REMOTE SENSING AND GIS FOR LAND USE PLANNING: AN APPLICATION FOR MAPPING ASBESTOS CEMENT ROOFING IN TIBURTINA, ROME, ITALY

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Abstract

This paper examines remote sensing detection techniques for data integration in GIS aimed at monitoring of asbestos-cement cover.
Specifically, will present the further developments of a former research activity aimed at mapping asbestos-cement roofing by means of MIVIS hyperspectral data. In particular it will describe the first results obtained so far while developing a GIS system for the monitoring of asbestos-cement roofing, which allows through the geo-coding of MIVIS data, to pose spatial and logical queries in order to assess the different interactions according the scale of analysis.
Therefore, this technique can furnish government authorities with an efficient, rapid and repeatable environmental mapping procedure that can provide information about the location of asbestos-cement cover. Finally this work will also face a preliminary risk assessment involving the health of both residents and workers in the neighbouring areas.

Keywords: *Remote sensing; Hyperspectral data; Asbestos-cement; Classification; GIS.*

1. Introduction

The extraordinary properties of asbestos as a strengthening fibre and thermal and acoustic isolation material, favored a notable use thereof in the most varied of fields in general and in building in particular. Table 1 shows the products most commonly used in building. Europe has large natural deposits of asbestos [1]. Currently asbestos is mined in Russia and Canada, as well as in China, Brazil, Zimbabwe and South Africa. Asbestos has not been mined in the United States since 2002. The United States is dependent on imports to meet manufacturing needs. Asbestos consumption in the United States was estimated to be 1,060 tons, based on asbestos imports through July 2012 [2,3]. Products made of asbestos-cement (a-c) are the most commonly used. In the unrefined mix used in the production of asbestos for roofing, the cement varies from between 84% and 90% [4].

These materials are subject to a complex degradation that results in a lesser consistency of the product and the surfacing of asbestos fibers in surfaces/on the exterior. A-c products become "friable" Environmental Protection Agency (EPA) when severe deterioration disturbs the cement matrix due to ice, acid rains, wind and so on, or when mechanical means are used for chipping, grinding, sawing, or sanding, therefore allowing particles to become airborne [5]. When present in air, asbestos fibers are extremely persistent and can cover very long distances because of their aerodynamic properties [6]. In the last century the use of asbestos fibers and items made of asbestos has caused a remarkable public health problem. The environmental and occupational exposure to asbestos has produced significant human health effects such as asbestosis, lung carcinoma, pleural and peritoneal mesothelioma [7,8,9].

Table 1. Main uses of asbestos products in buildings.

Material	Content
Spray recoating and isolating lining	Up to approximately 85% asbestos (prevalently amosite and sprayed chrysotile)
Isolating lining of pipes or boilers	In material, filters, padding generally speaking 100%. For other linings a mixture of 6-10% with silicone-calcium
Cables, ropes, materials	Generally speaking 100%
Asbestos cement (a-c) products	10-15% asbestos (chrysotile and amphibole)
Bitumen produces, tiles, vinyl flooring, PVC and reinforced plastic, varnishes, putties/mastics, sealants, plaster, adhesives	From 0.5-2% for putty sealants and adhesives, to 10-15% for tiles and vinyl flooring

According to the United States EPA, a material containing asbestos is deemed potentially hazardous only in a "friable state", i.e. when it can be crumbled or reduced to powder by hand pressure. Unlike the United States, where the use of asbestos is still legal but tightly controlled, on January 1, 2005 (following the directive 76/769/CEE) the marketing and use of asbestos containing products was banned throughout the European Union [6,8]. This health risk prompted the establishment of strict environmental regulations about working with asbestos and the creation of a policy intended to forbid the use of asbestos products. Italy was the first European country to cease the production and the use of asbestos and materials containing it (Law No. 257/1992) [6,10,11]. To understand the magnitude of this problem, it is estimated that in Italy 12 million tons of a-c sheets cover most industrial and agricultural plants, public and civil buildings [11]. At present, monitoring of asbestos-cement roofing is essentially based on direct detection, normally carried out by experts from the Local Health Authority (ASL). According to this approach, the detection of contaminated sites however causes a series of logistical difficulties with subsequent economic repercussions, above all when the investigation involves extensive territorial surfaces. An interesting alternative to traditional detection is remote sensing. It is not always possible however to obtain detailed analyses such as the exact identification of asbestos-cement roofing using remote sensing technology because of resolution limits. National Council for Research (CNR) owns and manages an advanced system of electronic shooting with Multispectral Infrared Visible Imaging Spectrometry (MIVIS) scanning, the founder of a new generation of hyperspectral sensory apparatus that works with a high spatial and spectral resolution, using a bimotor turbo propeller CASA 212/200 as aerial support, with the characteristics of a real flying laboratory. MIVIS is the archetype of a new generation of airborne, hyperspectral sensors and is a modular instrument composed of 4 spectrometers which simultaneously measure the radiation emitted by the earth's surface. MIVIS is a modular instrument made up of 4 spectrometers, which are able to produce a spectral sampling in 102 channels in the interval between 0.433 and 12.70 μm. [4,12].

Table 2. MIVIS technical 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

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The system 755 pixels for every line acquired with an IFOV (Instant Field of View) equal to 2 mrad, while the total FOV (field of View) results in about 71.059°. The unrefined signal is amplified, sampled and recorded in 12 bit [12]. This allows a detailed analysis and classifications when urban elements are to be recognized, and in particular when covering materials, such as bricks, stone, lead, copper, cement-asbestos, etc., are involved [13]. The implementation of the results of these classifications in Geographic Information System (GIS), allows the production of thematic maps, the calculation of areas and measurement of distances, and the comparison with other different information [14]. To this end, major research aims can be summarized as follows:

1) Describe the potentiality of MIVIS data for studying and monitoring a sub-urban area, chosen on purpose, characterised by a considerable presence of a-c covers;
2) Validating the utility of an image analysis system known as Spectral Angle Mapper (SAM), in the specific environmental conditions of the study area;
3) Implementation of the results of these classifications in Geographic Information System (GIS), which performs the Minimun Bounding Algorithm spatial analysis.

Finally this work will also face a In particular it will describe the first results obtained so far while developing a GIS system for the monitoring of a-c roofing, which allows through the geo-coding of MIVIS data, to pose spatial and logical queries in order to assess the different interactions according the scale of analysis. Therefore, the architecture of the system is aimed to government authorities for an efficient, rapid and repeatable a-c mapping procedure.

2. Study area: territorial, demographic and settlement dynamics

The MIVIS images used for this study were taken above Rome on 5 September 2010 at 10:41, at an altitude of 1.500 m, along the Tiburtina street, the historical consular road. A spatial resolution of 3m x 3m resulted (for details, see Table 3). The start and development of the buildings investigated in this study were favored by the road system, now the SS 5 Tiburtina. In this context, factory buildings were built for artisan use, mainly depots and warehouses to be rented out, using cheap easy-to-use materials, such as a-c. There is currently a situation of environmental disorder, where residential buildings, industrial buildings, sports facilities, open air depots and vegetable gardens stand side by side, by chance and as a result of speculative assessments of the contemporary city.

Fig. 1. Territorial framework of the study area. For the detail (see Fig. 3).

3. Materials

The following data were used in the framework of this study:

Table 3. List of the materials and data used in this research.

DATA TYPE	FORMAT	YEAR	DETAILS	PROCESS
AERIAL IMAGES				
MIVIS data (Multispectral Infrared Visible Imaging Spectrometer)	.hdr	2010	2 strips: - Flight time: 10:41; - Surface acquired (km2): 106.00; - Covered Area (km2): 87.195 - Resolution: 3x3 m.	- Geometric correction; - Enhancement; - Georeferentiation (UTM WGS84); - Mosaicking; - Classification; - Conversion to polygon.
MAPS				
RTM (Regional Technical Map) of Lazio	.tiff	2004	Scale 1:10.000	- Mosaicking; - Georeferentiation (UTM WGS84).
Distribution of asbestos roofing	Shapefile	2010	MIVIS data classified and converted to polygonal format (vector).	- Data cleaning; - Application of Minimum Bounding; - Intersection with the RTM.
ISTAT census sections	Shapefile	2011	ISTAT data of the 15th General Census of Population, 2011, polygonal format.	- Query; - Selection of sections within the study area. - Intersect with ISTAT data on workers and resident
Road infrastructure	Shapefile	2010	Data provided by Rome municipality.	Thematization: - GRA; - Highways; - Regional, provincial and municipal roads;
Buildings data	Shapefile	2010	Data provided by Rome municipality.	Thematization according to type of use: - residential - industrial - public buildings
Indexes on presence of a-c	Shapefile	2011	Indexes created with integration between MIVIS data and ISTAT table data, for census sections.	- a-c for resident index - a-c for worker index - a-c for exposed index (resident + workers)
TABLE DATA				
ISTAT data of the resident population and workers	.txt	2011	ISTAT data of the 15th General Census of Population, 2011, table format.	- Join Table operations with census sections; - Extraction of the information on residents, workers and local units, for census sections.
Decontaminated Roofing	.txt	2000 - 2012	Data provided by ASL RmH	Decontaminated Roofing
Abatement Plan	.txt,.tiff	2000 - 2012	Data provided by ASL RmH	Abatement Plan
SOFTWARE				
ITT ENVI, Versione 4.7		2009	ITT Visual Information Solutions	Digital image processing
ESRI ArcGIS, Versione 10		2010	ESRI	GIS elaboration

3.1. Data Processing

The investigated area was assessed from a qualitative point of view by a visual analysis of each separate channel. Such analysis stressed for most reflective channels an acceptable Relation Signal-Noise (*Signal to Noise Ratio* SNR), strictly corresponding to specifications provided by Bianchi et al. [15]. Only the quality of some channels (for instance 59,63) came out so below a certain qualitative standard that their use could be questionable. SWIR channels within the spectral domain 2.000-2500 μm (ch, 31-92) were provided with a filter to achieve an acceptable SNR as regards pixels.

3.2. Spectral Angle Mapper (SAM)

The radiometrically correct data were classified by using the *Spectral Angle Mapper* (SAM) method which enables to map quickly the similarities existing between image spectra and reference spectra [16,17,18]. The reference spectra can be determined either in laboratory or in field, otherwise they can be got from the image. The algorithm gives the spectral similarity between the two spectra by means of the calculation of the "angle" they form, and therefore the spectra are considered as vectors in a space whose dimensionality is equal to the number of bands. The similarity between an unknown spectrum *t* and a reference spectrum *r* comes out from the following equation:

$$\alpha = \cos^{-1}\left(\frac{\vec{t} \bullet \vec{r}}{\left\|\vec{t}\right\| \bullet \left\|\vec{r}\right\|}\right)$$

that can also be expressed as follows:

$$\alpha = \cos^{-1}\left(\frac{\sum_{i=1}^{nb} t_i r_i}{\left(\sum_{i=1}^{nb} t_i^2\right)^{1/2}\left(\sum_{i=1}^{nb} r_i^2\right)^{1/2}}\right)$$

where α is the angle between vectors and *nb* is the number if bands in the image. For each reference spectrum chosen in the analysis of hyperspectral images, the angle α is determined for every element of the image (pixel). This value in radiants is assigned to the corresponding spectrum in the output SAM image, one for each reference spectrum. The maps of the spectral angle produced show a new cube of data providing a band number equal to that of the reference spectra used for the mapping [17] .

The SAM algorithm implemented by ENVI [19,20] requires as an input a number of training areas or reference spectra resulting from specific "Region of Interest" (ROI) or spectral databank [21,22]. As far as this study is concerned, the input spectra (*training sets*) were extracted from ROIs (Region of Interest). ROIs were accurately selected by drawing polygons on the MIVIS image, so that all the asbestos-cement roof types (vaulted, pitched, flat) and the different exposure were properly identified, in order to best represent the heterogeneity of the class taken into consideration. In addition, ROIs were validated by comparing them to field survey (during the field verifications each site was catalogued in a document); however where field survey was not feasible, ROIs were verified by means of the photo interpretation of Google Maps.

3.3. Accuracy assessment

The classified images were then mosaicked. They totalized 120.878 m^2 of a-c roof coverings. Although the level of suitability is consistent with the real situation, with an overall classification accuracy which is equal to 95.9% obtained by the ROIs test [19], the visual inspection of the classified images, and especially field surveys, emphasized in some cases that asbestos-cement class was under represented on the map (see Figg. 2 and 4).

Fig. 2. Examples of a-c roofs variability.

As mentioned, the map (see Fig.1) showed omission errors due to pixels spatially missing which affect geometry of mapped buildings, creating irregular boundaries. Consequently, the need for a work strategy which could accurately identify a-c roof coverings, and which could be efficient to determine a functional geographic representation, led us to make additional spatial analyses such as the Minimum Bounding Algorithm (MB). For this purpose, classifications were converted from raster to vector format, thus obtaining a polygon feature for each a-c roof covering.

3.4. Minimum Bounding algorithm

Vector data, derived from the classification, were processed using ArcGIS [22] software package, which performs the MB spatial analysis. The Minimum Bounding algorithm calculates for each roof covering a new convex polygon containing all the points of the input polygon [14,23].

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Fig. 3. Map of the distribution of a-c roofing in the study area, with details (fig. 3a and 3b).

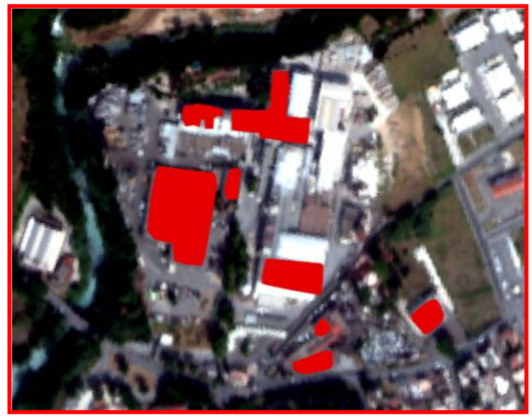

Fig. 3a. A-c roofing in the area of Tivoli (at the top of the image).

Fig. 3b. A-c roofing in the area of S. Basilio (below in the image).

The Minimum Bounding process has the main characteristic to create a new vector layer, removing gaps inside the polygons (holes caused by discontinuities or classification error). Polygons are, therefore, defined with a more compact surface, reducing the internal discontinuities of the a-c surfaces.

This procedure allowed us to define these polygons using the Convex polygons (convex hull) process. Convex Hull allowed to calculate the convex polygon of each a-c roof covering. The algorithm, as described by Ye [23,24], included two steps:
- Extraction of the points that characterize the vertices;
- Elaboration of a convex polygon, whose area includes all vertices previously extracted, minimizing its area.

In this study, it was used the convex hull geometrical process because it is turned to be more suitable for the characterization of the different roof typologies (vaulted, pitched and flat) and for the spectral variability due to shadows.

Classification SAM	Minimun Bounding
a-c = m^2 7.884	a-c = m^2 9.668

Fig. 4. Comparison between classification and Minimum Bounding method.

From surveys in situ carried out on a total of 12 covers, with a total of 300 points, has been verified the exact correspondence between the classification and the ground truth (RTM). Results are reported in Table 4.

Table 4. Comparison between elaborations, obtained on 12 covers of surveys in situ.

N. of covers	Class.	MB	RTM Ground truth	Class./RTM	MB/RTM
12	201	236	300	0,67	0,79

From table we may note that the technique of Minimum Bounding, improving overall definition of the cover (for example, by eliminating voids), is the technique with the best results in terms of accuracy.

4. Integration of remote sensed data with GIS

The Italian Ministry for the Environment, together with the Italian Ministry of Health, implemented Law 93/2001 (Art. 20) and Ministerial Decree 101/2003 (Regulating asbestos containing material mapping realization) in order to accurately map the presence of asbestos in Italy and to implement urgent remediation projects. To this end, all the Regions should make use of GIS, a tool of fundamental importance for the proper cataloguing of current hazardous situations and for a cartographic visualization of the detected sites.

A multidisciplinary research carried out by a group of researchers of the National Research Council of Italy (CNR), has been focused to the classification by means of MIVIS (Multispectral Infrared Visible Imaging Spectrometer) data of the a-c roofing. [4,13,14,25]. To meet the provisions of the D.M. 101/03, in this work, the research group develop a procedure based on the integration of remote sensed MIVIS data with GIS. As already known, the latter is the ideal software environment to manage complex systems where coexist parameters and elements of different nature [26,27].

In view of the multidisciplinary character of this work and the integration of data of different origin, the system created presents the following aims:

1) Prediction aim (location and study of a-c roofing with the aim of assessing the connected hazard).
2) Comparison aim (acquisition of data and information about single buildings).
3) Knowledge and training aim (choice of actions to be undertaken by ASLs).
4) Statistical aim (data storage, data management and processing to define the land maintenance strategies of ASLs and other Local Authorities).

The overall objective is to develop alternative ways for the participation of public bodies for the issue of a-c surfaces, and encourage open communication between the decision makers.

4.1. Architecture of the system

The system was designed in order to be easily used also by inexperienced user with the task of inputting and managing data. It was planned and structured both for direct operations (data updating, inspection of Abatement Plans, etc.), and post-processing operations. Based on data collected *in situ* this post-processing phase allows the evaluation of the distribution of asbestos in territory studied and the assessment of asbestos-related risk for workers and residents. The research group so opted for a simple, immediate and easily usable architecture.

The fundamental map is an abstract of the Regional Technical Map (RTM) of Lazio, integrated with high-resolution satellite image from Google Map, in order to have an immediate visual reference. In the first phase of realization of the GIS, data and information about the elements characterizing the study area, like roads, a-c roofing (geo-coded by UTM-WGS84 33N), decontaminated roofing (from archive ASL's), and ISTAT (Italian National Institute of Statistics) data, were gathered.

Each element collected in the territory was geographically located and put into shape files, on the basis of which some relations were created in order to enable *overlays* and spatial analyses to be carried out.

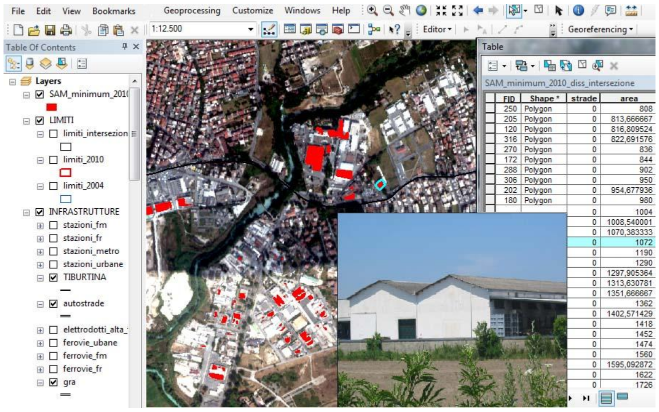

Fig.5. A-c roofing maps in the GIS system, over the MIVIS map. The window shows the integration between the different data (residents, workers, a-c, etc..) and a photo of the covers.

The shapes implemented in this phase are simply territorial study elements present in the sample area [ArcGIS Resource Center, 2011].

1) A-c roofing represented in red colour. Maps were produced by processing MIVIS data and validating them as previously mentioned.
2) Abatement Plan, according to the information received from ASLs about decontaminations already carry out and then inspected in situ.
3) Roads, present in the study area. The choice of viewing toponym was suggested by ASLs to make the task of inspecting buildings easier.
4) ISTAT data. The study area was subdivided into sections according to the subdivision of 2011 census; residential and workers density values were associated to each section.

4.2. Implementation of tables on characteristics still to be further studied

In the second study phase the GIS architecture, organized on different informative levels, was integrated with data collected through accurate inspections *in situ* as above mentioned. These data include declarations made by owners/tenants in forms and Abatement Plans presented to ASLs. All this information was gathered into tables on the characteristics of roofing, and an informative database on roofing present in the study area was then created. In particular, the tables associate to the shapes of buildings analysed are structured as follows:

1) A-c roofing, showing information on geographical location and extent of the roofing inspected, characteristics of the study area, size and constructional features of the roofing, construction date, purpose/use of the building, number of workers/residents, type of roofing material, its conservation state and possible presence of asbestos with a friable matrix inside it.
2) Presence of an Abatement Plan, with information about the geographical location and extent of the surface, the abatement technique used.
3) Roads, showing the fields referring to name, length, practicability and typology.

In the third and last phase the research group carried out a first assessment of the asbestos presence in the territory. As far as public health is concerned, parameters taking into account the percentage of asbestos present in each single census section were considered. As any law does not provide for at present the minimum or maximum limit harmful for human health, the density of asbestos at the national level was then considered, which is equal to 0.83% [7,8,9]. Interesting considerations emerge from the comparison of this national value with the density of the sections in the study area. As a matter of fact, it was noted that four census sections at least present a remarkable density of asbestos which reach values 3 or 4 times higher than the national mean, and high quantity of a-c for exposed. Consequently a particular attention should be paid to the protection of people's health in these areas (Fig. 6).

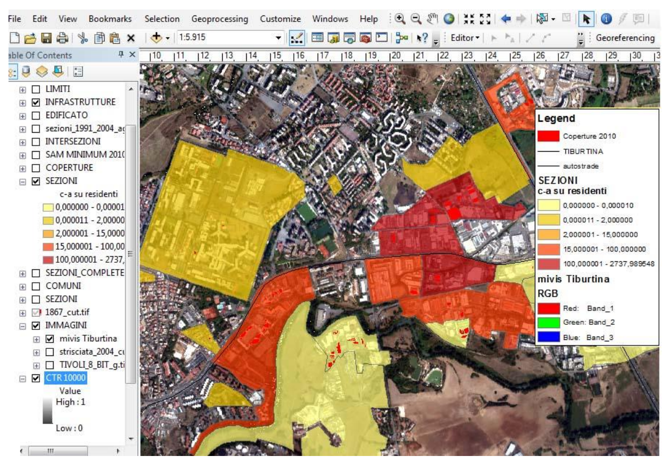

Fig. 6. Layout of the developed GIS mapping system over Tiburtina. With different colors is characterized the presence of a-c in m² in the census sections. The system indicates the risk in relation to residents.

Starting from remotely sensed data MIVIS and integrating them with cartographic data, statistical and environmental collected, were obtained a set of indicators and environmental data relating to census sections. The system is therefore essential for proper management by the Public Administrations of the study area, which suffers from many critical environmental issues [28].

5. Conclusions

The so far attained results confirmed good potentialities in the use of remotely sensed MIVIS data and data processing techniques for mapping a-c roof coverings. The methodologies illustrated in this work totalizing a surface of 120.878 m^2, with an accuracy of 95,6% obtained from ROIs test in ENVI and 79% from survey in situ assessment. Through combining data retrieved from MIVIS, ISTAT and RTM in GIS environment, it was possible to accurately map out the area of interest and the territorial profile of the area in short time. Minimum Bounding algorithm allowed us to obtain more accurate maps, reducing drastically working time; RTM was used as ground truth, given the characteristics, which are unique in their kind (scale, updating schemes, and topology), as confirmed by field surveys.

Moreover, the present work aimed at realizing a GIS for ASL users, though still in progress, gives rise to different considerations, both of theoretical and operative nature. The system proposed in this study represents the first effort for defining a procedure able to map, assess, and more in general, characterize a-c roofing present in urban areas, by using innovative instruments of investigation and spatial analysis such as GIS and remotely sensed data.

As aforesaid, the integration of these techniques of environmental survey enables an unlimited number of heterogeneous variables, which can be integrated and interrelated each another, to be rapidly managed by ASL users. Additionally, in the future, with the insertion of the GIS into latest tablet, it will be possible for ASL's to check and/or update information about each building in real time, to verify whether Abatement Plans were actually carried out, etc., so reducing the risk of mistakes in registering information or data loss.

In view of the above considerations, it is hoped that the system becomes a substitute or an integration at least of the current approach in Italy of managing a-c roofing. Moreover, its simple structure and easy accessibility make this instrument an effective support for workers with the task of inspecting territory.

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