Remote Sensing, Laser Scanner survey and GIS integrated method for assessment and preservation of historic centers: the example of Arsita

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SUMMARY:
Object of the present paper is to show an integrated study regarding assessment and preservation of the Arsita Municipality historic center (district of Teramo), a small town damaged by the Abruzzo earthquake (Italy) occurred on April 6th, 2009, carried out in the framework of the post-seismic reconstruction plan. The paper describes a multidisciplinary and integrated work related to technical in-field, DGPS (Differential Global Positioning System) and Laser Scanner surveys, associated with GIS (Geographical Information System) and other advanced Geomatics techniques, such as Multispectral Remote Sensing and Remote Sensing Proximity. Radio-controlled UAVs (Unmanned Aerial Vehicles) used for high ground resolution, has been fundamental for damages detail observation in the inaccessible parts of buildings and roofs survey. The above said surveys resulted fundamental to support hazard analysis and building vulnerability evaluation, devoted to propose mitigation actions and urban habitat rehabilitation strategies in the historic center.

Keywords: seismic hazard, historic centres, remote sensing, GIS, laser scanner 3D.

1. INTRODUCTION

About two years after the April 6th, 2009 Abruzzo (Italy) seismic event, a scientific team set up by ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) with Universities of Pescara-Chieti, Naples "Federico II" and Ferrara visited the Municipality of Arsita (district of Teramo), a small town damaged by the earthquake, to show its resources for training and demonstration activities within the Master in "Bio-sustainable Architecture" of University of Bologna. The investigation, continued in the current year, has been focussed on the effectiveness of a multidisciplinary approach based on the simultaneous application of Remote Sensing techniques, GIS (Geographical Information System) tools, DGPS and Laser Scanner surveys, together with quick procedures for vulnerability evaluation, continuing a research approach targeted on hazard, vulnerability and risk evaluation in the historic centres. A group of about twenty researchers and stage graduates (architects, structural engineers, geologists, Remote Sensing and GIS experts, art historians, and other technicians) began a work targeted on the following topics: assess natural (mainly earthquake and landslide) and anthropogenic hazards, construction vulnerability (including earthquake damage, structural details, maintenance, materials features) and risk; perform in situ surveys (topography, landscape and land use analysis, urban planning and architecture, infrastructure, etc.); evaluate energy efficiency and sustainable techniques for future interventions. The next phase of the activity (this year) will consist in the detailed preparation of the Post-earthquake Reconstruction Plan for the Arsita Municipality (through in situ and laboratory work), which is going to be entrusted to ENEA (as team leader), with the support of the above mentioned universities.

This paper concerns the part related to the surveys, DGPS (Differential Global Positioning System) and Laser Scanner, satellite and UAV remote sensing through radio-controlled vehicles, GIS system, support to the vulnerability assessment of the historic centre.

2. REMOTE SENSING AND GIS METHODS APPLYED FOR LANDSCAPE AND GEOMORPHOLOGY STUDIES

2.1. Satellite image analysis

In this study we have applied the techniques of satellite and UAV remote sensing using radio-controlled vehicle (drones). The satellite remote sensing allows a synoptic view of the study and observation in different spectral bands (from visible to infrared) of the earth's surface; for this purpose has been acquired a Landsat 5 TM satellite scene of November 2006 with a spatial resolution of 30 m of the study area (Fig 2.1.). The image has been used for the geomorphologic characterization through photointerpretation and land cover types with automatic classification techniques. The objective of image classification is to replace visual analysis of the satellite data with quantitative techniques for automating the identification of features and land coverages in a digital satellite scene. This involves the analysis of multispectral image data and the application of statistically based decision rules for determining the land cover identity of each pixel in an image (Lillesand et al., 2004).

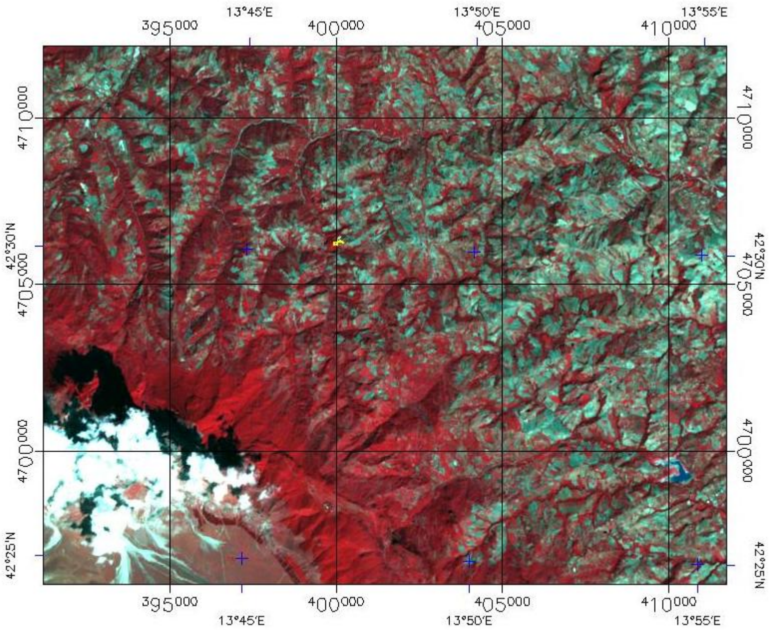

Figure 2.1. Landsat 5 TM multispectral satellite image: the colour image shows the morphology of study area and the land cover (in red the vegetation, cyan the bare soil). The city of Arsita is in yellow colour.

Photointerpretation for any purpose relies on several basic characteristics of surface and land coverage: tone, texture, pattern, shape, context and scale called also “key interpretation” and they are all more and less qualitative attributes; these are used in different combinations in the interpretation of digital images (aerial and satellite).
The Landsat satellite image (Fig. 2.1.) allowed the characterization of the landscape and geomorphological description of the study area; the photointerpretation of satellite data has revealed an fluvial network with a dendritic drainage pattern type and characteristic of homogeneous lithology

of sandstone and shale.

2.2. UAV remote sensing

UAV remote sensing is a set of techniques for collecting data through the use of various kinds of sensors (optical, chemical, etc.) mounted on carriers operating at low altitude. Normally, the proximity sensing is used in all those cases where it is not possible or convenient to use the traditional platforms to collect data from high altitudes (small agricultural plots, archaeological excavations, buildings surveys).

Figure 2.2. The drone in the historic centre of Arsita

The UAV sensing is performed using specific types of aircraft including the most interesting technical characteristics, current performance and future potential are radio-controlled UAVs (Unmanned Aerial Vehicles); among these, UAVs or drones, used in Arsita, are a class of radio-controlled aircraft that can operate with the use of remote sensors on board (Fig. 2.2.).

Figure 2.3. The roofs of the historic centre and the damage.

The drone is fitted with an HD camera mounted on a carriage tilting in the three xyz axes; the whole system is controlled by a multi-channel radio. The photos taken from UAV have affected the roofs of buildings (Fig. 2.3.) and the landslide close to historic center, see Fig. 2.4.

Figure 2.4. The landslide area and the drone in situ.

The Figure 2.4. shows the landslide area, very important for the damage found in the buildings of historic center, and the drone in action to survey the area; with use of sensors in situ it will possible to monitor the landslide in the time.

2.3. Data merging and GIS integration

The acquired data have been integrated in GIS, a computerized information system that allows the acquisition, storage, analysis, display and return information from geographic data (geo-related). For the processing and spatial analysis of GIS data, was used open source software QGIS (http://www.qgis.org) and Grass (http://grass.osgeo.org). These procedures are used to combine image data for a given geographic area with other geographic referenced data sets for the same area. The extracted data from the photointerpretation and classification of satellite images were matched and processed with other spatial data: lithology, CORINE Land Cover, geomorphology, hazard (Fig. 2.5.).

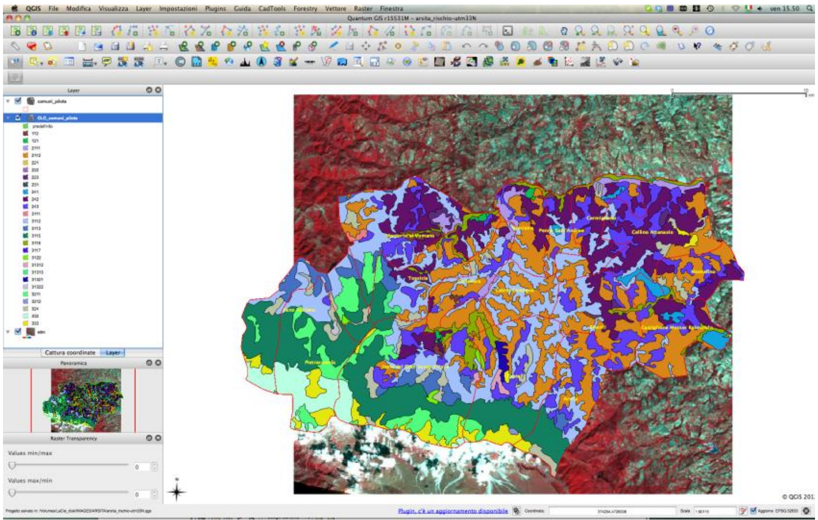

Figure 2.5. GIS processing of geographical data in software QGis: satellite and spatial data overlap and tried to get new thematic maps and spatial indexes. In the lower right, the Municipality of Arsita.

The raster satellite and vector territorial data were processed in a GIS environment, by clips and intersection geoprocessing tools in order to obtain spatial indexes that allow the realization of maps of integrated risk.

The project allows to develop an innovative method of work; the principal goal is to collect any type of data using the new technologies like tablet and smartphone. The first step is to develop a database for enter the data on digital supports. The operator, in situ, with the tablet or smartphone, enters the data like vulnerability forms, building data, damages, etc., and he take the photo for the database. All data are entered offline but it is possible to work online with a server database.

Figure 2.6. Database and data entry system.

The methodology has several advantages: any data is georeferenced, the operator inserts, real time, notes, sketches and measures. The in situ investigation allowed to collect a lot of data at different levels. The second step is check the data collected from any source and transfer them to the server while the third step is to convert all analogical data in digital format. In Fig. 2.6. there is a diagram of the system.

All existing maps have been collected: vector data and raster data like aerial photo (Fig. 2.7.), satellite image and DEM (Digital Elevation Model). GIS software aim is to describe, analyze, question and represent all the different layers of the information; in fact, when a multidisciplinary approach is followed in the study the geo-database represents the best solution and synthesis, providing an updated "vision" of the territory.

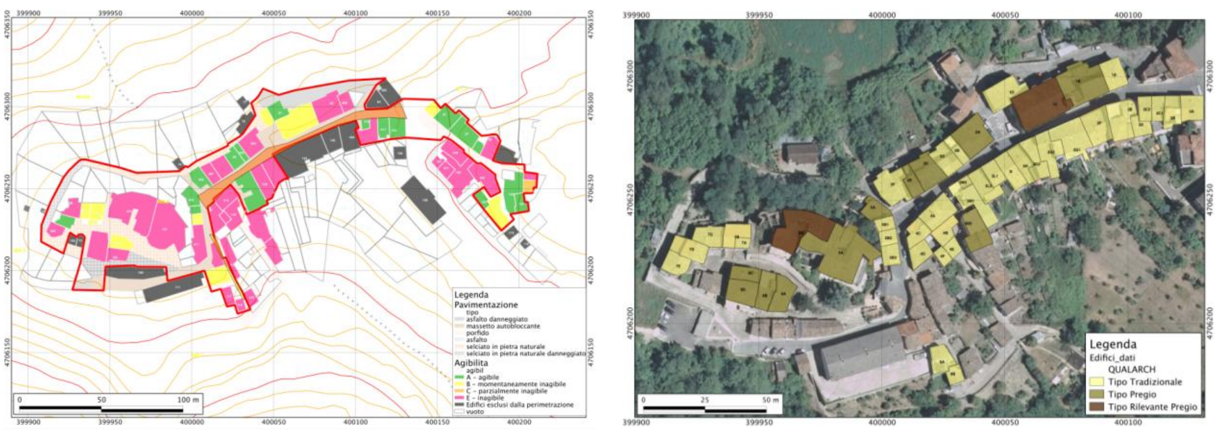

Figure 2.7. Vector and raster data displayed in a GIS environment.

All the materials, present in the geo-database, are available on line to the researchers, for immediate consultation, modification, update and query. The GIS work is in progress; new modules, like WebGis and mobile GIS that query the data in central database, will be implemented.

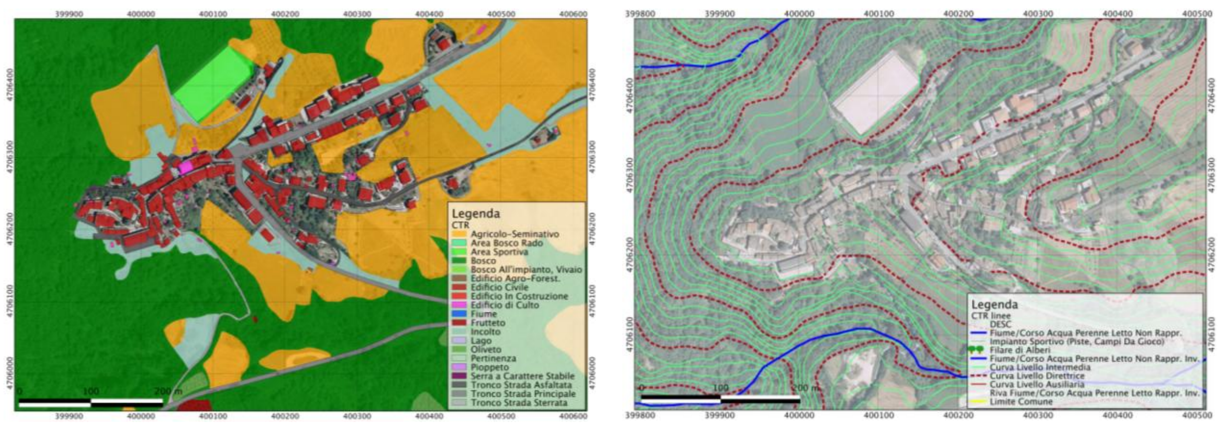

Figure 2.8. Vector data displayed in a GIS environment: land cover and technical regional maps.

3. TOPOGRAPHIC AND LASER SCANNING SURVEY OF THE HISTORIC CENTER

In the framework of this multidisciplinary project a laser scanner survey of the historical center of the town of Arsita was included with topographic support. The topographic survey consisted in the measurement by DGPS (Differential Global Positioning System) of a set of points along the Arsita city centre main street, in order anchor positions for the parallel Laser Scanner investigation. The topographic survey was conducted with two dual-frequency DGPS Trimble receivers 5700 model . It was chosen to use the "Fast static" survey style with an acquisition frequency of 15 seconds. The total duration for each session was setted to 10 minutes, with at least the availability of 6 satellites during the measurement, otherwise the measure has been prolonged in time, till 20 minutes.

The main aims of the this task were: to acquire the geometry of the front façade of the buildings facing the main streets in order to recover features like doors, windows, ledges, railings together with the main outlines of the structures; to provide useful data for the generation of a 3D model of the historic center together with CAD drawings; to identify, where the geometrical dimension was perceptible according with the laser scanner resolution, cracks and damages in order to plan the restoration of buildings with urgent priority, due to their precarious conditions.

The survey took place during July 2011, lasting for three days, and was operated by a crew of three technicians. It had to be interrupted before the conclusion of the digitization of the whole center, due to bad weather conditions which could have affected the quality of the data acquired. More than half of the historical city center was digitized creating a final point clouds of approximately 29 million points. Twelve stations were realized starting from the old tower in the south west corner of the town and moving toward north east along the main streets.

Due to hostile conditions encountered in an environment affected by an earthquake, the laser scanner was powered either connecting to the electric power line, or using an UPS (Uninterruptible Power Supply). The laser scanner involved was the Leica Geosytems HDS 3000, controlled by the proprietary software Cyclone through a dedicated notebook, which can acquire up to 5000 points per second with a range of around 300 meters. The field of view (FOV) of this model is 360 degrees on the horizontal axes and 270 degrees on the vertical axes, with an accuracy of 3 millimeters at 50 meters certified by the manufacturer. The resolution chosen in order to be able to extract CAD plans and sections with a scale 1:100 was 2 cm x 2 cm. This parameter means that the distance between each point was 2 cm x 2 cm. For each station there were placed reflective targets (at least three) used during the post processing phase to register all the single point clouds in a unique reference system.

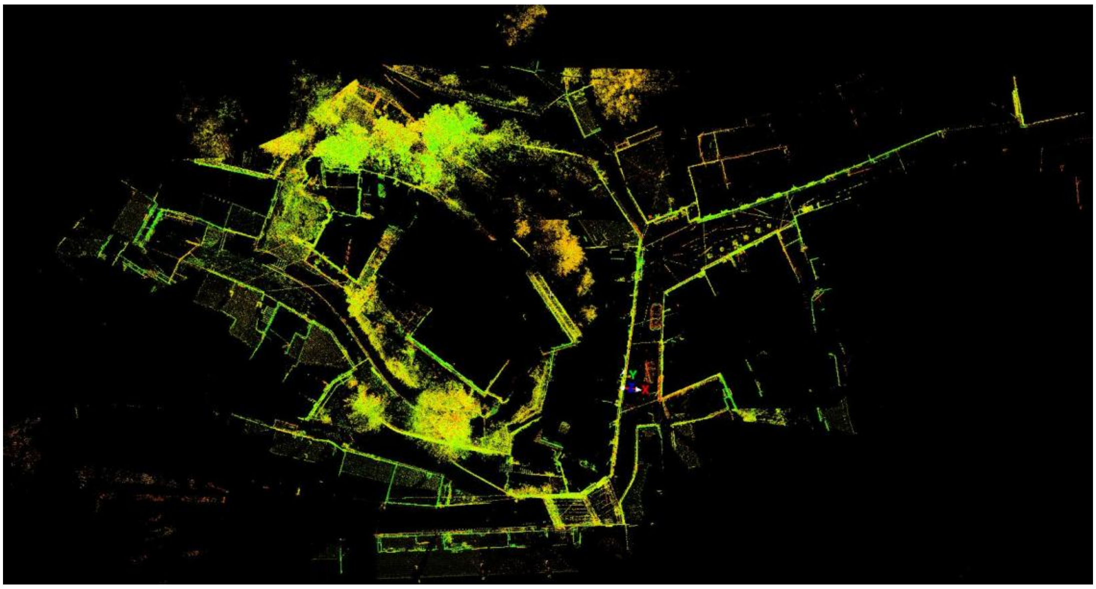

Figure 3.1. Total Point Cloud Data of the historic centre of Arsita

Some of the area of the town were closed by fences and thus not accessible due to safety conditions. Moreover some structures were obstructed by the vegetation which has been growing wide after the earthquake and the subsequent evacuation of some houses and buildings. These two critical factors resulted in missing data which have to be integrated with different techniques or further surveys.

After the data acquisition on the field, the point clouds have been elaborated using the software Cyclone. First step was the alignment (registration) of all the twelve stations in the same reference system. This task can be accomplished either in a full automatic way exploiting the reflective targets acquired during the survey, which are recognized by the software, or using a semi-automatic approach.

A semi-automatic alignment is mostly characterized by two main steps: the first one consists in the identification of homologues points (at least 3 in *Cyclone*) in the superimposed area of the two range maps (point cloud acquired from a station). In this step the operator's intervention is massive and time consuming. The second step is represented by the automatic alignment, until the average distance between the two range maps is minimized (ICP- Iterative Closest Point).

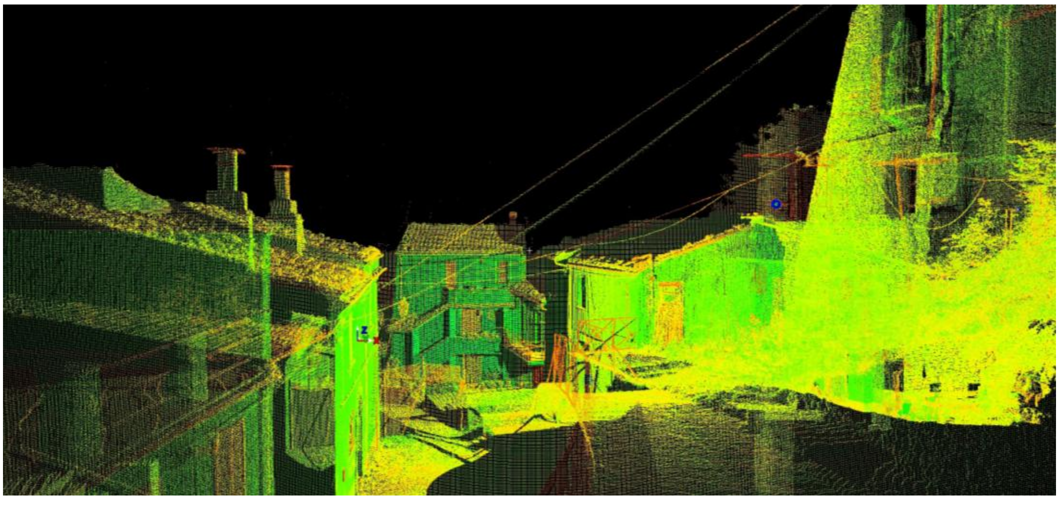

Figure 3.2. Point Cloud Data (reflectance value)

The ICP algorithm is widely used for geometric alignment of three-dimensional models when an initial estimate of the relative pose is known. The algorithm is conceptually simple and is commonly used in real-time. It iteratively revises the transformation (translation, rotation) needed to minimize the distance between the points of two raw scans.

After the global alignment, the point cloud has been filtered in order to remove objects or artifacts acquired during the survey but not useful for the final goals. This was performed both applying different kind of automatic filters and removing manually the unwanted data. All the “noise” was then placed on a specific and dedicated layer.

The first output made available was an application accessible via web to interact and visualize the point clouds. This was possible through the Leica Geosystems Trueview plug-in for web. Lately, for each buildings have been created peculiar UCS, prospects and orthophotos, useful to extract CAD drawings from the point cloud. This operation have been performed manually exploiting the Leica Geosystems plug-in Cloudworx for AutoCad. This plug-in allows to take advantage of many Cyclone features and commands inside AutoCad environment.

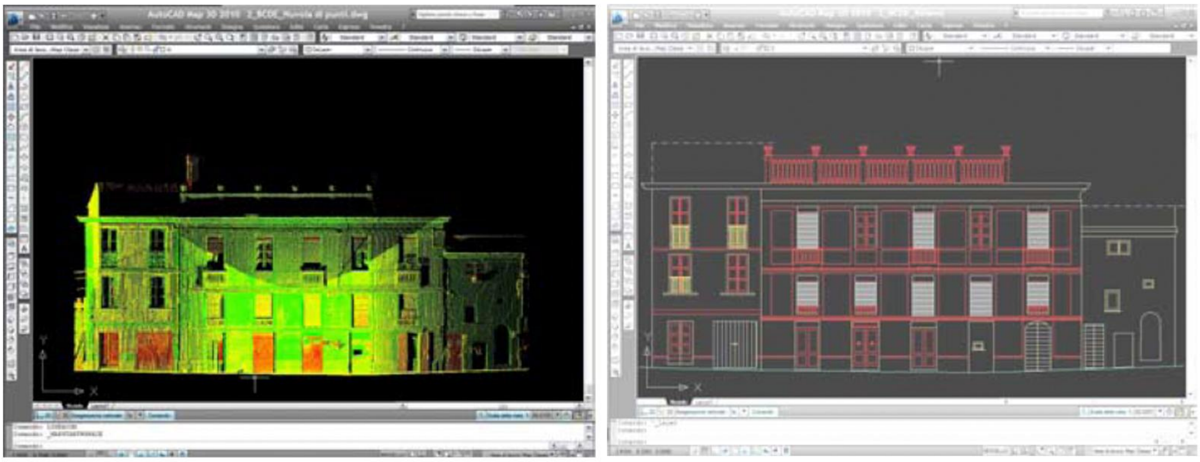

Figure 3.3. Orthophoto Image and Cad Drawing

At the end of the data post processing the final results consisted in: global point clouds of the historical city center of Arsita (29 million points); CAD drawings of all the façades of the buildings placed along the main streets (scale 1:100) and acquired during the survey; orthophotos and different kind of views of the 3D model; trueview application to interact via web with each single point cloud acquired during the laser scanner survey.

4. DISCUSSION AND CONCLUSIONS

A preliminary campaign in the surrounding land provided suggestions for the next hazard analyses to be done, focussing especially on earthquake and landslide (geological and seismological aspects).

The technical scientific activities performed at Arsita until now are only the first demonstration step of a more complex work, which will be completed within this year by a multidisciplinary team (introduced above), in the framework of the realisation of the historic centre reconstruction plan, which is going to be entrusted to ENEA as team coordinator. The plan is addressed to propose, as final output, guidelines on urban planning, structural intervention, and sustainable development, based on the definition of mitigation actions and urban habitat rehabilitation strategies, avoiding conflicts with the conservation criteria of heritage.

The approach described in this study is multidisciplinary, and allows the crossing of spatial data and in situ, from different methodologies, for the subsequent creation of thematic maps of integrated risk.

The methodologies used are resulted fundamental to support hazard analysis and building vulnerability evaluation, devoted to propose mitigation actions and urban habitat rehabilitation strategies in the historic center. The approach, in fact, is at a preliminary stage and is expected to develop a multidisciplinary model with highly detailed data that allow a more reliable classification of integrated risk.

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