ACTIVE (LIDAR) AND PASSIVE (MULTI/HYPERSPECTRAL) REMOTE SENSING TECHNIQUES FOR SUPPORTING THE EVALUATION OF THE URBAN SEISMIC VULNERABILITY

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ABSTRACT:

The extensive vulnerability assessment of the existent urban settlements is strictly required in many Italian regions where, despite the relevant seismic risk, the percentage of existent buildings designed without seismic prescriptions is higher than 50% . This paper describes the methodologies implemented for evaluating the geometrical and typological parameters of buildings in selected areas of Avellino (a seismic municipality in Southern of Italy), using different data remotely acquired by means of aerospatial platforms in order to support a suitably extensive estimation of seismic vulnerability at urban level. The activities were based on integration of digital aerophotogrammetry and laser ranging (LiDAR) techniques devoted to 3-D reconstruction (containing buildings geometrical parameters) of selected test areas. In this framework, data acquired by LiDAR sensor have allowed to obtain both the ground DEM and the buildings heights and shape over entire administrative area of Municipality of Avellino. These results were integrated with those derived from multi/hyper-spectral remote sensing techniques to achieve information about the structural typology of each building in the test areas by means different “data mining” approaches. In particular here the structural types of buildings have been estimated with 80% of accuracy using on purpose configured ANN (Artificial Neural Network). In such a way the integrated use of various information, coming from the different techniques, has allowed to produce, for each building within the test areas, useful information in terms of geometrical and typological parameters to be used for their extensive vulnerability assessment.

1. INTRODUCTION

Italy is one of the Mediterranean countries mainly susceptible to the seismic risk. In the last 2500 years, in fact, over 30000 seismic events of intensity equal to IV-V degree or higher have occurred in our country. Although all the national territory has been interested by significant earthquakes, except the Sardinia island, the highest values of seismic strength have been recorded along the Apennine ridge. In the southern Apennines, the area including Irpinia and Benevento province represents the most stroked zone, with seismic high energy events (magnitude between 6.5 and 7), occurred many times during the last centuries.

The consequences of a strong earthquake on the human, social, economic, cultural and historical tissue of the beaten area is enormous: in fact, besides an high number of casualties, in many cases it deeply damages the historical-cultural heritage and the economic-social structures. In Italy, the ratio between the damages produced by earthquakes and the energy released during the events is much higher compared with that of other Countries subjected to relevant seismic activity, i.e. California (USA) or Japan. As an example, the 1997 earthquake in Umbria and Marche Regions has produced severe damages (homeless: 32000; economic damage: approximately 10 billions of Euro), similar to the 1989 California one (14,5 billions of $ USA) but characterized by an approximately 30 times lower energy than 1989 event.

This arise mainly from an elevated settlement density and from the remarkable fragility of our building patrimony. A study produced by the Italian National Seismic Service (see the following tables 1 and 2) evidenced that more than 10% of the building patrimony of 64% of the Italian municipalities is potentially subject to an elevated vulnerability. Over the next 100 years, in 31% of the Italian municipalities at least 10% of the edifices could made out of use after a seismic event. A rough evaluation gauges that there could be approximately 800 casualties/year and beyond 1 billion of euros the direct damages deriving from probably earthquakes in Italy.

Seismic municipalities	Territory seismic surface	Peoples living in seismic municipalities	Buildings with an anti-seismic project
37%	45%	40%	35%

Source: Italian National Seismic Service

Table 1. Seismic classification over Italy (1984)

Italy	North	Centre	South
35%	30%	27%	39%

Source: Italian National Seismic Service

Table 2. Buildings protected from earthquakes in seismic zones

In this context the assessment of the vulnerability of the built patrimony is a problem in evidence for the most Italian territory, on which the percentage of rooms in buildings designed and realized in absence of anti-seismic prescription exceeds largely the 50%. Therefore it turns out very important to implement effective instruments for extensive, timely and repetitive analyses of the existing urbanized areas in order to gain for each building its geometric and typological more meaningful parameters that, joined to those of soils, allow effective estimate of vulnerability to be used for improving the prevention and mitigation methodologies, to support of the policies of territorial planning and the eventual post-event management.

2. METHODOLOGY AND RESULTS

The basics information necessaries for the evaluation of buildings vulnerability include those related to their three-dimensional geometry (mainly height or number of floors) and the type of adopted constructive technique. The recent advances of remote sensing techniques in terms of sensors, platforms and systems makes them very attractive and able to supply effective contribution to these specifics monitoring needs in terms of geometric resolution, operability and accuracy. From this point of view, taking account of the requirements for extensive estimate over existing urbanised areas and the previously illustrated needs a methodology has been implemented and calibrated with the objective to answer to these requirements using remotely sensed data taken by aerospatial platforms. In particular, as synthesised in Figure 1, the extensive appraisal of the geometric parameters of buildings has been carried out by means of active LIDAR technology (Crosilla F. et al., 2007) supported by aerophotogrammetric techniques (Pollino M. et al., 2005), while for the edifices typologies multispectral and hyperspectral data acquired by airborne and satellite platforms have been used in conjunction with others auxiliaries information and “data mining” approach.
The employment of GIS techniques coupled with tailored ground calibrations of above described procedures has allowed detailed estimation (at a scale of 1:2000) of geometric and typology attributes for every building in test areas with consequent assessment of its vulnerability index within an on purpose configured geo-database suitable to support local policies decision makers and planning of ad-hoc interventions in case of pre/post-event different scenarios.
Although for iron concrete buildings that represent the majority of the housing patrimony present on the Italian territory, could be possible more rigorous approach based on vulnerability defined as probability of damaging (derived from the related fragility analytical trends calculated for standard structures), the important presence of constructions in masonry especially in the historical centres of municipalities pertaining to the large historical patrimony, often with remarkable cultural features, justifies our more simplified approach mainly based on the index of vulnerability I_v. I_v is defined through the statistical analysis of the damages on the build patrimony inventoried as a result of the seismic events happened (Giovinazzi, Lagomarsino, 2001) in the paste on a regional basis. Such index is based firstly on the typology of the constructions which identifies macro-groups with those more representative in our test areas constituted by the reinforced concrete and masonry.

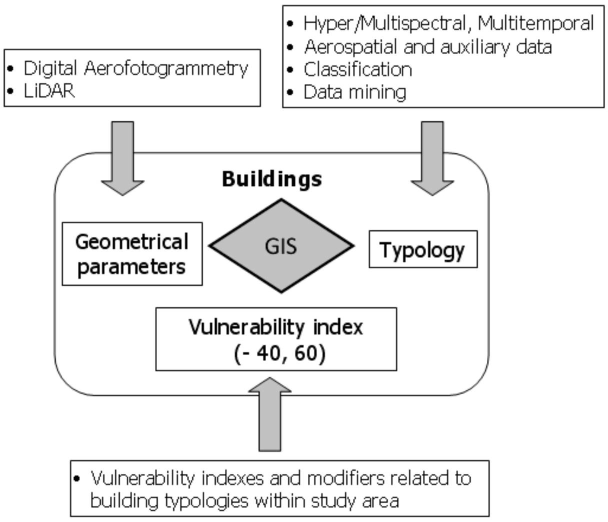


Figure 1. Methodology schema

Referring to this case study, if we take in mind only of the buildings in masonry they turn out more important those realized in full fire-bricks and those in masonry not armed with reinforced concrete floors, while for those completely in iron concrete it is necessary to distinguish from buildings constructed with required anti-seismic features after year 2000 from the others built before. The index I_v gets greater for the weaker structures more susceptible to be damaged and it has an interval going from -50 to 60. In addiction to the buildings typologies, I_v is related also to other parameters and above all to the geometric ones which determine the modalities of response to the seismic wave in terms of displacements.

Typ.	*Cod.*	*Construction age*	I_v	*Maintenance*	*Floors N°*			*Agglomerate*
					1-2-3	*4-5-6*	*6+*	
Masonry	M6	From 1946 to 1971	30	6		5	10	6
		After 1971	20			5	10	6
Reinforced concrete	PC1	Before seismic classification (<2000)	20		-6		6	6
	RC2	After seismic classification (>2000)	0		-6		6	

Table 3. Vulnerability indices and modifiers for the buildings typologies presents over the study area

For the three above described prevailing typologies in the zone of interest indicated by related codes (Cod.), in Table 3 are shown the indices of medium vulnerabilities (I_V) with typical age of construction and the respective modifiers, depending on the level of maintenance, the height (expressed in number of floors) and from the belongings to agglomerates (Giovinazzi, Lagomarsino, 2001). Besides these parameters, other proposed modifiers include the building’s symmetry in elevation and planimetric and the geological/geotechnical characteristics of the soils beneath. Therefore, in general, besides relative information to typology and state of the construction, it’s important to have also information on height, surface and shape of the buildings existing in the urban area of interest, from which to derive the geometric parameters modifiers of Table 3.
A LIDAR airborne remote sensing mission was planned and carried out in 2007 over the entire municipality of Avellino through an equipment Optech ALTM 3100 to acquire range point cloud data with an accuracy of 4 points for square meter

and a flight plan designed to optimize the three-dimensional restitution of the buildings in the urbanized areas. The LIDAR raw data, once filtered and georeferenced, were then processed through original methodologies implemented and calibrated on the areas of interest(Borfecchia F. et al. 2007), to extract the DTM (Digital Terrain Model) of the ground and the altimetry in correspondence of the buildings (DSM, Digital Surface Model), both at a suitable resolution.
From these last ones, by subtraction it was then possible to derive extensively the heights and then the number of floors for singles buildings within test area.

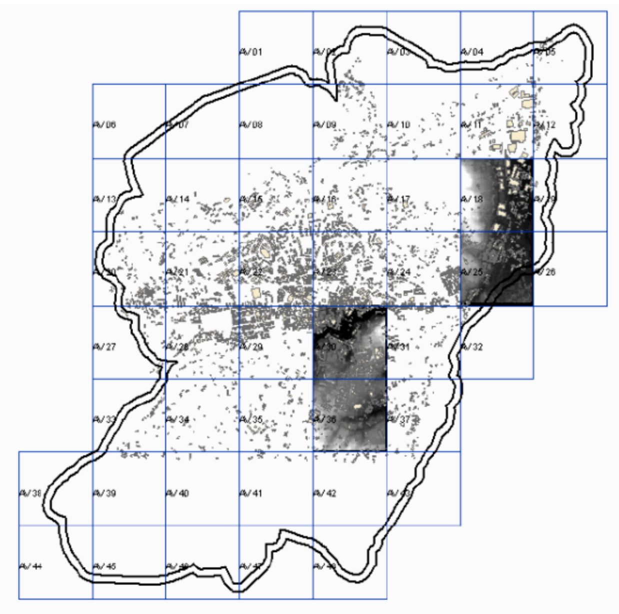


Figure 2. Avellino Municipality: distribution of built-up areas and synoptic table of LiDAR data collection (in grey tones, the DSM of two test areas)

Given that the Optech ALTM 3100 is able to handle the laser multi-returns from semitransparent tree canopies, more reliable estimates were carried out also in urbanised areas where the shape of edifices is partially occluded by trees or vegetation. The LIDAR data, opportunely processed, besides to concur to a better planimetric and altimetric definition of the buildings, were used also for the geometric characterization of the buildings roofs (in five classes) and for the location of the distribution of the vegetation in the study areas (Figure 1). In contemporary to the LIDAR data collection, by means of a digital camera was acquired a photographic RGB digital cover of the whole area in order to produce an orthophoto of the entire territory of Avellino, with a ground pixel size of 20 cm.
After the above described LIDAR and photographic data acquisition a further remote sensing task been carried out by means of an hyperspectral passive system using a programmable sensor with acquisition bands from the optical to the NIR (Near- Infrared). This airborne system, called AISA-Eagle, is capable of collecting up to 244 bands, ranging from 400 to 1000 nm and spectral resolution of 2.33 nm. In order to optimize the spectral signatures at building level, and considering the high correlation of the spectrally contiguous records, for the Avellino mission the AISA-Eagle acquisition range has been divided in 31 bands (table 4). The spectral signatures of the roof of every building obtained from such data (Figure 3) were then used in a integrated and synergic way with the others information (referring mainly to geometric features of buildings) obtained through aerophotogrammetry and LIDAR, for estimating the building typologies present in the areas of interest.

N. band	c−λ (nm)	FWHM
1	402,01	10,1
2	417,61	10,1
3	436,61	10,1
4	455,61	10,1
5	474,61	10,1
6	493,61	10,1
7	512,61	10,1
8	531,61	10,1
9	550,61	10,1
10	569,61	10,1
11	588,61	10,1
12	607,61	10,1
13	626,61	10,1
14	645,61	10,1
15	664,61	10,1
16	683,61	10,1
17	702,61	10,1
18	721,61	10,1
19	740,61	10,1
20	759,61	10,1
21	778,61	10,1
22	797,61	10,1
23	816,61	10,1
24	835,61	10,1
25	854,61	10,1
26	873,61	10,1
27	892,61	10,1
28	911,61	10,1
29	930,61	10,1
30	949,61	10,1
31	968,61	10,1

Table 4. Spectral characteristics of AISA-Eagle bands

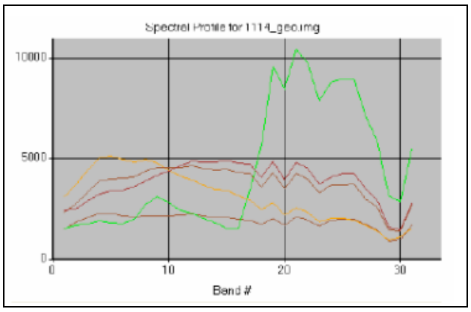


Figure 3. Hyperspectral signatures of buildings roofs (shades of red) and vegetation (green) over the study areas.

To such aim “data mining” methodologies (S.B. Kotsiantis, 2007) were implemented and used, particularly Artificial Neural Network (ANN), KNN and Decision Trees, were calibrated and validated through ground surveys data collection acquired at same time of the LIDAR flight (Table 5), according to the general schema reported in Figure 4.

Code	*N° of buildings*
PC1	38
RC2	189
M6	6

Table 5. Ground collection of building structure typologies

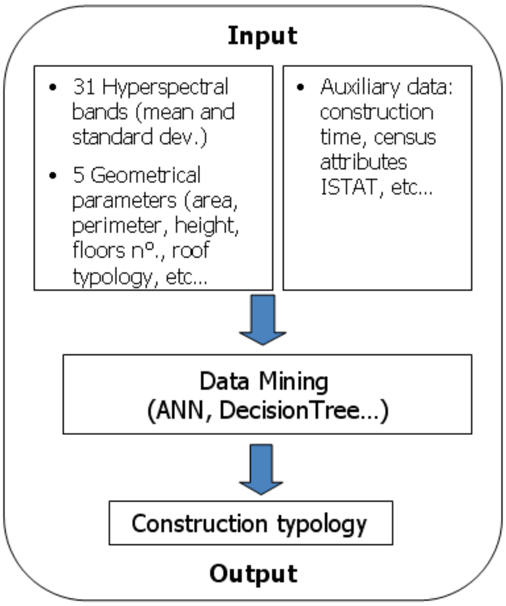


Figure 4. General processing schema to recover construction typology from geometrical, spectral and auxiliary data of each building

In the Figure 5 is depicted the schema of the ANN network utilized (P. Brierley, B. Batty, 1999) with related accuracy matrix obtained. In this case, 60 randomly selected occurrences of the in situ survey data were used for training, while the remaining provided the validation of the network. Taking particular care to avoid overtraining, an accuracy greater than 85% was achieved.

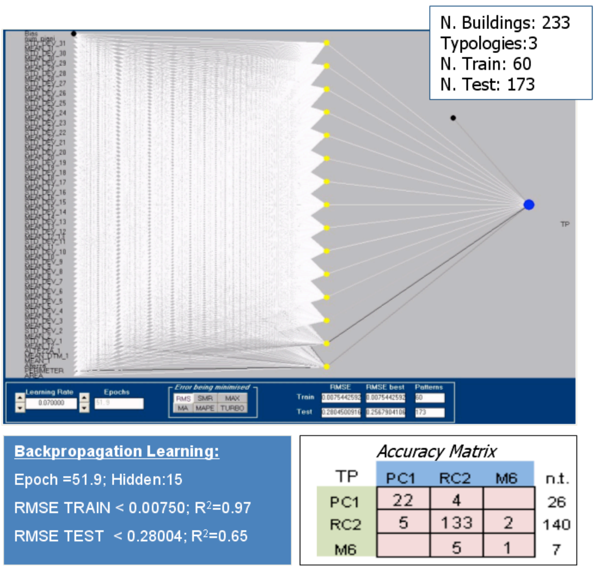
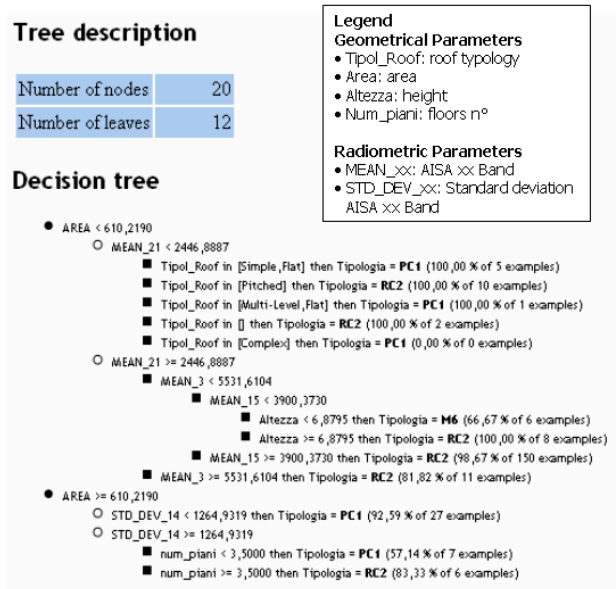


Figure 5. Sketch of the ANN network used and the parameters get from the test data. Calibration data and test of the Neural network with the joined accuracy (85%) over the test area

Decision Tree (Figure 6) and KNN were the others "data-mining" methodologies exploited (Quinlan, J. R., 1993 e 1996), according to the schema of Figure 4.

The performance of ANN and Decision Tree methods are similar when we used all the in situ data of the buildings within test area for their calibration. On the contrary, probably due to insufficient in situ sampling data, especially for M6 class (masonry), Decision Tree shown lower suitability in case of more reliable processing schema based on training/validation approach.



Error rate			0,0515				
Values prediction			Confusion matrix				
Value	Recall	1-Precision		PC1	RC2	M6	Sum
PC1	0,9211	0,1250	PC1	35	3	0	38
RC2	0,9630	0,0267	RC2	5	182	2	189
M6	0,6667	0,3333	M6	0	2	4	6
			Sum	40	187	6	233

Figure 6. Decision Tree calibrated using all the 233 buildings in situ data with related Confusion Matrix and partial performance for the three classes evaluated.

3. CONCLUSIONS

Considering that the adopted buildings typologies are appreciably correlated to the age of their construction, as synthesized in Table 3, others remotely sensed multispectral data from the Landsat MSS/TM-ETM+ multitemporal series together with QuickBird images at higher spatial resolution, were processed to estimate the urban sprawl thematic evolution maps in the areas of interest (Figures 7 and 8) aiming at improving the location of buildings with different typologies. Taking into account the Landsat spatial resolutions which happens bigger than typical building size a Spectral Mixture Analysis (SMA) approach coupled with a "pixel-swapping" algorithm was adopted for the MSS-TM/ETM+ series, while for the QuickBird data both standard classification and "Object Oriented" methodologies were utilised.

Finally a last improvement was planned, based on information delivered from the Italian Institute of Statistics (ISTAT) and organized by the means of census sections. An example of used procedures is depicted in Figure 5, where an ANN network was configured to estimate the buildings typologies in the test area starting from the known in situ data of 233 buildings and making use of both the hyperspectral signatures and the geometric parameters of every building, with an overall final accuracy of beyond 85% (Table 6).

In Figure 9 a final map of the vulnerability distribution for each building in test area calculated on the basis of Table 3 is shown. How we can see the ANN network was trained using a sample of 60 buildings data while its validation has been carried out on the remaining 173.

Three were the buildings typologies considered, one of which in masonry and the others two in reinforced concrete (with and without anti-seismic features), with a meaningful dependency from the age of construction.

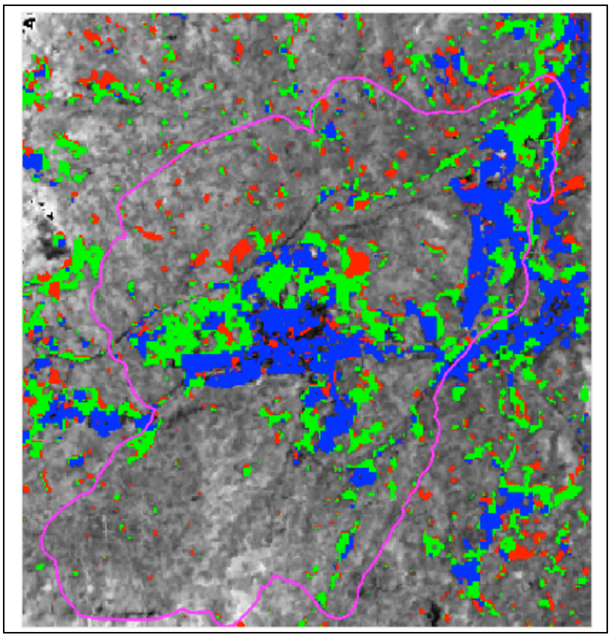


Figure 7. Urban sprawl in Avellino Municipality derived from the multitemporal Landsat series. MSS (blue 1975), TM (green 1993) and ETM (red 2000), via an SMA (Spectral Mixture Analysis) approach. Background: TM B4 and Municipality boundaries in violet

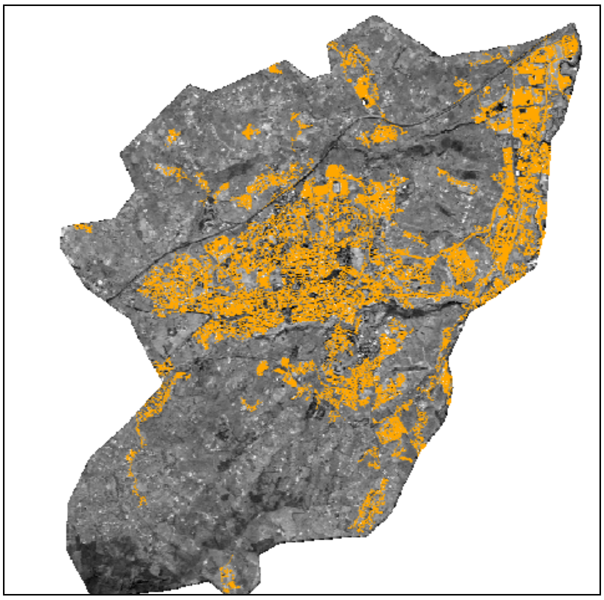


Figure 8. Urbanized distribution (yellow, layed upon the panchromatic channel) get by means of classification (Maximum Likelihood) of QuickBird images (May 2006)

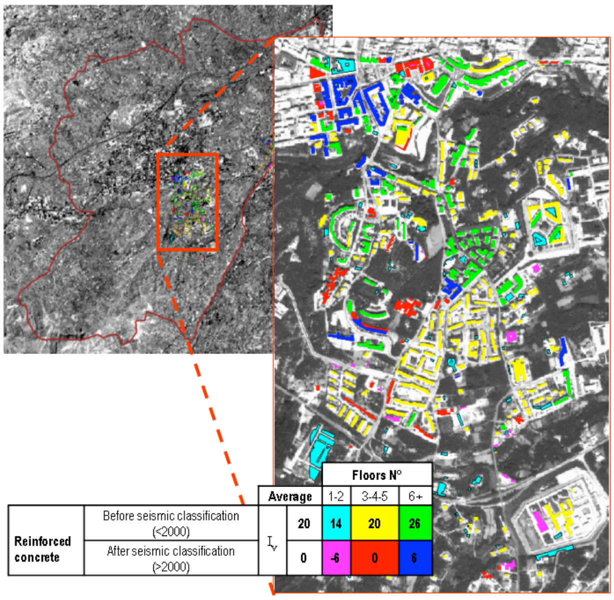


Figure 9. Distribution map of vulnerability index I_v calculated on the basis of Table 3. Background: Landsat ETM-Pan (2000) e QuickBird (2006)

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