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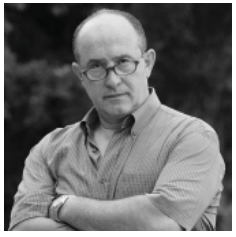

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The historic centre of Poppi, an urban-scale analysis for assesment of seismic risk

Il centro storico di Poppi, analisi a livello urbano per la valutazione del rischio sismico

The town of Poppi as a case study to address the question of analysing historic centres in terms of their documentation, preservation and safety.
The work was divided into three areas: the realization of a reliable survey, an appropriate reconstruction of the current state and the identification of the critical elements of the building fabric. The survey was carried out using 3D laser scanning technology to obtain high quality documentation of the artifacts and a graphic display able to show their architectural value. Cataloguing was used to gather the information needed to identify the building system. The question of safety was also addressed both through the analysis of street fronts to identify possible deformations, and by examining the inclination of the straight sides of the arcades. A thematic summary map was realized using this data system.

Il borgo di Poppi quale caso studio per affrontare la questione dell'analisi dei centri storici, declinandola secondo i temi della loro documentazione, conservazione e sicurezza.
Il lavoro si è articolato in tre tematiche: la realizzazione di un rilievo affidabile, un'appropriata restituzione dello stato di fatto e l'individuazione degli elementi di criticità del tessuto edilizio.
il rilievo è stato realizzato utilizzando la tecnologia laser scanner 3D, per ottenere una documentazione dei manufatti di elevata qualità ed una rappresentazione grafica in grado di restituirne il valore architettonico. La schedatura è servita a raccogliere le informazioni necessarie per la comprensione dei fenomeni edilizi. Il tema della sicurezza è stato affrontato sia con l'analisi dei fronti strada per individuarne le possibili deformazioni, sia con l'esame dell'inclinazione dei piedritti dei portici. Sulla base di tale sistema di dati è stata realizzata una cartografia tematica di sintesi.

Keywords: urban survey, certification of the survey, drawing methods, plastic deformation, sismic safety, pillar inclination.

Parole chiave: *rilievo urbano, certificazione del rilievo, protocollo di restituzione, deformazioni plastiche, verifica sicurezza sismica, inclinazione dei piedritti.*

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AIMS OF THE PAPER

This paper considers the analysis of historic centres, addressing the matter of their documentation, preservation and safety. Italy, highly anthropized even in the most remote locations, has a wealth of historic centres of outstanding architectural value, but is also vulnerable both in terms of seismic and hydro-geological risk. Given the recent earthquakes which have struck various regions of central Italy, we decided to take a closer look at Italy's architectural heritage and the strategies needed for its conservation.
The project for the case study on the town of Poppi involved three main aspects: conducting a reliable survey certifiable on an urban scale, documenting the current state of the buildings analysed, and identifying the critical elements within the architectural fabric.
The survey was carried out using 3D laser scanner technology so as to obtain high-quality documentation of the artefacts from a metric and morphological point of view and combined with a protocol for checking and certifying the data acquired, given the sensitive nature of its use to assess the seismic vulnerability of buildings. Lastly, the survey density was organised so as to provide a graphic representation able to fully reproduce the architectural and historic value of the village, also able to capture any signs of structural instability.
A census card system was also developed to document the current conditions and gather the information needed to understand how the building structure developed
This data system was then used to construct a thematic summary map, permitting an overview of the documented features.
The question of safety was dealt with using non-invasive street front analysis aimed at identifying possible deformations of the external walls combined with a thorough investigation of the inclination of the straight sides of the arcades these too performed using the potential offered by the laser scanner survey data.

GENERAL THEME

The theme chosen for the case study was the town of Poppi (Fig. 1), the main town of the Municipality of Poppi, situated on the top of an isolated hill with a characteristic L-shape, on the right bank of the Arno River, in a central position dominating the Casentino valley.
The valley was an important communication route from prehistoric times onwards, where medieval roads set on paths of Etruscan and Roman origin connected the numerous small towns of the valley with each other and with the surrounding valleys. Roads which in medieval times ran along the Casentino valley and which were particularly important for getting across the Apennines on routes between the North and South of the peninsula [1].
The need to guard the roads led to the development of significant fortification from the tenth to thirteenth centuries, so much so that today Casentino has a wealth of historic centres, where the original layout may still be discerned. Among these is Poppi, which given the quality of its architecture is certainly the most interesting and the best preserved centre. Conditions made possible thanks to its inhabitants' attachment to the town, with an intense reconstruction of the houses, but mainly due to its elevated position, on the crest of a hill with steep sides, which has always limited its area of ex-

Fig. 1. A picture of the historic centre of Poppi, specifically the area where the first survey campaign was conducted of the crest of the hill which via Cavour runs along, seen from the Castle.

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pansion, especially after the second world war. These favourable conditions have enabled the town to maintain its appearance and its original dimensions over the centuries.

CURRENT STATE

After the disastrous earthquake of L'Aquila a census and assessment of the damage ensuing from the earthquake was made; for the first time the tools and potential offered by laser scanner technology were used systematically. The technological and methodological maturity achieved by laser scanner instruments has led to their widespread use in the sphere of town planning. The need to find state of the art technological and methodological solutions able to allow adequate mapping with diagnostic investigations on the conditions of the building heritage, has led many researchers to experiment with the potential applications of the data provided by point clouds. Our research lies precisely in this area, with the specific feature of photographing the conditions of an architectural heritage still intact, namely that has not undergone seismic events of particular intensity in relatively recent times, which is well preserved and where refurbishing intervention has been limited. This therefore involves an assessment of the current condition and the simultaneous completion of appropriate prevention measures. The case study of Poppi is therefore of an urban centre that can serve as a model for assessing the ability of similar towns to resist earthquakes of significant magnitude but also to develop prevention models and protocols for intervention which can be easily applied to other historic towns with similar architectural features.

METHODOLOGY APPLIED

The documentation of the historic centre of Poppi was carried out in a series of three progressive survey campaigns a year apart from each other. The first campaign, performed in the spring of 2012, the results of which were partly described in the Marco Tocchi's thesis [2], were further expanded by myself [3] and have been combined in this paper. The first campaign was followed by the campaign in spring 2013 and lastly by the one in spring 2014. During the three survey phases the entire historic centre of Poppi was considered and specifically all the buildings inside the 13th century walls. The first survey analysed the path along the crest of the hill which Poppi stands on and in particular the Church of San Fedele at the Porta Santi Cascese or Porta a Fronzola (Fig. 2). The laser scanner equipment used in the three survey campaigns was different but the data from each was correctly integrated. In 2012 the survey was conducted using a Faro focus 3D, in the next survey in 2013 a laser scanner Z + F image 5006 was instead used while in 2014 a more modern Z + F Image 5010 was used. The equipment, although very different in terms of range, accuracy, ease of handling and ability to limit digital noise, are however all phase shift instruments

The significant size of the entire historic centre, its morphological complexity and the differen-

Fig. 2. The point cloud of Poppi from the Church of San Fedele to the Santi Cascese gate.

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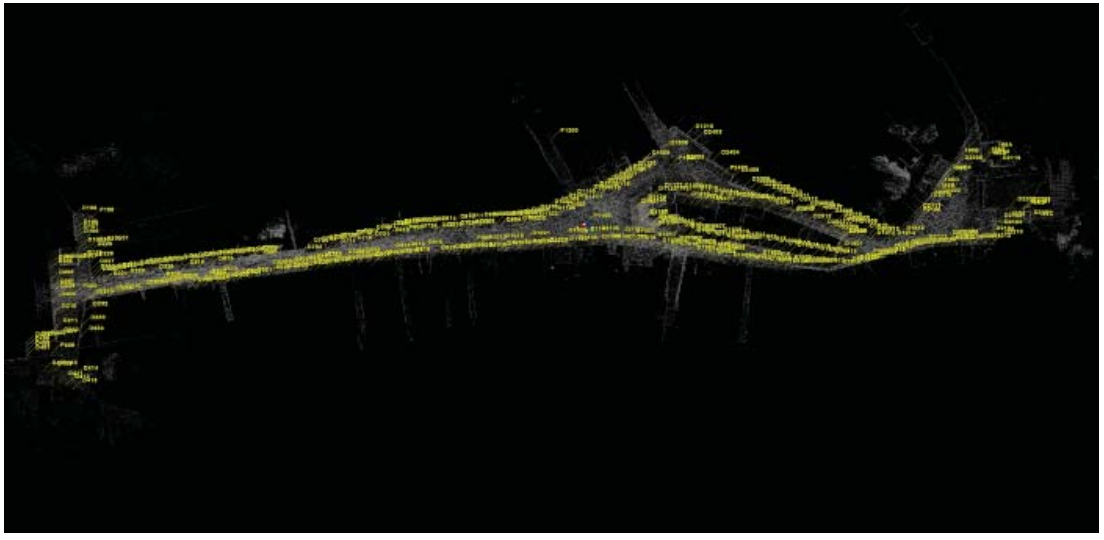
ces in elevation characterising it required the creation of a topographical polygon support, which proved crucial to unifying the entire project conducted in three different surveying sessions and to certify the data as well as verify its metric-morphological reliability. The certification process was carried out to verify the point cloud recordings and to match the CAD digitalisations with the point cloud data.
It was therefore the certification of the point cloud which characterised the case study in question, proving crucial to the certainty of the calculation results of the deformation dynamics.
Conducting a survey of an entire and extensive historic centre with significant variations in altitude, as in the case of this Casentino town, is an operation subject to errors and inaccuracies, due both to the morphological complexity-altitude and to errors that may occur during the acquisition process and perfecting [4] of the point cloud. However the highly technological instruments used in surveying operations require precise operating and verification protocols since the large amount of data produced and the existing interactions are difficult to control and need continuous and clearly defined verification operations of the quantity and quality of the data to be analysed. However in this case the checks on the quality of the data were even more stringent and thorough since the data collected would be used for markedly sensitive calculations; in fact the calculations for assessing the plastic deformations of the fronts required higher standards of quality and accuracy in the creation of the point clouds. It is therefore important to point out that despite the high level of detail acquired with the scans, to achieve an accurate and reliable result, criteria for further additional verification of the details of the individual recordings and the final data of the database created had to be established. This, knowing full well that the intrinsic control and reliability offered by the various software applications for point cloud processing is not sufficient to ensure maximum reliability of the survey.



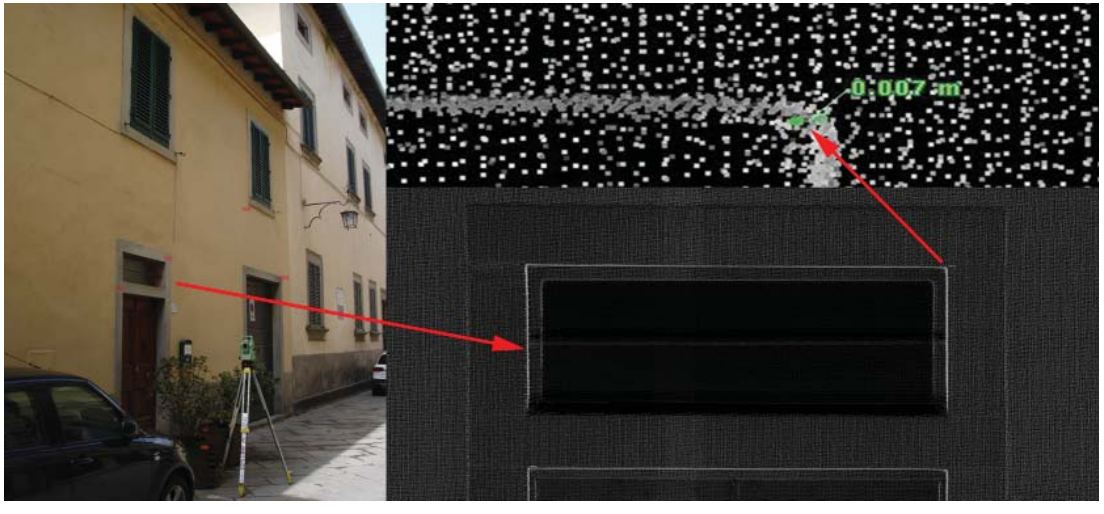


Fig. 3. The topographic survey with measurements of the targets required for the recordings.

Fig. 4. The certification of the points performed using the topographic survey.

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The protocol that our research group developed to conduct highly extensive surveys is based on various control tools which cross-check each other, and was organised as follows.
Behind the surveying operations is the topographic map (Fig. 3), this is the core infrastructure which the entire survey is based on. In this case a first topographical polygon was constructed on which to measure the targets for joining the individual scans, while a further topographical survey was conducted subsequently to measure the more recognisable architectural details to be used to match the topographical survey (Fig. 4), the point cloud and the correspondence of the digitalisation with the CAD drawing.
The second control tool was created by running comparative sections on the point clouds recorded, to check the alignment of the various section lines relative to the individual scans present in the recording. Further establishing, on the basis of specific accuracy [5] criteria , that the maximum misalignment between the various section lines was a centimetre (Fig. 5). This kind of comparison was used both in the intermediate scan registrations, and in the final recording of the entire survey. Cross-checking of the sections during recording and checking against the topographical survey made it possible to certify the survey with an appreciable level of accuracy, especially as regards the standards considered.
As regards the reconstruction of the data in.dwg format this was carried out using protocols already tested and procedures that provided for the export of raster images automatically scaled and referenced by the point cloud management software (Fig. 6). Their digitalization in CAD produced highly descriptive print-outs, which were in turn exported to create orthophotos for the production of records of the decay and material description of the fronts (Fig. 7).
The data extracted directly from the point clouds, namely the assessment of the non-planar nature of the points of a façade from an assigned ideal plane (Fig. 8 and 9) deserves particular attention. This methodology was, as regards our research group, first experimented in the towns and villages of Aquila in the crater left by the 2009 [6] earthquake to assess the consequences and the deformations produced by the earthquake on the buildings. The method was tested here to evaluate, if in addition to the macro deformations produced by an earthquake of significant magnitude, it was possible to measure and classify the smaller deformations due to settling that the passage of time and events usually leave in buildings. The findings of this procedure were used to develop a theory of the mechanical instability of the fronts (Fig. 10), which together with other investigations of

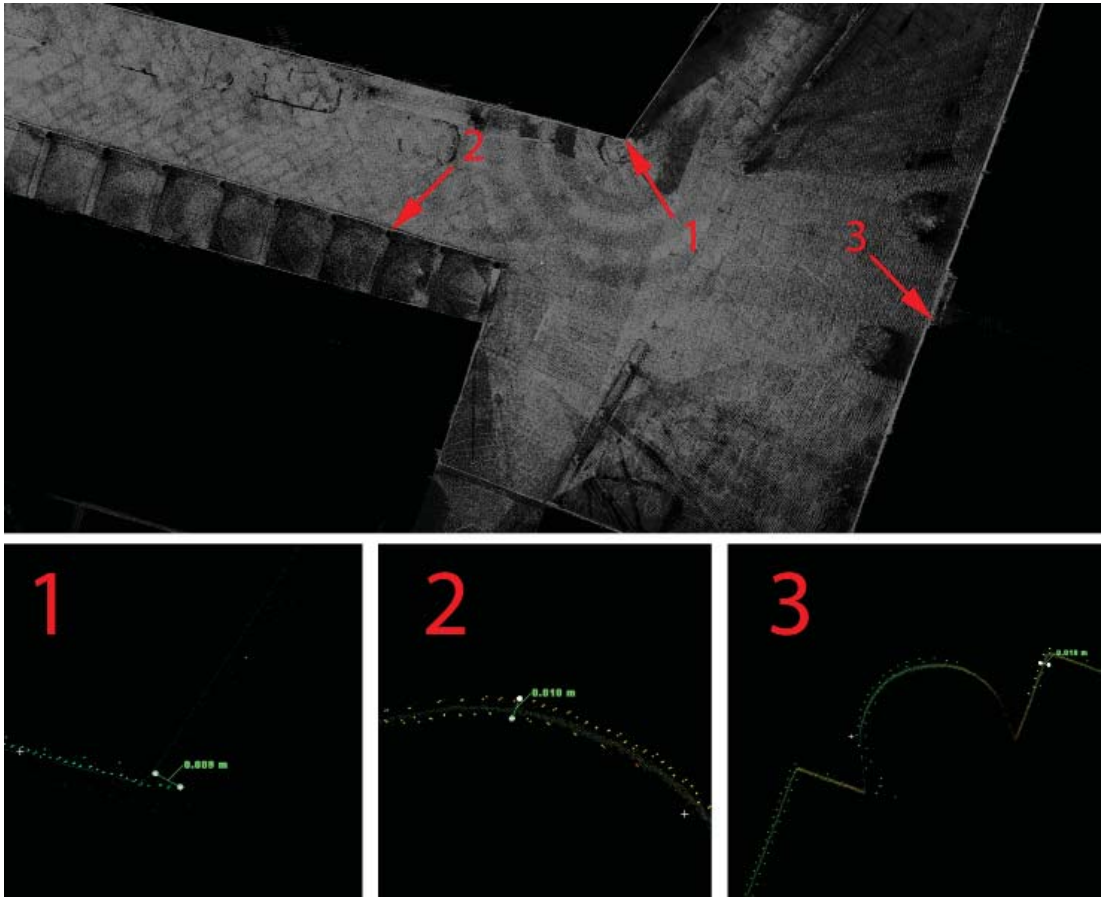

Fig. 5. The certification of the recordings conducted through verification of the sections.

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the static conditions of the buildings, made it possible to construct the tables for evaluating the safety of buildings looking onto city streets (Fig. 11).
The historical centre of Poppi which extends along the road leading from the medieval monastery of San Fedele and from the church of the same name to the seventeenth-century Cappella del Morbo, is characterized from a morphological point of view mainly by the presence of an arcade along almost the entire central backbone of the village. Given this characteristic it was deemed appropriate to conduct an accurate analysis of the state of the straight sides of the arcades (Fig. 12). The columns and sometimes the pillars supporting the arcades in many cases revealed obvious shifts from the ideal condition of verticality. Therefore it was considered appropriate, given the quantity and quality of data available from the laser scanner survey, to perform accurate measurements to verify the condition of possible collapse of the vertical elements. However, rather than assessing the inclination according to a single projection plane, it was deemed necessary to measure the actual inclination whatever the possible directions of collapse were. To achieve this, two horizontal sections were taken, one at the base and the other at the top of the column or pillar, at the capital where present. For each flat section of the columns and pillars the geometric barycentre was identified. With the barycentre of the two sections, one at the base and one at the top of the straight side, both belonging to a single reference system, it was possible to measure the projection on the plane of the intensity and direction of the displacement vector generated by the tilting of the column (Fig. 13). This operation was performed by assigning to each individual building its own reference system, in order to evaluate all the deformations together and formulate a risk analysis for any instability which each single building might encounter.

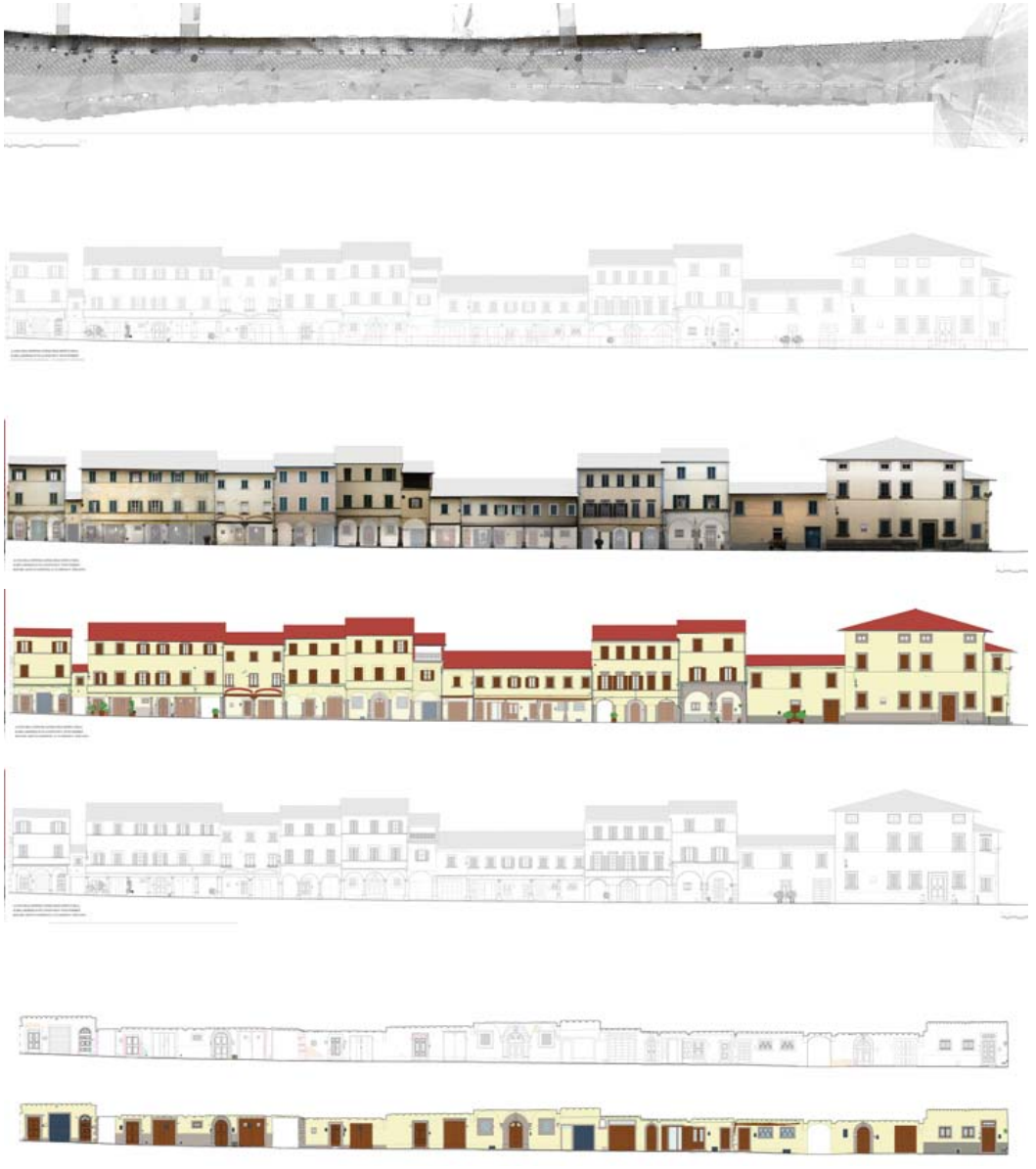

Fig. 6 and 7. Digitalisation of the point cloud and orthophoto of the urban fronts.

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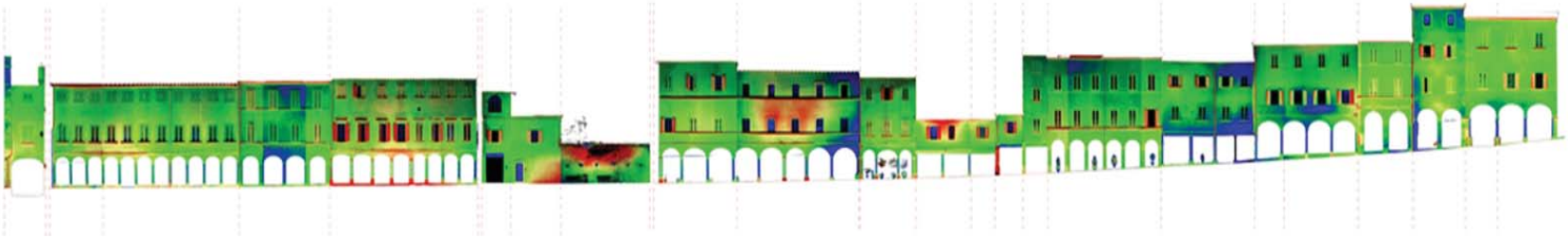

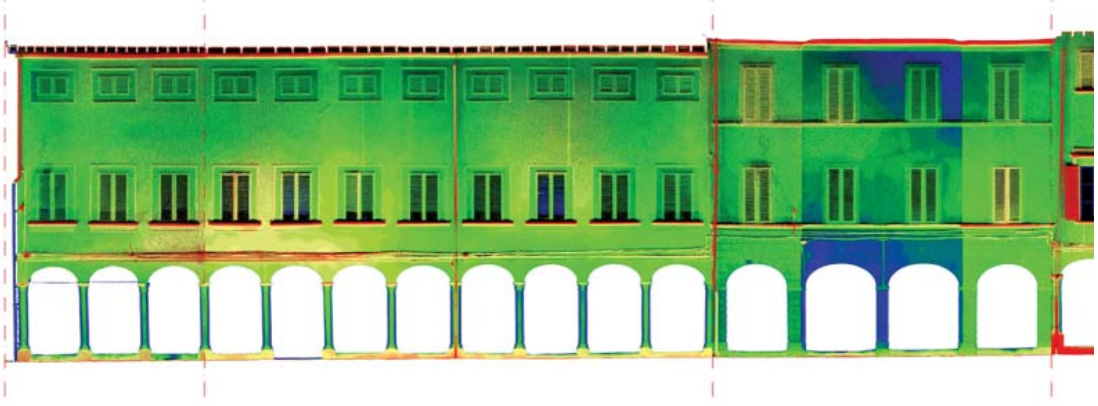

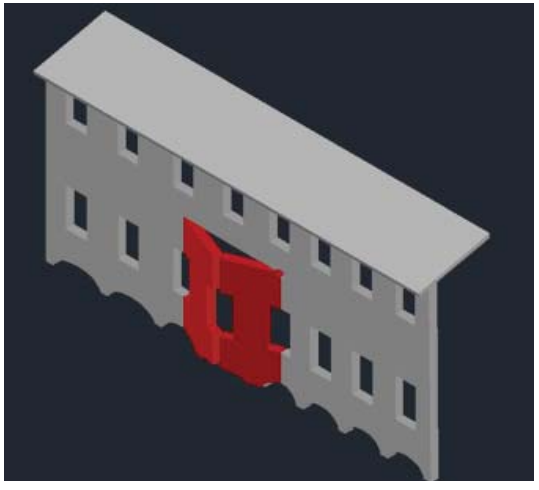

Lastly, the evaluation of the inclinations was performed using an absolute parameter and not the individual displacements. This parameter was obtained, thanks to the information resulting from our survey, i.e. the shift of the barycentre for the distance between the two horizontal sections.
The census of the town buildings added further to the information on the small urban centre (Fig. 14). The work was conducted so as to document the architectural characteristics of the individual buildings, the census sheets were merged into a data-base which was updated and revised as the work progressed. The first highly descriptive but hard to read and interpret version was simplified over time, given the fact that all the investigation work on the seismic vulnerability of the centre of Poppi needed to be conducted in operations which were rapid and at the same time inexpensive, thereby selecting only the information actually needed to achieve the required degree of confidence.

Fig. 8 and 9. Views of the non-planar nature of the points from an assigned plane-also called elevation map.

Fig. 10. Model of the presumed instability.

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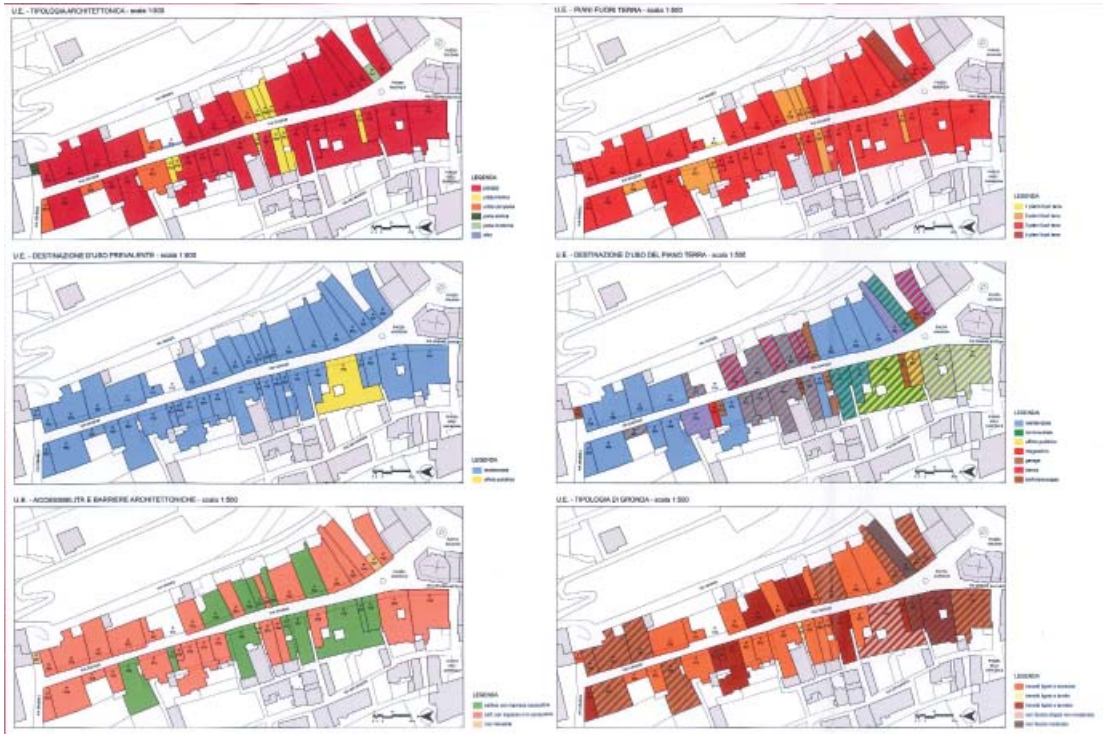

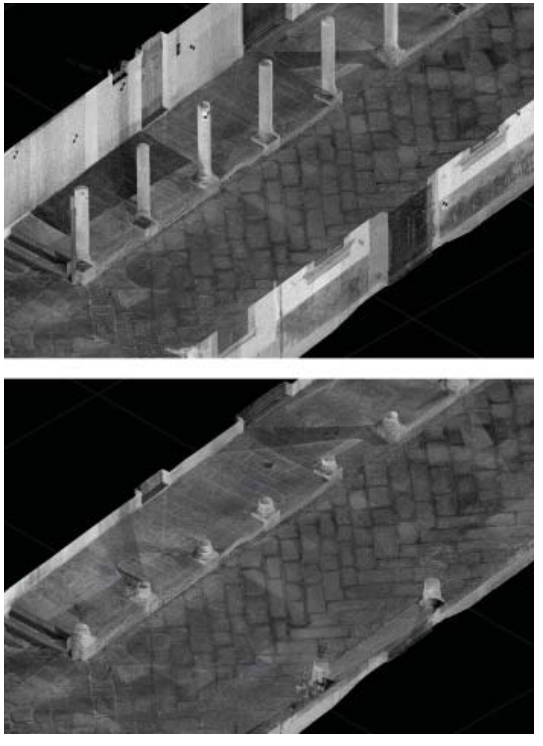

Fig. 11. Themed maps resulting from a combination of the results.

Fig. 12. Images of the point cloud with sections on the cut points of the straight sides.

RESULTS ACHIEVED

The use of modern laser scanning survey systems, thanks to the development of protocols for using the data produced, made it possible to develop this protocol for intervention in historic centres, achieving a high level of information. Through the many facets analysed in this case study, related mainly to the morphological aspects of the town centre, it was possible to assess the degree of preservation and the most significant aspects of decay. However thanks to the mechanical interactions on the instabilities of the buildings it was possible to concentrate on creating thorough thematic maps of the possible elements of risk in the town centre. These elements were identified on the façades and on the straight sides of the arcades, collected and shown in various themed maps and summarised in a single synthetic map giving an overall picture of the possible seismic risk and instability of each building examined (Fig. 14).
The nature of the analysis, carried out on an urban scale, without investigating the internal structure of the buildings does not set out to produce a complete and exhaustive examination of the static and structural nature of the buildings, but to act as a non-invasive investigative tool, which can be put into operation relatively rapidly and at moderate cost, able to provide in a precise and reliable manner the information needed for more

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thorough investigations which may result in consolidation and safety work on the structures.

INNOVATIVE ASPECTS AND ORIGINAL ELEMENTS

This paper is an organised and standardised collection of the experiences which our study group has developed over the last few years. The ability to create interactions between the data from the 3D laser scanner survey has led to the development of a rapid procedure for the assessment of seismic risk in historic centres. Among the innovative elements are the certification of the data and the reconstruction protocol, without which any consideration, especially of a structural nature, is vain. Another significant element is undoubtedly the assessment of the deformation of the fronts carried out thanks to the potential offered by the point cloud, and in particular the assessment of the non-planar characteristics of the points from an assigned ideal plane. As also the method of assessment of the inclination of the straight sides of the arcades is undoubtedly the result of the multiple possibilities of use of data from the point cloud.

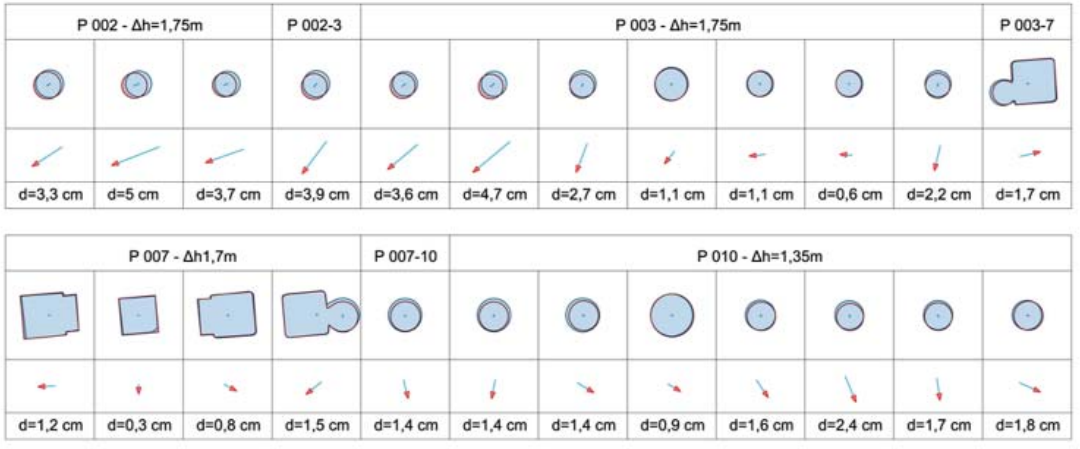

Fig. 13. Summary table showing the inclination vector of the straight sides.

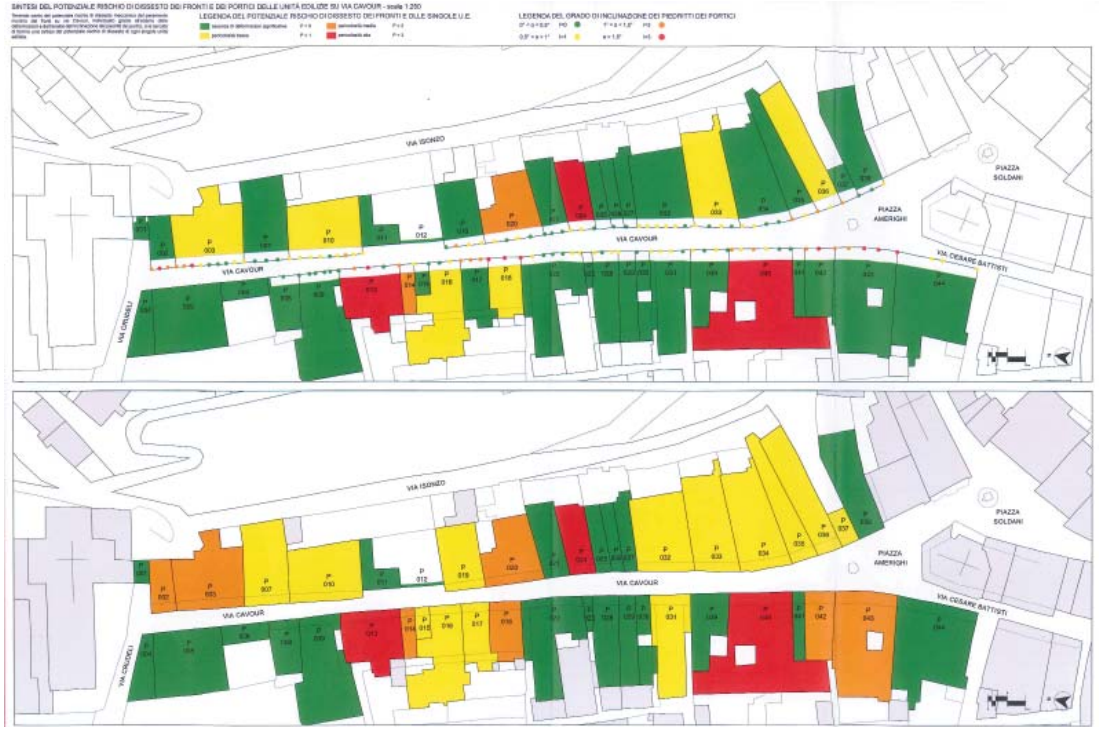

Fig. 14. Summary table of the seismic risk of the buildings.

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NOTES

[1] See Fatucchi A., Le strade romane del Casentino, in: Atti e memorie dell'Accademia Petrarca, Nuova serie, Vol XL, anni, 1970-72, Arezzo, 1970.

[2] Tocchi M., Il problema della documentazione conservazione e sicurezza nei centri storici: il caso studio di Poppi, Degree Thesis, Tutor Prof. Bertocci S., co-tutors: Dott. Arch. Pancani G., Dott. Arch. Minutoli G., Università degli studi di Firenze, Dipartimento di Architettura DiDA, A.A. 2012/2013.

[3] The term registration or recording "means the rigid rototranslation all the scans in a single reference system», Rinaudo Fulvio, La tecnica laser scanning:applicazioni architettoniche e urbanistiche, in La tecnica del laser scanning: teoria e applicazioni, edited by Fabio Crosilla e Riccardo Galetto, Udine, 2003, pp. 134-136.

[4] With the term "registration" is meant the rigid rototraction of all scans in a single reference system, Rinaudo Fulvio, La tecnica laser scanning:applicazioni architettoniche e urbanistiche, in La tecnica del laser scanning: teoria e applicazioni, a cura di Fabio Crosilla e Riccardo Galetto, Udine, 2003, pp. 134-136.

[5] To check the resolutions at the various scales reference was made to the following texts and standards: Having to decide the survey tolerances we could not but refer to the principles of perceptive abilities, handbooks and standards (ISO) since Italian legislation on the matter is rather inadequate. For the relative bibliography see: Docci M., Maestri D. (2010). Architectural and urban surveying manual , Bari, establishing the permissible errors (degree of reliability) for graphs at various scales, as indicated below: Scale 1: 200 ± 40÷60 mm; Scale 1: 100 ± 20÷30 mm; Scale 1: 50 ± 10÷15 mm; Scale 1: 20 ± 4÷ 6 mm; Scale 1: 10 ± 2÷3 mm. The ISO 4463-3 standard concerning the dimensional accuracy of survey drawings sets the limits of accuracy as: Scale 1: 200 ± 50 mm; Scale 1: 100 ± 25 mm; Scale 1: 50 ± 12 mm.

[6]Bertocci S., Minutoli G., (2012). Un database per il controllo della vulnerabilità sismica: il caso studio di Acciano. DisegnareCon..., pp. 0-0, ISSN:1828-5961

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