken under investigation
b. a table showing the overall environmental data when the measures have been taken (date, timetable, instrument settings, etc.)
c. relative numerical data of trichromatic coordinates, luminance, radiance and colour's purity, colour temperature and the values of the dominant wavelengths
d. graphs of the spectral reflectance
e. colorimetric diagrams (CIE 1931)
f. average reflectance of the material
g. information about the ancient material (building system, origin, etc.)
h. thermographic image of the ancient material with the relative reference data

The ID card gives a deep knowledge of the ancient material in order to assure a suitable conservation. More, if the object suddenly suffers damage, it could be an instrument for the restoring of the damaged material.

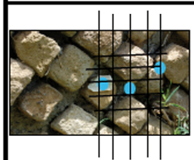
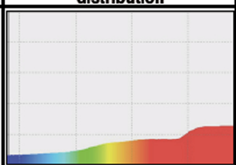
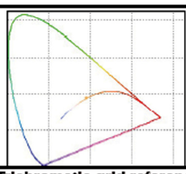
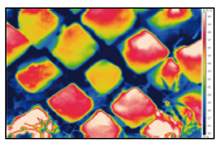
Card n.1	TUFF					
	Structure	Grain	Colour	Techinical element	Typology	
	Granular	medium	beige - light brown	Vertical elevation structure	Tuff-wall	
CHARACTERISTIC PROPERTIES OF THE MATERIAL					ENVIRONMENTAL DATA	
Grid	Shot point	Spectral reflectance distribution	CIE diagram	Infrared image	Hour	
					11,30	
Building technique		Dominant wavelenght	Trichromatic grid reference	Emittance	Rdiff	Rtot
masonry with external finiture in tuffblock		580	X= 1294 Y=1302 Z= 8196	0,92	81	881
Building age		Luminance	Colour purity	Thermal conductivity	Ediff	Etot
I century a.C		1058 E05	33,11	0,93	7660	77570
Dimension		Medium reflectance	Colour temperature		Valr	HR
about 10 cm		14,509	4064		0,63	61,5
POSSIBLE TYPOLOGY OF DECAY					Twb	Tdb
Little fracture, little break, humidity, superficial changes					23,45	18,66

Table 1: An example of material's ID card.

The possibility of using the data in Table 1 for an efficient lighting design makes this approach also useful for introducing a tool for the lighting design of archaeological environments and sites. The collected information allow to perform simulations with lighting software through data input related to reality of the environment. It is possible to choose the best technological solutions that are able to

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create the proper atmosphere without altering the visual condition of ancient materials. Last, the results of the simulations are reliable thanks to the use of the real reflectance data, consequently allowing to test among several choices of luminaires' typologies, assuring a good technological efficacy and a compatible integration that not modify the state of conservation of the archaeological heritage.

Conclusions

This research concerns the study and the analysis of optical and physical properties of materials through the use of a portable spectroradiometer. The aim is to introduce a methodology for the diagnostics and the investigation of cultural heritage. Because of its "not-invasive" properties, this technique is a good alternative to the traditional instruments that require a direct contact with the surfaces to be examined, especially for the cases in which it is not possible to put the instrument close to the surface of the material. After the characterization of different types of materials, and after considering all the parameters involved (colorimetric values, reflectance, etc.) the information have been collected and organized in an orderly and simplified card that can be quickly and easily looked up. Each ID card contains and is able to provide all the information about a specific material, so that an evaluation of the state of conservation/deterioration can be carried out in a very simple way. By this way it will be possible to organize and plan restoring interventions. Moreover, this method could be very useful in the lighting design of archaeological areas.

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