A MULTISCALE GEOMATIC APPROACH FOR THE SURVEY OF HISTORIC CENTRES MAIN STREETS: THE CASE STUDY OF CAPITIGNANO, ITALY

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ABSTRACT:

The aim of this research is the identification of geomatics techniques and methods capable of representing historic centres in a rapid, detailed and accurate manner. Indeed, historic centres are a cultural heritage asset to be preserved, protected and conserved for future generations, taking into account the history of a community. The paper describes a geomatics methodology applied to the case study of Capitignano (Italy), one of the municipalities that was affected by the 2009 earthquake that involved numerous historic centres causing extensive damage, not only in terms of human lives but also to the cultural heritage. The integration of geomatics techniques made it possible to obtain a georeferenced point cloud that is particularly useful for the description of buildings in historic centres, both at the urban scale and at the scale of individual artefacts. In addition, it was also possible to produce orthophotos with a high geometric resolution that made it possible to identify lesions in structures quickly and accurately.

Key-words: *3D survey, TLS, Geomatics, Historical center, Conservation, 3D model*

1. INTRODUCTION

Multiscale territorial knowledge is an important tool for the protection and conservation of historic centres (Pepe et al., 2020; Fiorini et al., 2022); digital survey and 3D representation are the first step for the implementation of cultural heritage protection and conservation activities (Costantino et al., 2016). Nowadays, new methods and techniques for geomatics surveying are emerging to digitally describe historic centres (Tenedório et al., 2016) and, more generally, cultural heritage (Bitelli et al, 2017; Pepe et al., 2022). Especially for historical centres characterised by multiple risk factors, such as the seismic one, a detailed survey of characteristic elements and spatial relations with other buildings play a fundamental role. In fact, Italy is characterised by insisting on a territory at seismic risk; from north to south, mainly following the Apennine ridge, earthquakes cyclically occur that strongly damage entire geographical areas, putting the lives of hundreds of people at risk (Bini and Bertocci, 2017). Therefore, the realisation of an accurate 3D survey makes it possible to analyse the criticalities present on structures and, consequently, to identify measures aimed at protecting and safeguarding historical centres.

3D models can be performed using image-based 3D modelling or range-based modelling (RBM) (Luhmann et al., 2019). In this paper, we will use an approach based on the use of RBM, which provide a highly detailed and accurate representation of a 3D object or structure. An example of an active sensor is the terrestrial laser scanner (TLS), which enables the rapid acquisition of 3D point clouds in an accurate and detailed manner (Elbshbeshi et al., 2023). For this reason, the TLS is commonly used in construction, architecture and engineering for precise measurements of buildings, as shown in Liu et al., 2023.

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TLS offers many advantages with respect to other surveying techniques, acquisition speed, reliability of data, etc. and it allows to obtain point clouds even with high accuracy, even up to a few millimetres (Ebolese et al., 2019). Furthermore, 3D lasers are now available on the market with different features that can be easily adapted to each application (Costantino et al., 2022). The output of a scan is in general a point cloud of n observations consisting of 3D positions $(xi, yi, zi)_i = 1...n$ of each point in a Cartesian coordinate system with the origin in the lasers canner centre, as well as an uncalibrated intensity value of the reflected light.

The TLS uses these principles; time-of-flight (TOF) and phase-shift (PS). In the TOF, a short laser pulse is emitted towards the target and reflected from the surface; the scanner detector measures the difference of the sending and arrival time. In the PS measurement method, the distance is determined by the phase difference between the sent and received waveforms (Soudarissanane et al., 2021; Costantino et al., 2021).

The paper illustrates an urban survey experience aimed at the preparation of multi-scalar 3D digital models of the territory of Capitignano (Italy), one of the municipalities included in the crater of the 2009 L'Aquila earthquake, which not only caused painful events, but also took on the connotations of a destructive event for the historical and artistic identity of a territory (Varagnoli et al., 2009).

2. METHOD

Architectural and urban surveying in extensive post-earthquake areas, such as the urban centre of Capitignano, implies carrying out survey activities on a wide variety of inhomogeneous artefacts, with different problems, related for example to: the 'state of health' of the structures; the limited accessibility; the difference in survey scale, where it is not possible to proceed according to standardised operational and methodological schemes. The great diversification of scale is often found within the same site, implying the need to use more than one surveying instrument to survey and control them. The knowledge of the current state, conservation and valorisation, involve document-based interventions that can affect both the construction aspects of individual buildings and those related to the urban form.

The process that leads to the construction of the model can be summarised in the following steps: i) planning of survey activities; ii) geodetic framing and topographical survey at different scales; iii) laser scanner survey; iv) post-processing of geomatic data and identification of critical issues on structures.

3. CASE STUDY

The present study concerns the territory of the Municipality of Capitignano (Italy), which is composed of six hamlets: Aglioni, Colle noveri, Mopolino, Pag-Rovagnano, Paterno, Sivignano (**Fig.1**). In fact, the 2009 earthquake with epicentre in Amatrice (Italy) caused extensive damage to the public and private building heritage, both in the hamlets and in the historical centre, where there are important examples of historical buildings such as Palazzo Ricci, rebuilt between 1783 and 1839, and the adjacent Church of San Domenico built in 1579 (Varagnoli, 2015).

Moreover, the earthquake affected not only the heritage in its historical strongholds, but the entire housing fabric, rich in stratified layers from the various eras. Consequently, the identification of a methodology capable of representing the heritage of historic centres in a detailed, timely and precise manner assumes an important role.

a)

b)

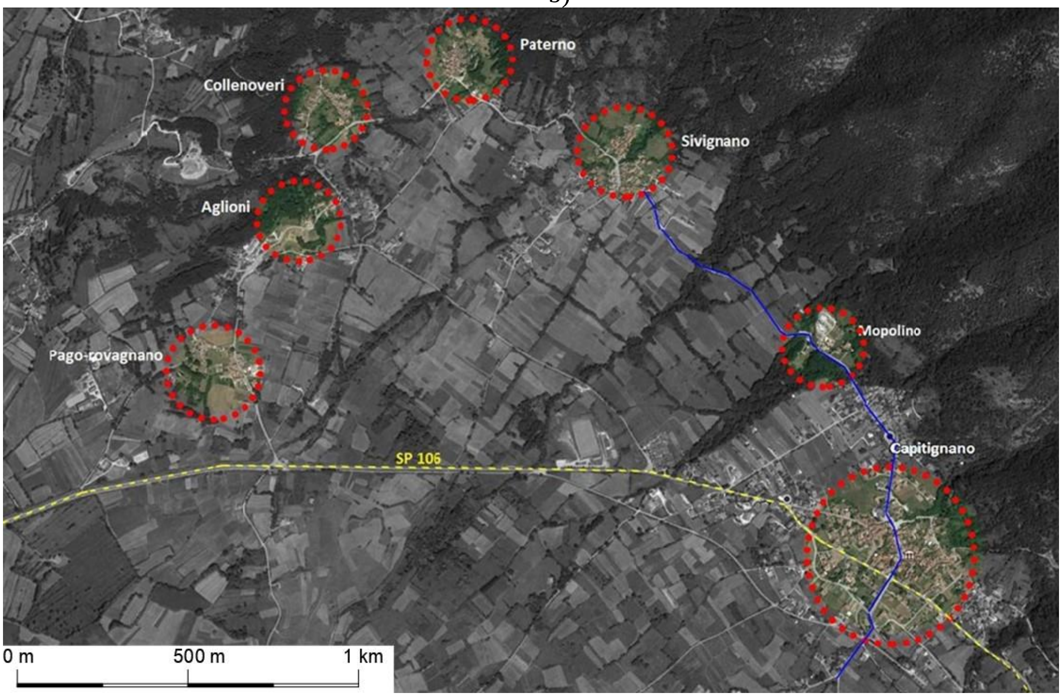

Fig.1 Cartographic outline (a) and identification of the six hamlets that make up the Municipality of Capitignano (b).

3.1. Planning of survey activities

Over the years, the study of architecture, historical centres, art and architectural artefacts has been characterised with multiple methodologies, both theoretical and technological. The intercommunication between the different surveying techniques provides indispensable elements of control and completion. In the light of the problems outlined above, it was considered that the use of the TLS technique supported by the established topographic techniques was particularly suitable for obtaining an exhaustive documentation of the heritage in a very rapid and economical manner. In planning the survey, account was taken of the indications provided by the 'Struttura Tecnica di Missione-STM' in the draft special specifications which represent an excellent contribution for both technicians and administrations in supporting the municipalities affected by the earthquake of 6 April 2009. The survey of the municipality of Capitignano is more concerned with the main axis of the village that connects the municipality to the six hamlets, up to interior details of the church of San Domenico built in the highest part of Capitignano. In planning the survey, several difficulties were taken into account, including:

- The vastness and fragmentation of the areas to be surveyed;
- The framing of the six hamlets and the village in a single reference system;
- The need to survey different areas, both on an urban scale (building encumbrances) and on an architectural scale (decorative details);

The surveying operations were preceded by careful planning that included the identification of homogeneous zones, and the consequent choice of suitable instrumentation. In particular, an ordered series of methodologies and procedures distinguished in the following phases were planned and implemented (see **Fig. 2**):

- GNSS geodetic survey (Leica ATX1230);
- Total station survey (Leica TCR 705);
- TLS long range survey (Topcon GLS1000);
- TLS medium range survey (Faro focus x130);
- Post processing of geomatics data.

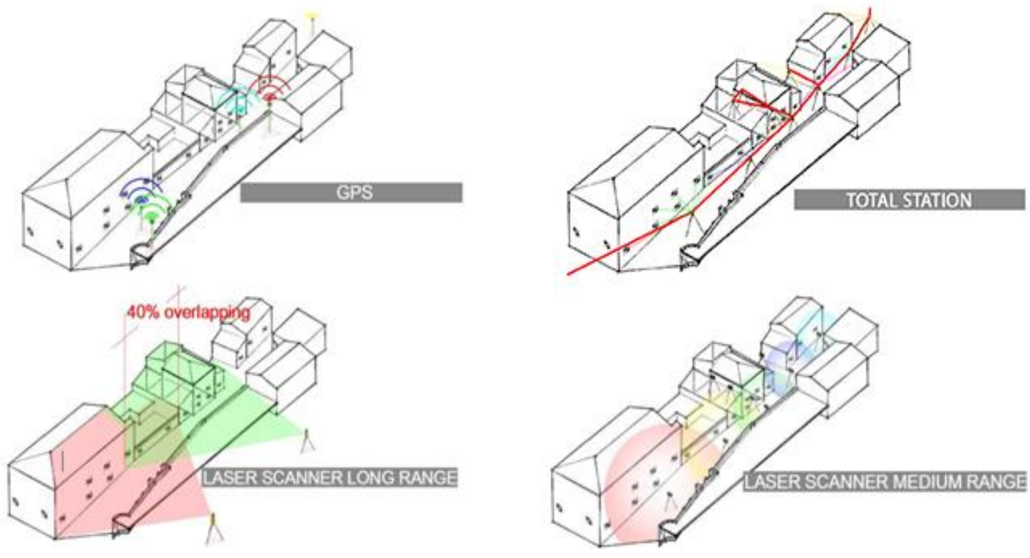

Fig. 2. Outline of the survey techniques used.

3.2. Geodetic survey and topographical survey

In order to unify the surveys of the various hamlets of the Municipality of Capitignano in a single reference system, it was decided to carry out a GNSS survey. The survey phase was preceded by a careful selection of the nearest points of the regional geodetic network; the points of the network thus identified will support the secondary network acquired with the GNSS. In particular, three points of the regional network were taken into consideration that frame all the areas to be surveyed. For the survey of the main street of Capitignano, a Leica ATX GNSS was used, taking care, after appropriate reconnaissance, to position the points of the secondary network so that they are clearly visible from the satellites and without reception obstacles. The points thus chosen are of service to the subsequent survey phases, both with the total station and the laser scanner, thus providing a common reference system for the various survey techniques and the six hamlets of the municipality. The result obtained from this survey methodology is a network of georeferenced three-dimensional points, homogeneously distributed over the survey area. Additional control points were materialised through the use of targets appropriately registered with the total station. The correct distribution of the targets in view and within the range of the instrumentation, were used for the integration of the surveys performed with the total station, and the surveys performed with the laser sensors. Two types of targets were prepared, two-dimensional flat targets and three-dimensional spherical targets. The flat targets consist of appropriately sized chequered sheets imprinted on the surfaces, while the spherical three-dimensional targets consist of spheres with a calibrated diameter of 145 mm. Both spherical and flat targets are recognised semi-automatically by specific software, thus constituting a true dialogue and control tool for the various measurement techniques. The GNSS survey was followed by the topographic, urban and detailed survey phase. The topographic survey was carried out using a Leica TCR 705 total station (angular accuracy 5" -1.5 mgon and d Electrooptic Distance Meter - EDM measuring program: Standard measurement of 2 mm + 2 ppm while infrared Tape of 5 mm + 2 ppm). The first step was designing the topographic network and, of consequence, identify the closed traverse. In this phase, flat targets were surveyed for the orientation of the scans, detailed points for the definition of the infrastructure networks (manholes, light poles, etc.) and for the 3D wireframe plano volumetric model. Lastly, each station of the topographic network was georeferenced using the GNSS secondary network Ground Control Points (GCPs).

3.3. TLS Survey

Once obtained the coordinates of GCP and targets by GNSS, the next survey phase involves the use of TLS instrumentation. For such a diversified urban scale survey, the use of two different types of terrestrial laser scanners was planned, one of the medium range type and another of the long range type. The long-range type laser scanner used is a Topcon GLS 1000 with a range of approximately 300 metres; the main feature of this latter TLS is:

- 3000 precise points/second scan rate;
- 330m maximum range at 90% reflectivity;
- 150m maximum range at 18% reflectivity;
- 4mm accuracy from 1m to 150m;
- 6” horizontal and vertical angular accuracy.

This type of instrumentation lends itself well to surveys of large portions of the territory, while it is slow and not very versatile for architectural surveys and surveys of small environments, having as a disadvantage the reduced camera angle (70 degrees). In particular, it was decided to carry out the survey with this type of instrumentation (Topcon GLS 1000), positioning the laser scanner at the furthest points of the country, so as to obtain a georeferenced point cloud using the previous GNSS points. The medium-range laser scanner used is a Faro Focusx130, which is capable of measuring up to speeds of 976,000 points/sec and up to a range of 130 m; the system also includes also includes an integrated colour camera, equipped with automatic parallax-free colour overlay of 70 megapixels. By the use of this latter TLS, it is possible to obtain a 3D coloured point cloud in easy and quick way. The individual scans were joined together using both flat targets whose coordinates are known, and spherical targets, whose centre of the sphere is taken into account. The scans were carried out by imposing fixed quality and resolution parameters in homogenous areas in order to achieve uniformity in the post-processing of the data.

Figure 3 shows the integration of the different geomatics techniques used for the surveys along the street of Capitignano.

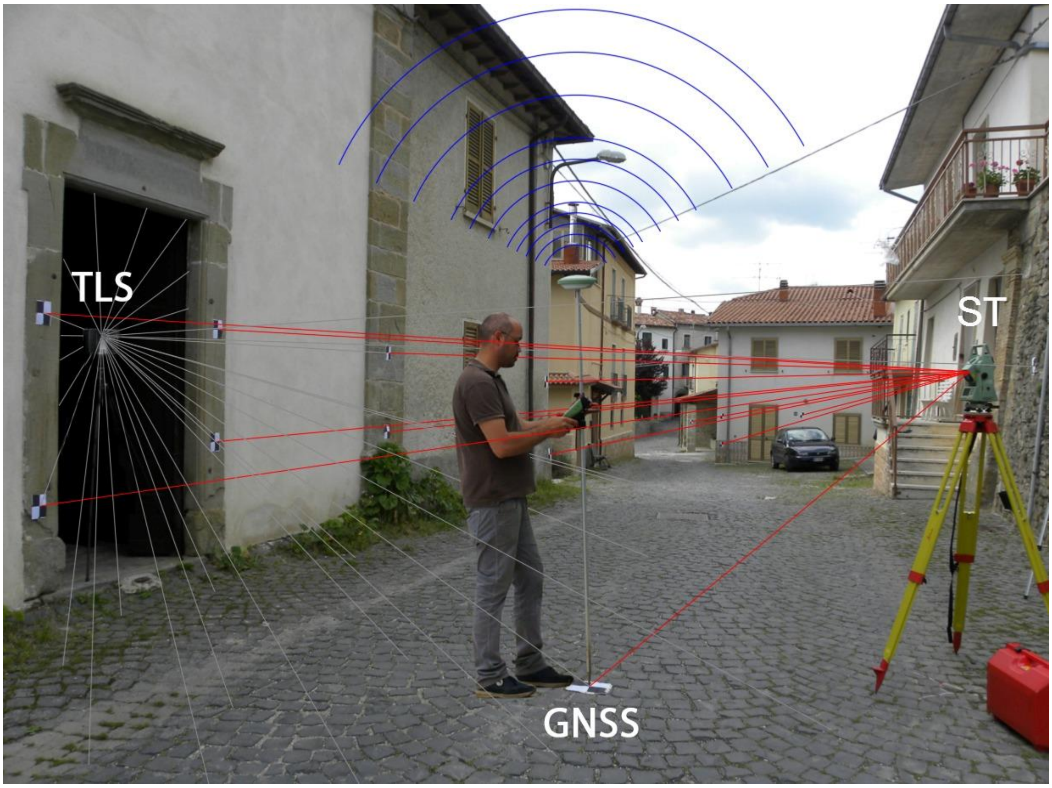

Fig. 3. Survey phases with GNSS, TLS and Total Station.

3.4. Post-processing of data

The post-processing of the data followed the same hierarchical line as the acquisition phases. Initially, the data obtained from the GNSS survey were processed to form a mathematical model, i.e. a table of data that was transformed into a geometric model by creating a general plano-altimetric table.

The processing of the data obtained from the total station survey involved the creation of two networks (primary and secondary) giving a higher hierarchical value to the primary network which was in turn linked to the GNSS survey. The result of this first processing phase is a three-dimensional and georeferenced planimetry, not only of the main village, but also of its hamlets. The plane coordinates thus extrapolated were used for the point cloud registration phase carried out with Topcon's Long range laser scanner.

Using the same methodology as for the topographical network, the wide-range scans were initially recorded using the coordinates of the targets and GNSS points whose coordinates were known, and then the scans made with the medium-range laser scanner were recorded using GNSS coordinates. The data obtained from this processing is of such a high consistency that, in addition to computers and software with great computing power, it is necessary to divide the work into several stages.

At the end of the process, it is possible to obtain a georeferenced point cloud.

4. RESULTS

The methodological approach described in the paper made it possible to obtain accurate and detailed models of the historic city centre examined. In particular, the output of the point cloud was generated in UTM33-ETRF2000 (EPSG:32633) cartographic system and in LAS format (a file format for the interchange of 3-dimensional point cloud data). The ellipsoidal heights were subsequently transformed into orthometric height by means by the Italian Military Geographic Institute (IGMI) grid *.gk2 based on ITALGEO geoid model (Barzaghi et al., 2007) and use of suitable software able to perform this task. **Figure 4** shows the high degree of detail of the urban-scale 3D models. The main road was divided into regular and morphology-related areas ensuring the same quality and resolution parameters in order to obtain homogeneous and easily manageable point clouds for the different users who can collaborate on the project. Furthermore, the several fractions were processed individually considering the number of scans.

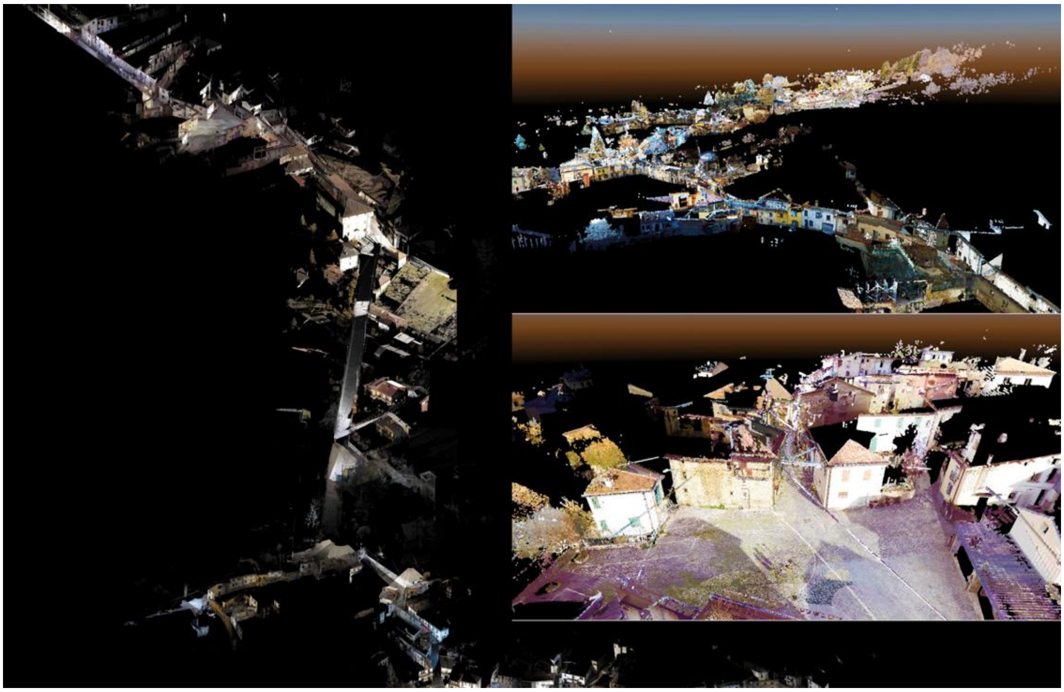

Fig. 4. 3D point cloud of the part of main street.

In addition, at the scale of the individual building, it was possible to obtain detailed models describing the geometry of the structure; indeed, thanks to the data acquisition with the internal camera present in the TLS, it was possible to obtain a coloured dense point cloud. One of the architectural emergencies in the area that has been noted is the Church of San Domenico in the hamlet of Mopolino. It was built in 1579 and suffered significant damage in the 1703 earthquake; in 1839, the building was restored to a design by Giuseppe Valadier, who worked at the Bishopric of Rieti (Varagnoli, 2021). A representation by point cloud of this church is showed in **figure 5a, 4b and 4c**. The further processing of the geomatics data makes it possible to extrapolate both horizontal and vertical sections of the entire urban complex, in order to be able to know, in addition to the geometries, any deformations due to the earthquake disruptions. Once the point cloud was obtained, it was possible to build a mesh model and, of consequence, to obtain a representation of a continuous surface consisting entirely of triangular facets (a triangle mesh). Subsequently, identifying a suitable plane of projection, it was possible to build the orthophoto of the area taken into consideration. On the orthophotos, it was possible to identify the areas with lesions by photointerpretation and analysis of an expert in the field of facility monitoring. For example, in **figure 5d** are showed in red colour the areas with lesions on the vault of the church of San Domenico.

(a)

(b)

(c)

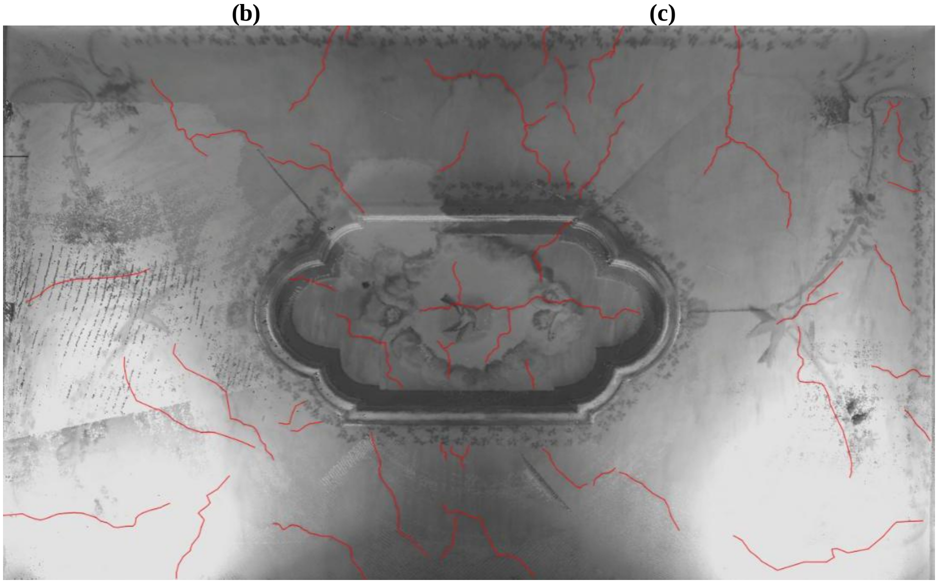

Fig. 5. 3D models of the Church of San Domenico: axonometric view of the point cloud (a, b, c) and orthophotos with indications of critical areas (d).

5. CONCLUSIONS

Over the years, the study of architecture, of historical centres, has been adorned with multiple methodologies, both theoretical and technological, which allow realistic 3D models to be obtained. The approach to the Capitignano case study, while addressing different urban scale survey problems, from a geomatics point of view, involved the use of techniques such as TLS, GNSS and total station. An interesting aspect discussed in the paper concerns the integration of the various geomatics techniques, which has allowed not only the integration of the various techniques, but also the unification in a single reference system of the hamlets located near the historic centre.

All the documentation produced thus represents an important support for future projects of restoration, maintenance, redevelopment and enhancement of the entire urban context and its individual constituent architectural entities. The creation of a database can therefore be used for an eventual cartographic update of the area subjected to the integrated survey.

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