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Original article

# Surveying the roofs of Rome

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ABSTRACT

This study is aimed at investigating a portion of the city of Rome by means of remotely sensed Multispectral Infrared And Visible Imaging Spectrometer (MIVIS) data. A particular attention was devoted to building roofs described not only as the last defining touch given to a building, the aesthetic conclusion to a whole construction process, but also as expression and sign of a society's level of civilisation, culture and technical skill. Through the classification of objects and materials, we propose to combine history and science as different ways of interpreting a city, in this case Rome, and to implement an image processing technique as an effective tool in urban planning.



## 1. Research aims

The main research aims of the work are:

- surveying the roofs of Rome through the processing of remotely sensed Multispectral Infrared And Visible Imaging Spectrometer (MIVIS) data;
- combining history and science as different ways of interpreting a city, in this case Rome;
- analysing the distribution of objects, materials and construction techniques in space and time, with special reference made to the continued use of a few materials in different historical eras;
- implementing an image processing technique as an effective tool in urban planning actions for the promotion of environmental sustainability – to be used for the time being in view of the future development and introduction of new technologies and sensors.

## 2. Introduction

The term "roof" properly indicates the covering on top of a building, the structure forming the upper waterproof finish, serving to protect against rain, snow, sunlight, wind, and extremes of temperature and which can be constructed in a wide variety of forms (flat, pitched, vaulted, domed, or in combinations, depending upon technical, economic, or aesthetic considerations) [1].

Since the most remote ancient times, this term was referred not only to the need for protecting people and their possessions against bad weather, but also to the concept of "shield", "shelter", "refuge", designed to express something more than a technological unit. This is a metaphor of dwelling, which evokes and designates the home itself, becoming an integral part of the building envelope [1]. In fact, the Romans generally referred the term "*tectum*" to their homes roofed with curved clay tiles (imbrex and tegula).

The Italian historian Giorgio Vasari defined it as an essential part of the overall image of a building, the harmonious and calibrated summation of a style, as intrinsic to it as the basements, the window and the *façade* [2].

Another key to understanding this feature is provided by Guido Nardi. He argues that roofing styles are one of the most universal signs adopted by human beings to define how they belong to a particular place [3]. In this connection, he cites a passage from an essay by Oliver Marc, [4], in particular *if a house in its totality can be understood as an image of the Self, the roof represents the spirit in its aspiration to unity or its fidelity to origins.*

In the Mediterranean countries tiles and bricks represent one of the oldest roofing materials used for building roofs. Their origins are deeply rooted in the need to waterproof flat roofs, commonly used in the ancient Egypt and all over the Middle East.

During the Renaissance, the great aristocratic families of Rome used to build opulent dwellings. According to Vasari, their characteristics with reference to roofs (materials and methods used) drew on the wealth and power of the Italian courts, the technical-scientific power of humankind over nature, roofs as the worthy conclusion to and correct proportioning of buildings [2]. They are emphasised by making them jut out beyond the supporting walls.

From the early 16th century into the Baroque period, a *hidden* style of roofing became widely used, and balustrades were often mounted above cornices that crowned the entire building [5].

In Europe, the city's ever-growing population and, as a consequence, the new dwelling requirements boosted architects to plan,

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starting from the mid-19th century, a particular kind of roof called mansard. This word is derived from a French architect, F. Mansart. It is a roof having two slopes on all sides with the lower slope steeper than the upper one [1].

At the beginning of the 20th century, with the Rationalism, the links to history gradually weakened, and the flat roof appeared alongside, and contrasted, with the traditional pitched roof. Le Corbusier is among the most important exponents of this new architecture in a rationalist and functionalist vein.

Nowadays, we can choose from a wide variety of "roofing systems" according to the geometrical morphology of land surface, structure construction methods and materials used. Nevertheless, in addition to the new technologies that have led to the introduction on the market of new roof coverings made of light, opaque or transparent materials, offering sometimes impressive decorative solutions, such as corrugated iron roofing sheets, fibre-cement sheets, polycarbonate or textile fibres, the use of a few materials such as tiles and bricks has persisted. However, the increasing attention to environmental sustainability issues has led to use roof coverings made of natural or environmentally friendly materials.

## 3. Urban remote sensing

The aforementioned introduction is a necessary prelude to a more detailed inspection of the roofs of a segment of Rome, expression and sign of a society's level of civilisation, culture and technical skill. This is as true today as ever.

Today, in Europe nearly 80% of the population lives in urban areas and, at world level, this percentage is equal to 50% [6–9]. In urban areas, remote sensing is still scarcely applied, however, prospectively, its potential of application is particularly important and potentially permits an analysis never carried out so far at such an operative level [10–12].

The images taken by MIVIS over the city of Rome allowed us to observe the city from above, to discover forgotten corners of the urban landscape, where historical squares, domes of churches, and in particular building roofs, can be easily identified on the basis of their geometry, colours and materials. A simple comparison between aerial photographs taken at a few decades' distance suffices to demonstrate how the use of the soil has changed over the years, to assess the impact of such change on the territory and the surrounding environment and, therefore, to forecast the future growth dynamics, with the further opportunity to devise sustainable development models based on a fair trade-off between urban expansion and environment conservation [11,13,14].

Nevertheless, it is not always possible to obtain a detailed analysis to accurately identify objects and materials within urban areas because of spectral resolution limits [15–18].

Indeed, with the technological advancement of satellite systems, recent satellite sensors now produce exceptionally high-resolution satellite images in a highly detailed scale (e.g., a pixel with a ground definition of a few centimetres). On the contrary, the spectral resolution, meaning the possibility to extend the survey simultaneously on different portions of the electromagnetic spectrum to improve the recognition of surfaces under study, still remains unresolved [19,20].

The spectral resolution commonly refers to the number of bands that comprises the range of spectral sensitivity of the system. This expresses the ability of a system to distinguish two adjacent wavelengths to best separate spectral characteristics (recognition) of surfaces, overcoming those situations where their behaviour is very similar and ambiguous and, therefore, difficult to be detected. For this reason, hyperspectral remote sensing is a major expanding sector [16,18–21].

To this aim, the Daedalus AA5000 MIVIS instrument, acquired by the Italian National Research Council (CNR) within the framework of its LARA (Airborne Laboratory for Environmental Research) project, has been intensively operative [21]. A number of MIVIS deployments have been carried out in Italy and Europe in cooperation with national and international institutions on a variety of sites, including active volcanoes, coastlines, lagoons and oceans, vegetated and cultivated areas, oil polluted surfaces, waste discharges, and archaeological sites [9]. MIVIS is a modular scanning system constituted by 102 spectral channels that use independent optical sensors simultaneously sampled and recorded within the interval comprised between 0.433 and 12.70 $\mu$m (Table 1). This instrument, with four spectrometers designed to collect radiation from the Earth's surface in the Visible (20 channels), Near-IR (eight channels), SWIR (64 channels), and Thermal-IR (10 channels), represents a second generation imaging spectrometer developed for its use in Environmental Remote Sensing studies across a broad spectrum of scientific disciplines.

In addition to a very high spectral resolution, MIVIS also provides a high spatial resolution, with a pixel of 3 m $\times$ 3 m. This allows a detailed analysis when urban objects are to be identified and, in particular, when covering materials such as tiles and bricks, marble materials, asphalt, lead, copper, asbestos-cement, vegetated areas, bare soils are involved. The assessment of the potential of thermal channels (8.2–8.7 $\mu$m) allowed us to deduce considerations on thermal performances related to objects and materials. The study carried out by Fiumi and Rossi [22] over the city of Rome has given a strong emphasis on the potentiality of MIVIS data for analysing the degree of soil permeability in the urban setting.

In this respect, the results obtained in the classification of hyperspectral data have shown the great potentialities of these tools applied to urban areas, complex situations with a high degree of fragmentation [9,11,12,15]. However, some key issues, such as the economic ones that could limit their use on a large scale, still remain unresolved. This has led the civil community to use less expensive technologies, which are very attractive also for systematic monitoring of the territory such as UAVs (Unmanned Aerial Vehicles). To cite only a few of the advantageous features of UAVs [23], these include:

- their flight performance: UAVs can operate in a wide range of operational altitudes (from 100 m to over 30,000 m) and have an elevated range of endurance (1–48 hours);
- their adaptability to various typologies of missions (e.g., in remote areas);
- their inexpensiveness.

However, several prerequisites must be satisfied to render UAV technology a viable, cost-effective and regulated alternative to existing resources. Major civil barriers include: the high costs of

**Table 1**
Multispectral Infrared And Visible Imaging Spectrometer (MIVIS) sensor technical details and spectrometer characteristics.

| Spectrometer | Spectral regions covered by the sensor | Range ($\mu$m) | Channels | Bandwidth (mm) |
|---|---|---|---|---|
| I | VIS (Visible) | 0.43–0.83 | 20 | 20 |
| II | NIR (Near infrared) | 1.15–1.55 | 8 | 50 |
| III | SWIR (Short-wave infrared) | 2.0–2.5 | 64 | 8 |
| IV | TIR (Thermal infrared) | 8.2–12.7 | 10 | 450 |