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Remote sensing analysis on Rome's squares

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Abstract

This work aims to contribute to better understanding the use of public street spaces. This paper presents the results of a research activity aimed at studying urban areas by means of remotely sensed data acquired over the city of Rome. This work regards Roma's Squares, a crucial element in the history of settlements and a best appropriate place not only for the study of urban development, but also for economic, social, functional and ritual. A remotely sensed pictures shot on the center of Rome (12.15 km^2), allows us to examine the reasons why some squares in the city of Rome gained their representative and monumental character. We tried to classify the elements and materials for a comparative analysis through an original approach to remote sensing data. The remote sensing data of Rome were classified using the Spectral Angle Mapper (SAM), algorithm. The technology is rapidly evolving, the new sensors have now better spatial and spectral resolutions to analyze that were unthinkable until recently. This allows us to demonstrate innovatively how to characterize and quantify the roofing surfaces and also to issue considerations on the aerial view of the city and some squares. Furthermore, through the historical reading, an attempt was made to interpret the dynamics of current use, trying to identify some critical issues in progress. The purpose was to issue a real code use to interpret the life that now and then takes place in the squares and spreads throughout the world.

1. Introduction

The word Piazza (latin: platea "broad street" greek: "plateia") indicates a free public space, surrounded by buildings [1].

Over the centuries, squares had served to different purposes basing on current needs of locals and the common feeling of the period. Some of these functions described by Garau [2], such as the exchange of goods, are still in place, while others have been lost (execution of capital punishments), others have evolved and have given rise to new characterizations that were once non-existent, for example being used for parking of vehicles.

From an economic point of view, the square may seem like a logical paradox: it is often a central area of great economic value, unedited and therefore apparently unused. In commercial terms, the Piazza could appear to be a waste. Instead, it is precisely the balanced, non-intensive use of space that gives the city the greatest value, even from a venal point of view. Just like the garden or the terrace of an apartment [3].

Cesare Brandi [3], introducing the volume "Squares of Italy", refers to the ancient Forum of the Romans: "in fact, they do not represent only the origin, the principle, but also the uncertain future of our squares and our cities".

The possibility of studying the history of cities, characterizing the places of human life over time, is an ambitious goal, especially if the city is Rome, which has undergone countless transformations from its origins.

Among the new investigation methods, remote sensing has become an important aid to traditional research methods in the study of the characteristics of the environment, built in particular in urban areas, a very complex and articulated context [4]. Remote sensing, through the synoptic vision (over large surfaces), is a new tool capable of studying urban areas and their dynamics. The results have shown a great potential of these tools applied to urban areas, complex realities with a high degree of fragmentation [5-7].

However, the use of urban remote sensing raises some questions: better use aircraft or satellite data, and which spatial and spectral resolutions to choose. The aerial platform allows targeted shooting even if with higher costs

(preparation of flight plans, authorizations, etc.), unlike the satellite it offers scheduled shooting with reduced costs.

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 [5,8]. The spatial resolution indicates the size of a pixel with a ground definition.

Although MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) sensor installed on board an airplane, its images have a good spatial resolution with a pixel up to 3m x3m.

The data acquired with this instrument composed of 4 spectrometers designed to collect the radiation from the earth's surface in the Visible (20 channels), Near-IR (8 channels), SWIR (64 channels) and Thermal-IR (10 channels), are also years from the acquisition excellent for use in the study of urban areas [9].

In consolidated contexts where there are no changes, such as historic urban centers, the applicative potential of these data does not run out over time, they remain effective many years later, in particular for the study of very fragmented areas (with an extreme pixel variation) for the characterization of many materials such as brick roofs, stone materials, asphalt, lead, copper, asbestos-cement, etc. [10].

The technical characteristics of MIVIS are reported in Table 1.

Table 1. MIVIS sensor characteristics.

Spectrometer	Spectral coverage	Channels	Bands ranging (micron)
I	Visible	20	0.43-0.83
II	Near Infrared	8	1.15-1.55
III	Shortwave Infrared	64	2.0-2.5
IV	Thermal Infrared	10	8.2-12.7

The availability of a MIVIS acquisition of an area of the historic center of Rome, at an altitude of 1,500 meters (corresponds to a pixel of 3X3 meters), for an area of 12,15 km^2, the excellent characteristics of data resolution (spatial and spectral), have suggested the realization of this work (Figure 1). With an experimental and innovative character, we retraced the history of some of the squares under study (Figure 1), most representative of the culture and different historical periods of the city of Rome.

With the use of remote sensing data, the elements and materials on the ground have been classified. Through an analysis of classified data, an attempt was made to read and interpret the life that took place and that takes place in the squares and that is spreading throughout the world.

2. Study Area

Seen from above, the scene is divided in two by the Tiber River and is characterized by very different parts (Figure 1):

- the compact city, the result of millenary stratifications, where you can see the urban solidity: the most authentic part built over more than twenty centuries (the districts);

- the expansions to the north and east, of the Baroque period, well organized, consolidated, of indisputable formal quality, but not stratified. The pre- and post-unification buildings follow one another with continuity, fairly consolidated, not stratified and of mediocre formal quality [4,11]:

- the green areas are interposed with the buildings, placed in the crown of the consolidated city known as "Villas", transformed over the centuries, but almost all attributable to the splendid gardens, created to complement and surround the Roman city in the late Republican and Imperial age.

In the study area there are numerous squares, dating back to different eras, which are the product of a design stratification and varied individual contributions.

3. Material and Method

They are listed in the Table 2, the characteristics of the data and the processing used for the study.

Table 2. List of the materials and data used in this research.

Data type	- MIVIS data; - Format .hdr.
Details	- 1 strips; - Surface acquired: 12.5 kmq; - Resolution: 3x3 m; - Georeferentiation (UTM WGS84).
Process	- Radiometric calibration; - Radiometric correction; - Classification (SAM method).

Figure 1. The study area taken with a natural color or synthesis in RGB (Red, Green, Blue).

The MIVIS data were calibrated according to the procedures described by Fiumi [4]. Radiometric calibration eliminates signal distortions due to sensor malfunction and the influence of external conditions at the time of acquisition and for example the different lighting conditions.

The radiometrically corrected data from the influence of the atmosphere layer that is interposed between the sensor and the investigated scene were classified using the Spectral Angle Mapper (SAM) method. The SAM algorithm implemented in ENVI [12] required as input reference spectra, deriving from specific "Regions of Interest" ROI, groupings of pixels having a lot of behavior similar) described in Table 3. As far as this study is concerned, the input spectra were extracted from ROIs accurately identified in the MIVIS image. Inside each ROI, areas having different morphological characteristics were selected: flat surfaces or ones with different exposure slopes, to best represent the variability of the area taken into consideration [5,6]. In this phase of the method, 11 ROIs corresponding to other surfaces were identified.

This classification methodology has already been performed in the course of previous research, here it is just summarized to provide a better clarification. For a more exhaustive discussion, see bibliography [4, 12].

Table 3. Classes of elements and materials present on the ground characterized in the classification.

Classes		Description
1	**Tiles and Bricks**	They are made of a natural material, namely clay, with the addition of coloring substances. They represent the older roofing material mainly used for civil buildings.
2	**Travertine and grits**	Travertine is a sedimentary stone made essentially of calcite, deposited by calcareous waters. Its characteristics make it ideal for paving external surfaces and roofing.
3	**Synthetic surfaces**	They are surfaces made of acrylic resins, polyester fibers and PVC especially used for sports ground flooring or for temporary structures outdoor facilities during the winter.
4	**Lead**	It is a corrosion-resistant material of sulfuric acid, and has been used since the Medio Evo for coverings of important buildings (dome of San Pietro).
5	**Other surfaces**	They are synthetic surfaces made of various materials used to floor both small or medium sports grounds (tennis courts, soccer grounds, lawn bowling grounds, etc.).
6	**Roads in bitumen**	They are covered by a bituminous material made of a mixture of hydrocarbons having natural or pyrogenic origin; this material plays the role of binder, as it joins inert.
7	**Roads in Sampietrini**	Is a natural material "leucitite", an eruptive rock typical of the Lazio volcanic areas. Used for paving streets or squares in the historic center of Rome.
8	**Treed surfaces**	Areas mostly covered by trees with deciduous leaves or evergreen (planes, pines and ilexes).
9	**Lawns**	Areas covered by vegetation with the prevailing presence of herbaceous vegetation.
10	**Bare soils**	Unvegetated areas, awaiting use (for sowing or urbanization).
11	**Water bodies**	This means Tiber River, but it is also referred to small artificial lakes and surfaces dedicated to pools.

The classification results were then evaluated by calculating the matrix of confusion [5,6,12], designed to verify or "to test" the performances of the classifier independently from the automated system [7,8]. The values of the matrix, expressed in percentages, are the cases of agreement between classification and reference spectra [5,6]. In this study, the input spectra were obtained from ROIs accurately identified in the scene, integrated with the direct field verification and the visual analysis of additive syntheses in RGB (Red, Green, Blue) and with Rome Capital colored photomaps at scales 1:500 and 1:2 000.

An analysis of the Table 2 shows that: a) the total classification accuracy obtained was equal to 84.68%; b) most classes were extracted with an accuracy ranging from 62.10% (Other surfaces) to 95% (Water bodies).

In particular, it is worth noting that, Tiles and bricks (77.47%) class tends to be confused (geological correlation), with that of Bare soils (92.17%) mainly in the nearest neighbor areas characterized by the presence of large areas of clayey soils.

4. Distribution of classified elements and materials

In the classified MIVIS scene (Figure 2), the visual analysis allows both to distinguish the distribution of the different spectral classes, as well as to make some initial observations. In this regard, Foody (2002), defined the visual analysis as the first and most important phase of evaluating the effectiveness of the methodology.

The classification highlights the very close link between the Tiber River (3.23%) and the buildings (Tiles and bricks and Travertines and grits, 21.61%). What is striking is the urban solidity and formal organization of the building, the fact that there is the contiguous part of the large bend to the left of the Tiber, in the Trastevere District, densely built and layered and a dense network of narrow streets. It corresponds to the heart of the medieval city characterized exclusively by Tiles and brick roofs (10.10%), paved in blocks of Basalt (3.32%) [4].

At the heart of the medieval city with the Tiles and brick (Figure 2), the urban expansions of the renaissance baroque period are juxtaposed to the north and east, with well-organized rectangular blocks of formal quality and a regular road network. The large surfaces of Piazza Navona, Piazza del Popolo and Piazza San Pietro do not pass unnoticed, which appear as "gashes" in the medieval urban fabric, characterized by buildings with roofs in Tiles and brick and Travertine, and floors in Basalt.

The well-established Baroque expansions are followed, steadily, by pre- and post-unification expansions, not stratified, recognizable in the image by a certain regular pattern.

As you exit the city, the brick roof is replaced with flat roofs in travertine or similar materials (grits, tiles, etc.).

In this area it's striking how the road network ends up in into the squares. Proofs of that are Piazza Mazzini and Piazza Risorgimento. The large straights of tree-lined avenues are clearly visible, this creates a network where vehicular traffic flows and whose squares constitute the junctions, points of convergence and hinges of roads.

This first analysis on the classified image in Figure 2, constitutes a necessary basis, which is however deepened in the continuation of the work.

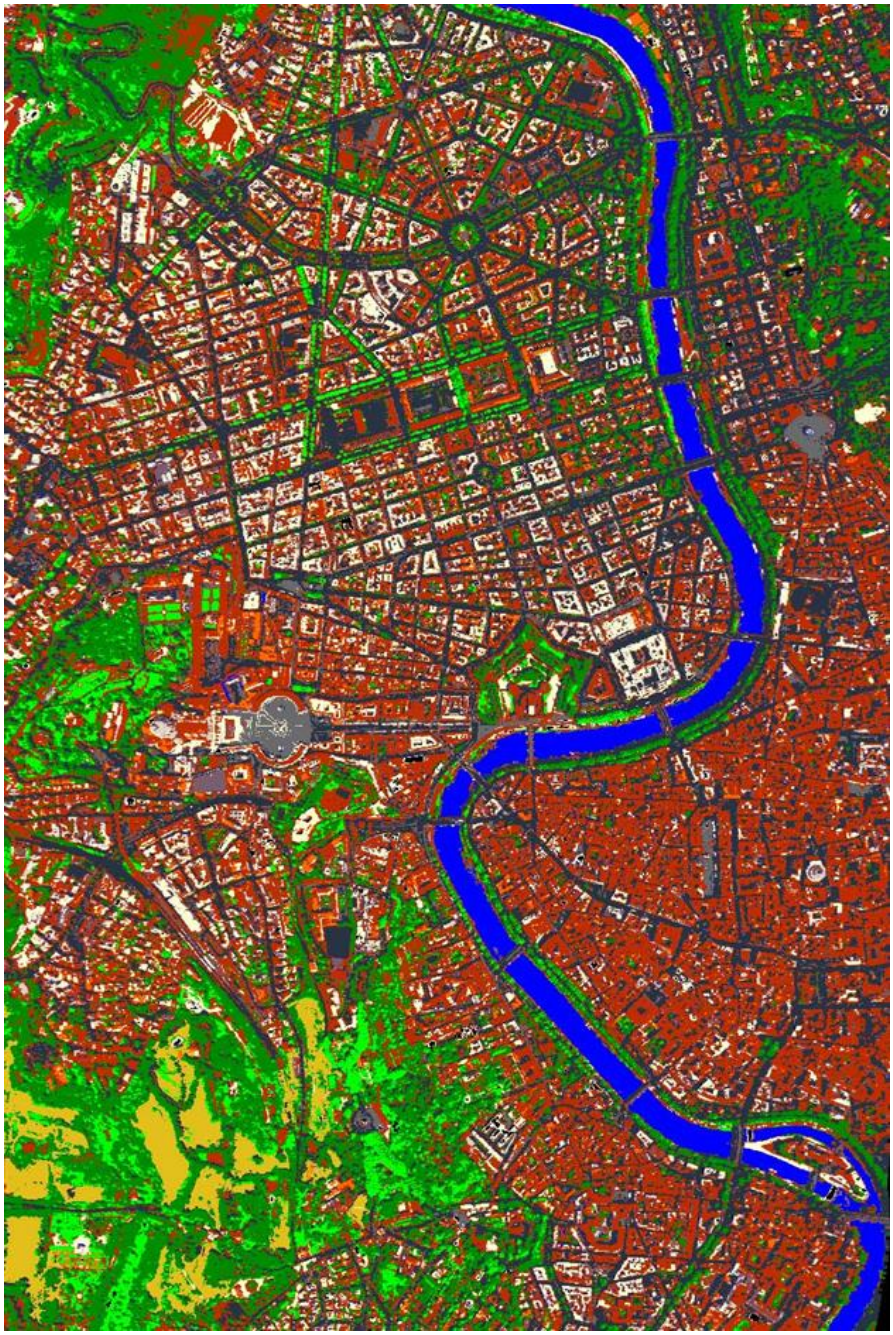

Figure 2. Classification of elements and materials.

4.1. The medieval squares

In the Trastevere District, to the left of the Tiber, below the Tiber Island, it is an area that in the Middle Ages saw its spaces subordinated to the activities of the Ripa Grande port and strategic points for the control of the Cestio and Rotto bridges [13].

In this area, the MIVIS elaboration emphasizes a densely built urban fabric with Tiles and bricks roofs (31%) and Basalt pavements (12%), where the winding and narrow streets wind their way (Figure 3).

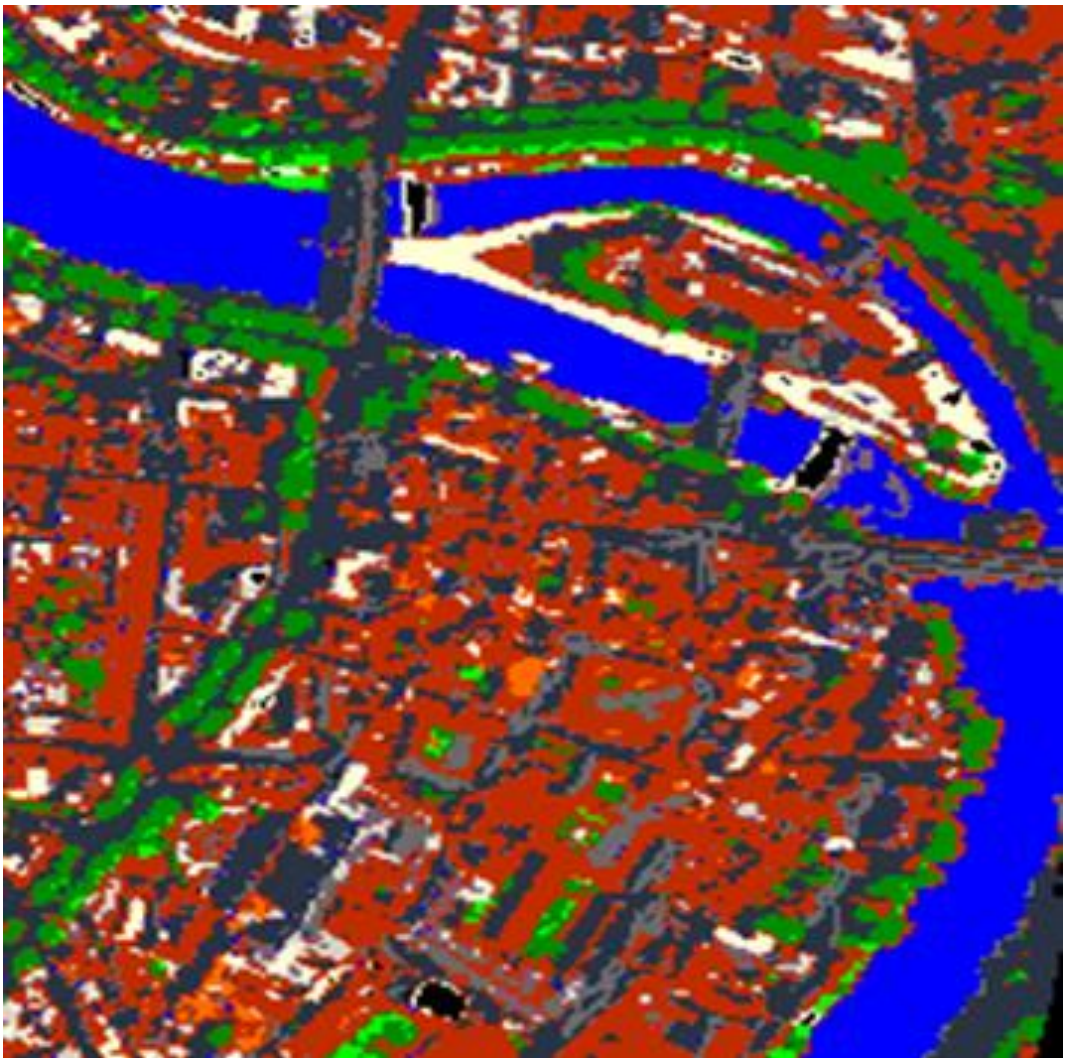

Figure 3. Detail of the classification on the Trastevere District.

Some of the cornerstones of medieval buildings, cited by Sitte [14] and which we find in the elaborated image, are the "closed" circumscribed spaces, a sort of large "excavated" courtyards that isolate them from the rest of the town. These characteristics also correspond to the concept of a medieval square: a finished place, distinct from the rest of the city [15].

In this regard Conti [16], asserts: “the shape of the squares was rarely regular. The medieval cities and their parts were in fact never built on the basis of a project, but were the result of a series of choices made from time to time by arranging, adjusting and modifying the pre-existing buildings. They grew in an organic way similar to that of a living organism that remodels, rearranges, replaces, progressively inserts the old parts, no longer functional, with new ones”.

While maintaining its role as the setting for collective life and urban planning, inherited from tradition and from the past, in the Middle Ages the Piazza assumes a different function depending on the buildings it overlooks [14].

If several activities took place in the Roman Forum (administrative, judicial, commercial, political, religious and worldly), the square in the Middle Ages was conceived to host only one activity [14]. In fact, three canonical models of Piazza have been handed down through the centuries and which will coexist, often contiguous, each of which fulfilled a specific role: that of the market, place of business; the religious one, overlooked by the churches; and finally, the civic one, surrounded by the palace of power.

The medieval squares of the city of Rome (Figure 3), located in the Trastevere District [17], do not escape this scheme. Among the most significant area Piazza dei Mercanti (pixel 190), Piazza Santa Cecilia (pixel 90), Piazza in Piscinula (pixel 170). Unfortunately, today their original structure is altered, as over time they have been gradually incorporated into more recent constructions.

Piazza dei Mercanti, belongs to the type of place of business, where traders traditionally met, who landed in the nearby port of Ripa Grande, with small sailing boats or hulls pulled by buffaloes.

At the end of the seventeenth century, the construction of the refuge for the poor "San Michele" canceled the presence of many buildings on the square, used as shops and warehouses [15].

Adjacent to Piazza dei Mercanti, we find the religious squares overlooked by the churches from which they take their name, including: Piazza Santa Cecilia (9th century), Piazza di San Francesco a Ripa (11th century), Piazza in Piscinula (11th century) (Figure 3).

The religious squares are not places of worship, or at least, not in the proper sense, but they are strictly associated with buildings of prayer, they are open sacred places (churchyard) essential to the life of the church behind [1,16], highlights that they were used, to give breath and prominence to the house of God, in the dense and uninterrupted texture of houses leaning against narrow streets typical of medieval cities.

In the processed image (Figure 3), the forms of the buildings are not compact and with a high degree of fragmentation. The homogeneity of the volumes of the buildings that can be seen in the twentieth century neighborhoods is absent.

If the square in the Middle Ages played an essential role in the urban scenario, as a place of sociability and collective recognition where people met in a space rich in history; today, however, the squares of the Trastevere District have been transformed into utility spaces, for parked cars, restaurants with outdoor spaces furnished with tables, umbrellas, fans, nebulizers, flower boxes [18].

The homologation of activities and the privatization of public spaces, in fact, completely distorted the identity of these places [18].

4.2. The Renaissance and Baroque squares

Observing the MIVIS elaboration, in addition to the strong signs impressed by nature, such as the course of the Tiber River (3.23%), the formal organization of the building is striking, for this reason Piazza Navona and Piazza del Popolo do not go unnoticed (Figure 4-5).

Figure 4. Detail of the classification of Piazza Navona.

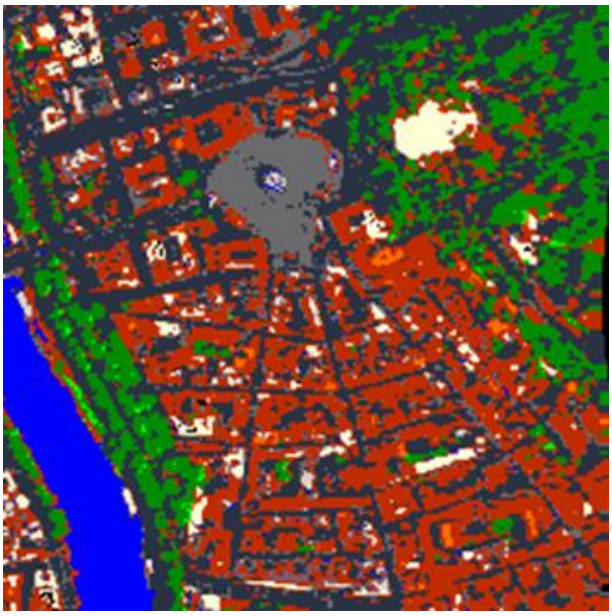

Figure 5. Detail of the classification of Piazza del Popolo.

What is surprising in the elaborate images, besides the large dimensions, is the shape of these squares (Figure 4-5). In this regard Sitte [14], highlights “in the Renaissance and even more in the Baroque, architects were more concerned with the shape of the squares than with their functionality. They refer to ideal theoretical models in which beauty derives from the rational harmony of mathematical laws and the use of perspective ".

In fact, a closer look in the elaborated images (Figure 4-5), highlights the curved shapes, with sinuous trends, the Piazza becomes an aesthetic and perspective episode, almost a scenario [3].

Observing in the elaborations (Figure 4-5), the Squares appear, as “gashes” in a medieval urban fabric, offering a more modern or decent and more representative look to the medieval environment in which they were going to settle. Many times, they are an element of pure urban embellishment, rather than an element of utility. In this regard Conti [16] states: "The medieval square originated from below, from the thousand needs of the population, the Renaissance one then the Baroque one, on the contrary, proceeds from above from the vertices that find here the space to impose their power and demonstrate their social importance ".

In the classified image (Figure 2), looking towards the bend of the Tiber to the right of St. Peter's Basilica, we can observe the elongated shape of Piazza Navona (Figure 4), whose surface is approximately pixel 1.330, paved in 1870 in Basalt (7.11%) with a convex trend, previously it was concave to favor flooding for the enjoyment of the

population until 1866. The elaboration highlights almost all the roofs in Tiles and bricks (52.6%) and at the center of the square and the two extremities of the fountains that adorn it, in Travertine and grits (4.08%), by Giacomo della Porta, with the presence of pixels belonging to the Water class (0.7%).

On Tiber's right side (Figure 2), there is one of the most important elements of the Baroque city: Piazza del Popolo (Figure 2). The elaboration highlights the complex of the Piazza consisting of two large interlocking structures: the gigantic elliptical basin that connects the Porta del Popolo to the north (for centuries it was the privileged access to the city from the north).

One cannot help but notice in the elaboration, the vast pavement in Basalt (7.3%), equal to pixel 1.200 the three road axes called Trident, which cut the ancient urban fabric in a clear way converge at the center of the large oval square. The center is characterized in the classification, by a few pixels, corresponding to a Travertine obelisk (4.4%) dating back to the pharaoh Ramses II and a fountain with Water (5.4%) designed by Giacomo della Porta. Until 1998 this square was a large parking lot for the city, today it is a pedestrian area, occasionally used for large events.

The classification (Figure 5) clearly characterizes the ramp of the Pincio promenade to the east of the square; a solution of integration between architecture and nature Trees (12.4%) which has harmoniously reconnected the monumental pre-existing structures, providing the city with the first public park of modern era. The lookout paved in Travertine (gravel) surrounded by historic trees (Cedrus libani, Quercus ilex, Pinus pinea).

The shape of the square assumes its current shape only at the end of the nineteenth century, by the architect Giuseppe Valadier. In this regard, Conti [16], describes Baroque architecture "The new squares thus become the urban extension of the living rooms, gardens, aristocratic courtyards. They are the perfect scenography for a performance in which the actors are the aristocrats". Brandi [3], defines the Squares: "prodigies of communication even before that of architecture".

The baroque squares become places to stroll. The humble public functions - markets, crafts, popular festivals, festivals - are left to other squares, usually those of the medieval city [3].

This is the golden age of the square, later the unstoppable decay begins.

4.3. The squares of the twentieth and twenty-first centuries

Since the 19th century, the industrial revolution has led to changes in urban settings to facilitate the mobility of people and goods, thanks to the technical evolution of transport systems that have forced cities to adapt their public spaces to rail, trams and cars. Rossi [11], in this regard states that: "this has led to the reduction of some public spaces to monofunctional and technical spaces devoid of the social, cultural and symbolic values generally attributed to the public space of the historic city". In Rome, under the Giolitti government (1903-1921), new districts were built between these Prati and delle Vittorie, designed and built to house the administrative structures of the Regno of Italy and the residences for state officials. The study area includes: Piazza Mazzini, Piazza Cavour and Piazza Risorgimento.

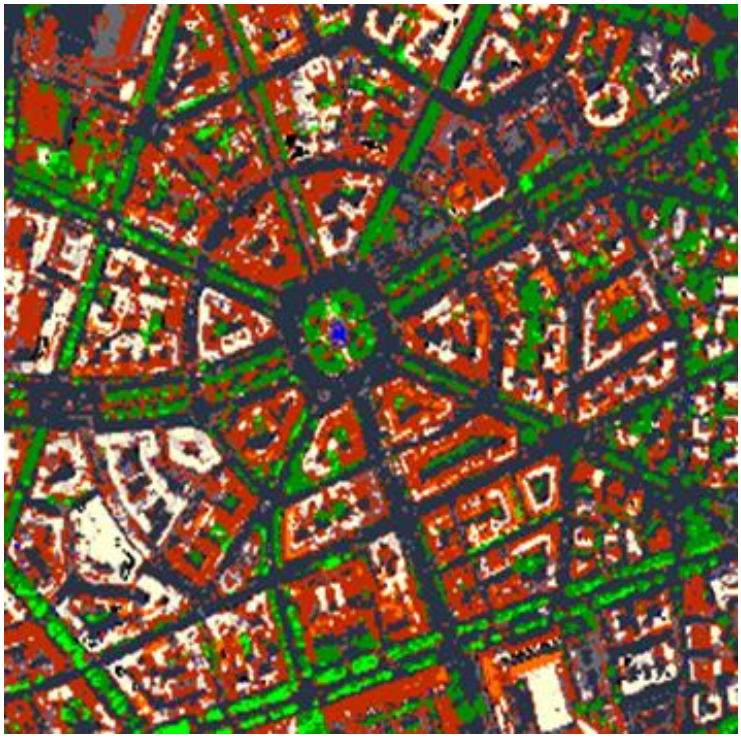

Figure 6. Detail of the classification of Piazza Mazzini.

Observing the detail of the classification of Piazza Mazzini (Figure 6), the "swirling" large open and circular space is amazed, of pixel 1.844, with a ring road that runs all around the square, and eight wide tree-lined streets that converge symmetrically, forming a star. In the center, a large flowerbed, the hub of the neighbourhood (pixel 620). The classification highlights in the center of the square the presence of a few pixels of Water (0.1%) of a large fountain, called "fountain-garden", by the designer Raffaele De Vico (1881-1969); it is bordered by Lawns (1.1%) and Trees (14.02%), and by a path paved with gravel (cobbled river gravel). Everything appears as a harmonious agreement between the different elements that follow a precise design, which sees the main traffic route in the large tree-lined avenue of Viale Mazzini.

The shape, size and furnishings of the twentieth-century squares followed the functional needs that gradually emerged [11]. The scale is completely different from that of previous eras: no longer the meter of man, but the meter of the vehicle. The Squares are no longer felt as a living organism, in the medieval or Renaissance style, but as a large network of nodes that connect the great road itineraries together [17,18].

In summary, the town planning of the last century made no distinction between the functions of the squares. The church as the theater, the market as the station, the government building as the public garden all had the same type and the same shape of the square: opened on all sides to car traffic, with the main building isolated and vast spaces surrounding hime [19-21].

Closer to nowadays the meaning of the word Piazza is getting lost, replaced with the word largo, or open space, or open space [22,23].

An example of this is Piazzale degli Eroi, also conceived as a function of traffic, crossed by thousands of cars every day (pixel 766), (Figure 7).

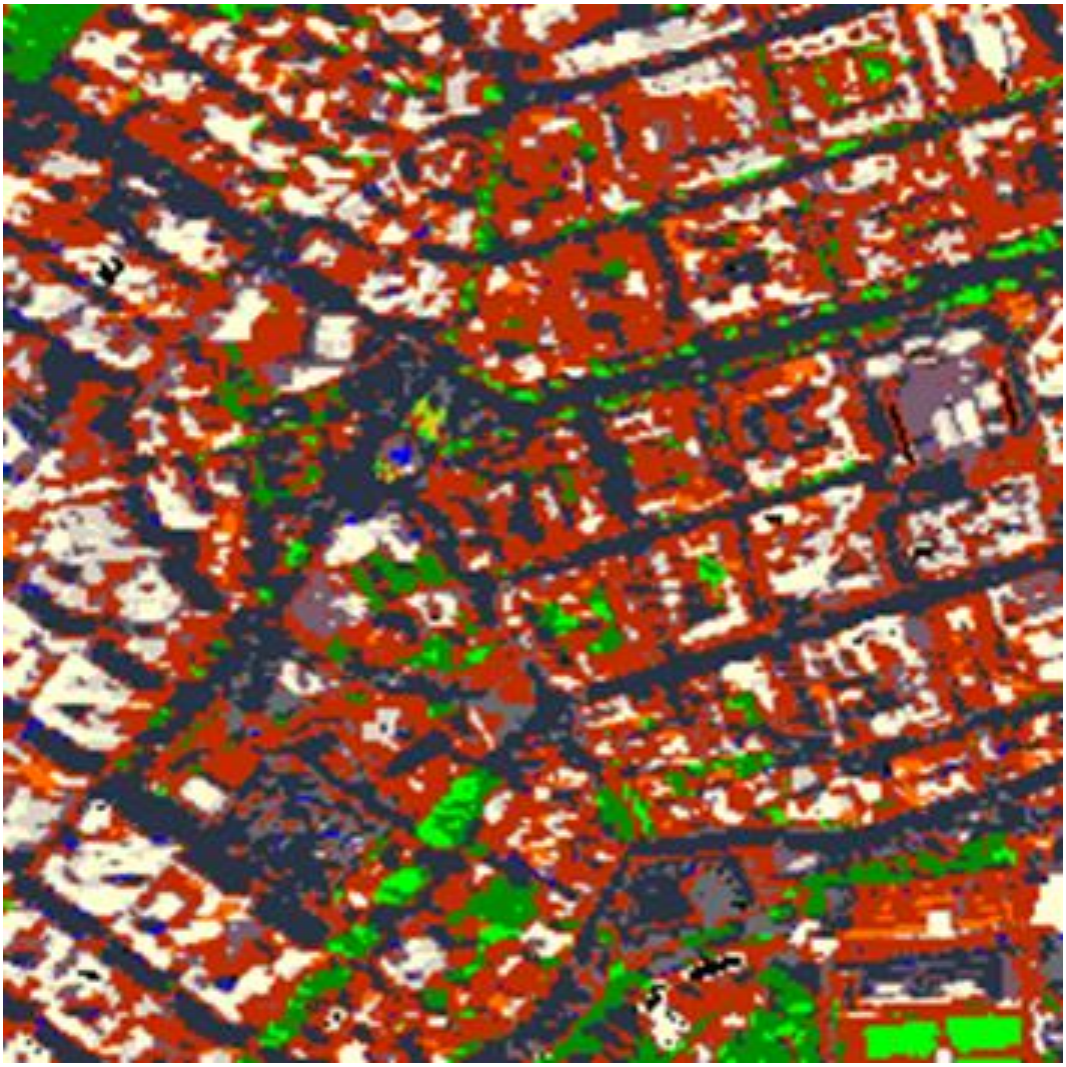

Figure 7. Detail of the classification of Piazzale degli Eroi.

The classification in Figure 7, shows a great heterogeneity of the pixels, complex spatially and spectrally, as they are linked to the variability of the dimensions, shapes and covering materials, all that produces some kind of environmental disorder. Processing of statistical data shows a great heterogeneity of the ground surfaces: Tiles and bricks (12.8%), Travertine and grits (15%), Road in asphalt bitumen (6%), and an almost absence of natural

surfaces Trees (0.6%), Lawns (1.5 %). Almost imperceptible, in the center of the square (pixel 30) there is the fountain-exhibition of the Peschiera Aqueduct, inaugurated in 1949, it is made of concrete and travertine, and currently under an unstoppable decay, guarded by seagulls and garbage (bottles, weeds, waste various) that are disfiguring the newly restored work.

Since the last century, very few squares have been built, if not traffic-crossing places [3,17].

Today there are new concepts of the square, for example social networks or shopping centers, however none has actually replaced squares, but rather they have surrogated their functions [20,21].

5. Conclusion

This work aims at tracking history of some squares in Rome, using MIVIS remotely sensed data. The MIVIS data of Rome were classified using the Spectral Angle Mapper (SAM), algorithm. This allows us to demonstrate innovatively how to characterize and quantify the roofing surfaces and also to issue considerations on the aerial view of the city and some squares.

Satellite technology is rapidly evolving. The new sensors have now better spatial and spectral resolutions to analyze that were unthinkable until recently.

In addition, on Google Earth satellite images are available today on web and thus allow us: to fly anywhere on Earth, to consider the Earth in a brand-new way.

All of that is changing the education system thus providing additional information which has never been obtained before.

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Conflicts of interest

The authors declare no conflicts of interest.

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