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Original article

Semiautomatic detection and classification of materials in historic buildings with low-cost photogrammetric equipment

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ABSTRACT

The detection of materials and damage in building facades by means of near-infrared digital images is not a widely explored field in architectural research, especially in rehabilitation and historic building surveys. The aim of this work is to study whether spectral classification image methods, which are frequently used in remote sensing land applications (non-contact geophysical techniques), could be applied in the architectural field to detect various construction materials in historic building facades by means of low-cost photogrammetric equipment. Several classification methodologies were applied to different image band combinations, which led to the conclusion that the highest accuracy is obtained with a multiband image composed of visible and near-infrared bands. We also performed a derived measurement of the real surface of the facing material, demonstrating that low-cost instrumentation could be useful in architectural interventions in cultural heritage to identify construction materials in a non-destructive way.

1. Introduction

Historic buildings are particularly valuable constructions in cultural heritage. Non-destructive techniques are suitable for a detailed study of physical characteristics, such as material composition, pathology, and many other physiognomies in these singular and delicate buildings without damaging the heritage.

Remote sensing classification is a non-contact geophysical technique based on the reflectance of objects gathered in digital sensors. Usually, the sensors are placed in satellites and will detect solar radiation reflected by the earth's surface along the electromagnetic spectrum (reflectance). The sensor captures spectral information in an extra-visible range, generating a wide spectral image with wavelengths ranging from ultraviolet to infrared. The different physical response of the Earth's objects is the basis of their classification.

Even though sensors are traditionally assembled in airborne devices, any terrestrial digital photographic camera could be used to detect the physical composition of objects. Consequently, multispectral or hyperspectral terrestrial cameras have been used for multiple purposes [1–3].

In the context of using the near-infrared spectrum in remote sensing, it is important to focus on studies in archaeology, history, archaeological excavations, and cultural heritage, especially paintings, including those on ancient walls. In these cases, the sensors used are cameras closely located to the object studied and configured to obtain information beyond the visible spectrum. The investigations of Atlas et al. [4], Sfarra et al. [5] and Cosentino [6] are examples of applications of this method in the painting field, and the research of Fiumi [7] and Rogerio-Candelera et al. [8] shows applications of this method in the archaeological area.

Other methods based on the infrared spectrum have been widely developed and tested [9,10]. Infrared thermography is a non-invasive tool that can realize fast and accurate building diagnostics. In this context, researchers such as Imposa [11], López et al. [12] and Lerma et al. [13] have been looking for new applications of thermography in the architectural field. In the area of the recognition and detection of damages in construction, this system is particularly interesting as it allows an easy location of diverse pathology. In particular, thermal infrared cameras have been frequently used for the detection of materials and damage in historic building facades [14–16], and in the case of Sfarra et al. [17], an innovative hybrid thermographic (HIRT) approach is presented combining both the time component and the solar source to obtain quantitative information of historical buildings. Increasing interest in energy savings in new or old buildings has also led the development of thermal infrared cameras that can distinguish temperatures in an object's surfaces [18–20]. Therefore, it is quite easy to identify calorific gains or losses in building envelopes and propose appropriate solutions.

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Fig. 1. Aerial view of Cáceres. The location of the Episcopal Palace.
Adapted from the aerial images of The National Cartographic Institute of Spain.

Nevertheless, our non-destructive proposed method, based on near-infrared spectrum images (not thermal), has not been widely explored in the scope of architectural research, particularly in terms of rehabilitation and historic building surveys. Among the few studies related to the subject are those of Lerma [21] and Del Pozo et al. [22]. Other authors, such as Hernández-López et al. [23], suggested that low-cost digital reflex cameras with different spectra such as visible and near-infrared are effective for cultural heritage recording. Previous studies also point to the suitability of the system for facade studies, in which several materials are identified in the walls of different churches, but these investigations were not conducted in any depth [24,25].

2. Research aim

The principal aim of this work is to study whether spectral classification image methods, usually employed in remote sensing of the Earth's surface (land applications), that use non-invasive geophysical techniques could be applied in the architectural field to detect construction materials in historic building facades by means of low-cost photogrammetric equipment (digital reflex camera and near-infrared filters).

The specific objectives are as follows:

- determine whether the inclusion of a near-infrared spectrum in the visible one of digital photographic images is favorable for material recognition in historic building facades;
- ascertain if the proposed methodology identifies different states of the same material. For instance, different surface finishes, textures, shades, surface primers, etc;
- consider whether the classification methodologies can automatically recognize some type of damage or pathology that has not been previously observed, in particular, those that cannot be detected by the human eye;
- confirm whether the proposed method is able to perform measurements on the surface of the studied facing materials with enough accuracy.

3. Materials and methods

3.1. Cáceres Episcopal Palace

The Cáceres Episcopal Palace is located in the UNESCO World Cultural Heritage Site of Cáceres (Extremadura, Spain). It was selected among others because it enjoys geometrical simplicity with no protrusions, and there is a clear and open space around the main facade. The building dates from the Gothic-Renaissance period and is in the ancient, walled city. It stands on Saint-Mary's Square next to the cathedral and extends to the city battlements, as shown in Fig. 1.

According to Lozano [26], construction began in 1261 when the episcopal houses were located in this area of the historic city. Later, in 1418, Coria's bishop, Frey García de Castromuno, built the western part and the tower in the gothic style. Finally, in 1544, Hernando de Ovando's house was added to the palace. The work ended in 1587 as the inscription in the facade shows. A study by Campesino [27] concluded that these works were in response to several reforms inside the villa executed by the ruling class in the fifteenth century, and more took place in the sixteenth century. In later centuries, no significant changes occurred in the property, other than minor alterations either because of use or because of necessary maintenance (Fig. 2).

Episcopal Palace is an urban palace with an irregular gothic plan, looking quadrangular shape because of later expansion works. It consists of two storeys, a defensive tower at one end of the plot, a peristyle courtyard, and a cistern, which was used as an impluvium tank to collect and store rainwater. Its formal composition denotes a markedly defensive palace.

The structure is based on load-bearing walls, except for the columned courtyard. Facades are formed of ordinary masonry walls of quartzite rock. Granite ashlars are at the corners and openings, which confer stability and regularize the masonry. Brick vaults constructed without falsework (typical of this area) and wooden slabs of beams were used for the horizontal structure.

The main facade is oriented to the southeast, and it faces Saint-Mary's Cathedral. Renaissance elements predominate. The most prominent feature is a high semi-circular front door with several ornaments [28]. There are two windows with a finely carved grid