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INTEGRATED SURVEY FOR ARCHITECTURAL RESTORATION: A METHODOLOGICAL APPROACH IN THE CASE STUDY OF CODIPONTE (MS)

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ABSTRACT

A preliminary survey campaign is essential in projects of restoration, urban renewal, rebuilding or promotion of architectural heritage. Today several survey techniques allow full 3D object restitution and modelling that provides a richer description than 2D representations. A single technique or a combination of several ones might be employed. Especially when documentation at different scales and with different levels of detail are foreseen, the latter will likely be necessary. The paper describes an architectural survey in Italy: the two most relevant remains in Codiponte (MS), damaged by the earthquake in 2013, in the context of a project of restoration and conservation. In this site, a 3D survey was necessary to represent effectively the objects. An integrated survey campaign was performed, which consists of a GPS network as support for georeferencing, an aerial survey and a field survey made by laser scanner and close range photogrammetry. The case study, thanks to its peculiarity, can be taken as exemplar to wonder if the integration of different surveying techniques is today still mandatory or, considering the technical advances of each technology, it is in fact just optional.

KEYWORDS

Cultural Heritage, Comparison, Photogrammetry, Laser scanning, Restitution, Integration

1. Introduction

The survey of cultural heritage sites is a truly interdisciplinary activity, where surveyors, historians, architects, town planners, structural engineers, etc. are involved. The goal might be just the documentation – consider for example the establishment and population of 3D digital libraries in order to ensure that heritage sites are (digitally) available to future generations (<http://www.cyark.org>, Balletti et al., 2015) – rather than preservation, restoration (Günay, 2011; Oreni et al., 2014), promotion (Barazzetti et al., 2015), rebuilding, maintenance and monitoring (Brumana et al., 2013a), etc. In this context, 3D survey and 3D restitution are particularly significant since they give a higher number of information than the 2D representation and make it possible to have a global view of the object under investigation in one illustration, being able to manage all components simultaneously. 3D survey techniques allow acquiring, rapidly and with a fair automation level, a great deal of real world data at high resolution. Thus, the 3D

models obtained by restitution increasingly correspond to reality, being however the user able at any time to reduce the complexity of the information returned, according to the scale of representation or the aim of the survey. Moreover, 3D survey is particularly fitting to represent and investigate urban areas when drawing urban or architectural projects (Visintini et al, 2007), in order to convey the spatial perception of the object within the landscape and to perform simulations for visual impact analysis. In recent years, the need to store, organize, retrieve information and use it for further analysis led to the development of GIS and lately of Building Information Models (BIMs, Eastman et al, 2011; Murphy et al, 2011) for the management, respectively, of territory and architectural heritage (Achille et al. 2012). So the creation of 3D models (suitable for the implementation in such systems) is becoming a requisite. Attention is also paid to the time domain, with specialised modelling software that accounts for the historical developments of the site. Also the fruition of such products, thanks to webGIS

and web-based interfaces to a datasets, is open to a larger public (Agugiario et al, 2011). In these cases, the possibility of visualizing a 3D model is more suitable to the need and the expectations of the public, since its comprehension is immediate and closer to reality. Many authors (Remondino, 2011; Grussenmeyer et al., 2012; Brumana et al., 2013; Fassi et al., 2013; Balletti et al., 2015; Kersten et al., 2015; Rodríguez-González et al., 2015) in recent years dealt with these topics but the discussion is not concluded and many questions are still open. All these researches underline that to reach the best result in terms of accuracy and completeness of the models it is important to perform an integrated survey, which takes into account topographic measurement, laser scanning and close range photogrammetry techniques combined together. Integration allows overcoming the specific limitations of each technique, having more complete results. However, nowadays, laser scanners and photogrammetric software are more and more performing and have improved their capabilities, overcoming many of their respective traditional drawbacks and points of weakness. For instance, laser scanners integrated cameras became more and more sophisticated allowing acquiring high resolution/high quality images of the object and providing colours for the point cloud. Photogrammetric software, on the other hand, in the last few years improved constantly the automation of all the orientation and dense matching procedures, which made the technique viable also for non-expert users, and specialized the matching algorithms toward multi-image block geometry, which in many cases reduces consistently all the drawbacks connected to point stereo-visibility (i.e. occlusions). In other words, are integrated surveys still necessary today? When a single technique should be employed and when, on the other hand, should many be used concurrently to provide an adequate result? From a practitioner point of view, the choice to integrate several surveying techniques always comes at a price: the most obvious resides in the need of acquiring/renting different (often costly) equipment, but users should also take into consideration the costs of the technical training, of the logistics and so on. If skills and equipment can be easily found in surveying companies, often, in the context of small/medium architectural restoration projects, the surveying activities are assigned to

a more general-purpose professional. To put the previous questions in a context, in the following case study of an architectural survey in Italy is presented. It concerns the documentation of the two most relevant remains in Codiponte (MS): the castle and the bridge. The survey was executed in the context of a project of restoration and conservation. Like many medieval or even older Italian villages, Codiponte has been built on hills or mountain slopes. Today, although partly inhabited and with increasing deterioration of buildings and walls, thanks to their narrow stone paved streets, the staircases, the arcs, it offers a unique atmosphere and represents an exceptional and challenging environment for a modern 3D survey. Building on the remarks on the survey results, the second part of the article deals with the methodological issues concerning the integration of different techniques. The aim is to understand if today the different indirect survey techniques, i.e. laser scanner and photogrammetry, are still to be considered complementary or alternative and so, if their integration, as the case, is mandatory or optional.

2. *Codiponte case study*

Codiponte is a village in the municipality of Casola in Lunigiana (Tuscany, Italy). It is located in the Province of Massa and Carrara at about 250 metres above sea level. It takes its name from the ancient bridge ("Ponte" in Italian), set over the River Aulella, still open to traffic and important and distinctive feature of the village. The village rises up on the Via Francigena and has been an important settlement since the 7th century BC. The present settlement dates back to Middle Ages and is placed on the slope of the hill. The bridge and the castle represent the most significant elements of the village, both for their history and for their architectural and artistic features. The bridge dates back to 11th - 12th centuries, is a three-span bridge and the masonry is of bricks and stones depending on the time of construction. In fact, the bridge underwent numerous reconstructions and reinforcement because of collapses and damages due to flooding of the river. The castle, which would represent the focus point of Codiponte but now it is in ruins and is largely collapsed and damaged by weed, overlooks the entire village. Due to its advanced state of decay, its original structure is

not well recognizable anymore. Originally, it had a square perimeter with many internal elements, with stairs and vaults, and was subdivided in two levels. On 21st June 2013 a big earthquake hit the village and the castle was further damaged. Due to its current preservation state, the goal of a complete recovery for its reuse is unrealistic. However, the local administration has required a project of promotion of the entire village, with emphasis on the restoration and conservation of the ancient castle, to preserve, at least, its state of ruin and avoid collapses that could jeopardize the houses below, and a project of reinforcement of the bridge, which is damaged in particular in correspondence of the arch and the abutment near the road. The project has been awarded to DICATeA and so an accurate preliminary survey campaign, of the village and specifically of the castle and the bridge, was performed.

2.1 Survey campaigns

The aims of the survey campaign were essentially two: collecting all the information on the artefacts (such as geometry, structure, materials, state of damage, crack system and so on), in order to address the restoration project, and, at the same time, providing a BIM of the castle as useful instrument to evaluate the restoration choices and plan the maintenance actions. For these reasons, a 3D survey was performed and the models obtained were used to extract the two-dimensional required documents (orthophotos, plans and cross-sections) and to implement the BIM system. Differently from Navelli, the object of the survey was more circumscribed and the range of survey scales was more limited, corresponding to architectural and detail scale. Despite this, since the general recovery project must cover the entire village, a large scale survey of location was performed through UAS (Unmanned Aerial Systems) photogrammetry. As in the previous case study, a GPS network was realized to provide the GCP to which anchor both the aerial survey and the architectural survey of the castle and the bridge. In this way, all the measurements are referred to the same reference system in UTM-WGS84 (ETRS89) coordinates with orthometric heights.

2.2 The survey of the village

The terrestrial survey started with the creation

of a GPS network made of 16 stations along the



Fig. 1: Orthophoto with the survey area highlighted.

village streets. This allowed the creation of a stable reference system according to which all data were registered. In this case, many of the locations chosen to provide good GCP coverage of the area are at the edges of the urban settlement near (or inside) the surrounding woods. A good satellite constellation geometry was therefore required, with quite long static measurement sessions, which in turn required a careful schedule of the survey. On the basis of these GCPs the photogrammetric survey of the village was carried out. Due to the small size of the area under investigation (ca. 380 x 280 m) and the need to complete the survey in short time and with low cost, a UAS survey seemed to be the optimal solution. The drone used was the fixed-wing Swinglet CAM produced by SenseFLY. It is particularly functional because, being realised in Expanded Polypropylene (EPP) foam and carbon structure, it is very lightweight which makes it able to fly up to 30 minutes with a single battery and so, in this case, to complete the planned mission with just one flight. The Swinglet CAM was equipped with a Canon IXUS

125 HS camera with 4 mm focal length optics (35 mm equivalent focal length is 24 mm) and a resolution of ca. 16 Mpixels. Unfortunately, previous experience showed that often the quality of the images acquired by this platform is not optimal if compared with higher quality but heavier cameras. During the flight planning, this issue was taken in consideration opting for a much smaller

GSD than the one strictly required for the desired mapping scale (1:500). Overall 124 images arranged in 12 strips cover the entire area and the neighbouring lands on the opposite bank of the river. They were flown at 120 m of relative elevation, with a longitudinal overlap of about 80% and a sidelap of 60% and a GSD (Ground Sampling Distance) of 4 cm/pixel. The GCPs had been materialized on the ground using black and white targets. The block was adjusted with the commercial software PhotoScan. The residuals on Ground Control Points, which depend on the coherence between the block structure and the control network, are on average of 1.8 pixels, corresponding to about 7.2 cm on the ground. The photogrammetric DSM and orthophoto generation (see Figure 1) was carried out again using PhotoScan.

2.3 Bridge survey

The survey of the bridge was rather simple.

The object (see Figure 2) has a linear structure that allows measuring all parts without occlusions and is easily accessible especially in summer time and in the first months of autumn, when the riverbed is almost empty and the flow rate negligible. As far as the choice of the surveying technique is concerned, the advantages and disadvantages in the use of TLS or photogrammetry in this case are comparable. The bridge is indeed accessible both to position the scanning stations and to take the images even under the arches; moreover, the texture, the light conditions and the object dimensions did not favour a technique rather than the other. Nevertheless, having the possibility of using both techniques and considering the advantages that an integrated survey generally produces, a survey with each was executed.

The bridge survey was supposed to deliver a complete and deep knowledge of the object status in order to assist the restoration project. In this respect, photogrammetry was particularly efficient in producing orthophotos as base for surface deterioration analysis. Moreover, the bridge was affected by weed, in particular bushes in correspondence of the abutment near the road.

At the time of the survey campaign, the vegetation was still present and so was necessary to update the 3D model after weed removal in order to have the possibility to observe cracks in the masonry. With progress in the restoration works, additional surveys were required to update the model. Again,

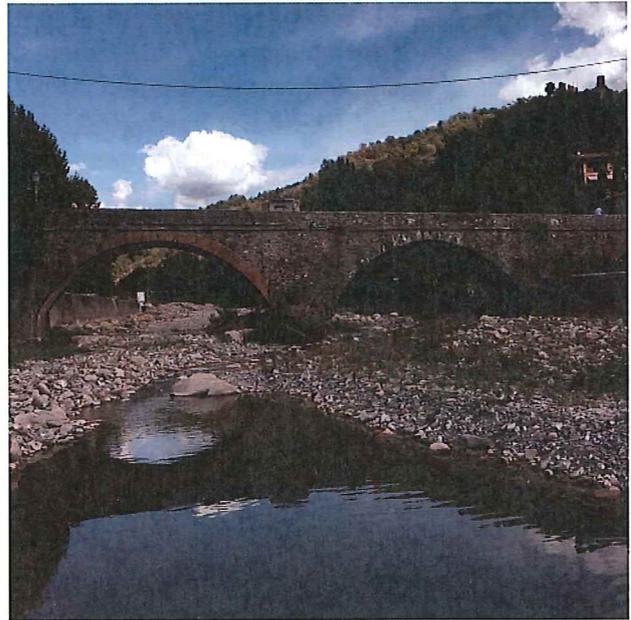


Fig. 2: The bridge.

in this regard photogrammetry was more suitable than TLS, thanks to its flexibility and possibility to add new images to the original block. However, terrestrial photogrammetry was not sufficient for the complete acquisition of the bridge, being impractical for the survey of the extrados. A drone being not available at the time of the bridge survey (performed later than the village survey), a laser scanner has been used to this aim. Seven scans were performed with a Leica C10 scanner over and all around the bridge in order to have points in common with the photogrammetric model and co-register them. The photogrammetric survey was performed with a Nikon D3x camera with calibrated 35 mm optics. Overall 131 images were taken and processed with PhotoScan. A bundle block adjustment was performed using some points gathered from the laser point cloud as GCP, so that the two models were generated in the same reference system. The comparison of the two DSM (photogrammetry-based and TLS-based) (see Figure 3) showed minimal differences, in the range of TLS expected accuracies (ca. 5 mm). The upper part of the bridge, acquired by the TLS, was used to integrate the missing parts in the photogrammetric DSM. From the assembled model, all the traditional products, such as orthophotos, cross-sections and elevation, were obtained (see Figure 4, 5).

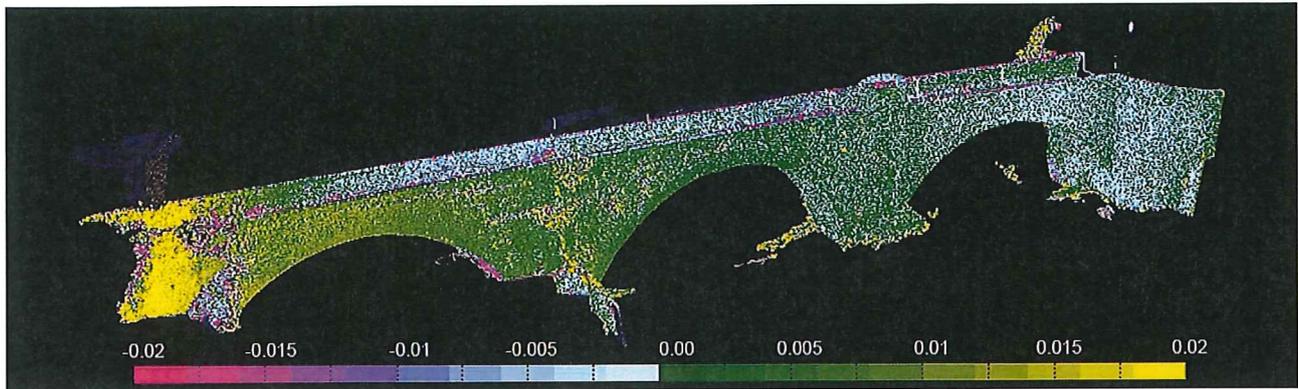


Fig. 3: Comparison map between the TLS point cloud and the photogrammetric model of the bridge



Fig. 4: Orthophoto of the bridge.

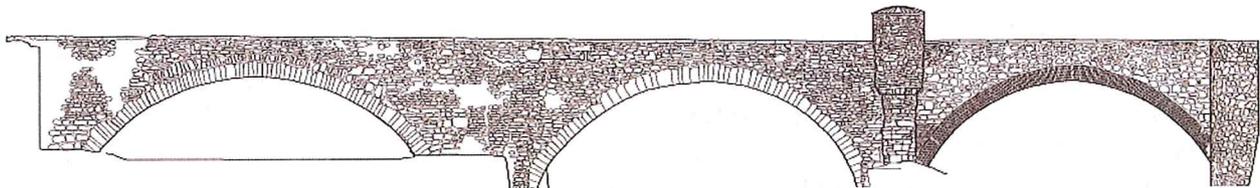


Fig. 5: Elevation of the bridge.

2.4 Castle survey

The castle (see Figure 6) stands on steep, very rugged terrain covered with vegetation that infests the castle. It was in fact necessary to remove a large part of vegetation to carry out the survey. As already mentioned, the castle is in ruins, with many collapsed parts reduced to heaps of stones. Performing a complete and time consuming direct survey with tapes and range finders of the less damaged parts was dangerous for the safety of the surveyors, due to the precariousness of the structure. So, as far as

the architectural survey is concerned, the direct survey of the accessible and less unstable areas had been integrated with a TLS and terrestrial photogrammetry survey (Figure 8), the latter much faster (and consequently much safer), as far as data acquisition time is concerned. Also in this case, an integration of the two techniques was not strictly required: both approaches provide satisfactory results with comparable overall workload.

The photogrammetric acquisition is much faster but requires a careful planning of the block geometry to provide a complete reconstruction. Its

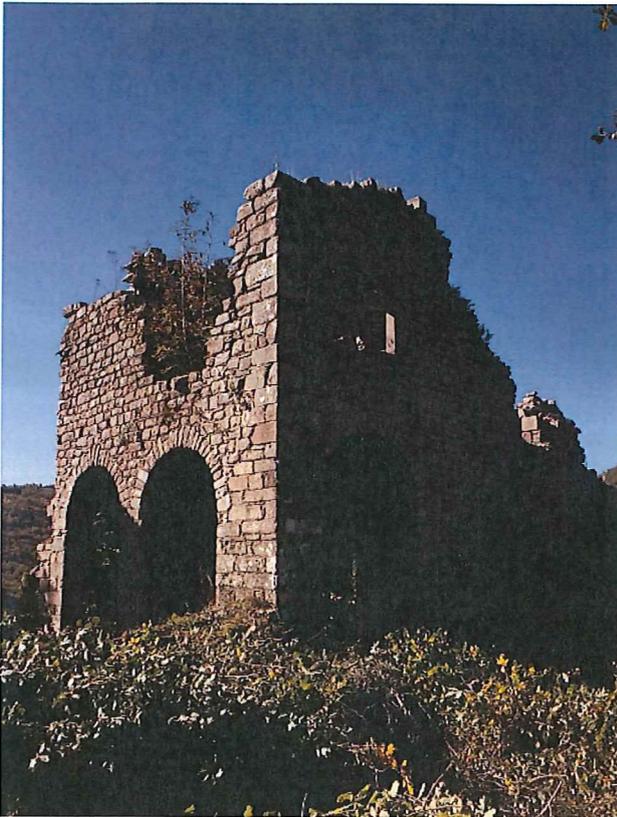


Fig. 6: The castle on the top of the hill.



Fig. 7: Orthophoto of the castle.

integration with UAV acquisition of the top parts of the castle (such as the top of the walls or the extrados of the vault, nonvisible from the ground) is straightforward, and DSM and orthophoto generation (Figure 7) can be successfully operated with automatic Structure from Motion and Dense Matching algorithm implemented in commercial software. The survey of GCP is mandatory and requires additional field operations. On the other hand, TLS survey requires longer measurement sessions on site, but provides immediate reconstruction with lower chance of incompleteness. If georeferencing is not required, TLS does not need the survey of GCP if a strong network of scan stations can be set.

The final model was obtained integrating terrestrial and UAS photogrammetry, while the TLS point cloud was used as term of comparison and for selection of the GCPs.

3. *Final considerations and conclusion*

In the first half of 2000, with TLS spreading fast, photogrammetry seemed to lose ground

and surveyors split between the opposing factions. After some time, in most paper a settlement for “integration is better” seemed to prevail. Then, “the comeback of photogrammetry” (Haala, 2009) opened again the discussion on which technique is the best. There is little chance that the debate will see the end and certainly this is not the goal of this paper. However, there is no doubt that progress in DSM generation from images has greatly improved in recent years, both in completeness and accuracy of the survey. So, if the self-employed professional that occasionally is involved in small architectural surveys has a background in photogrammetry, in our opinion he should opt for photogrammetry, less expensive and highly versatile. On the other hand, the scope and variety of characteristics of more demanding surveys at architectural or urban scale can only be faced by surveying companies. They have the expertise and the incentive to use, as single or integrated techniques on a case by case judgment, both techniques.

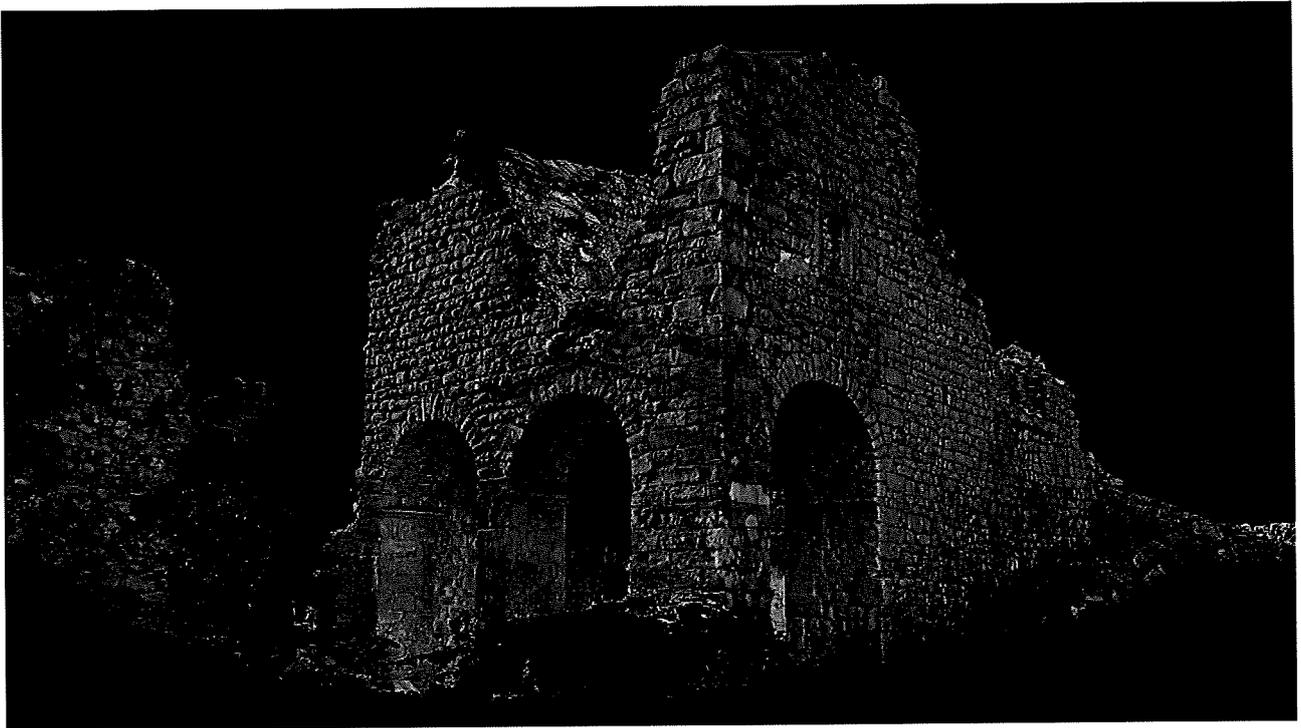


Fig. 8: Castle photogrammetric model.

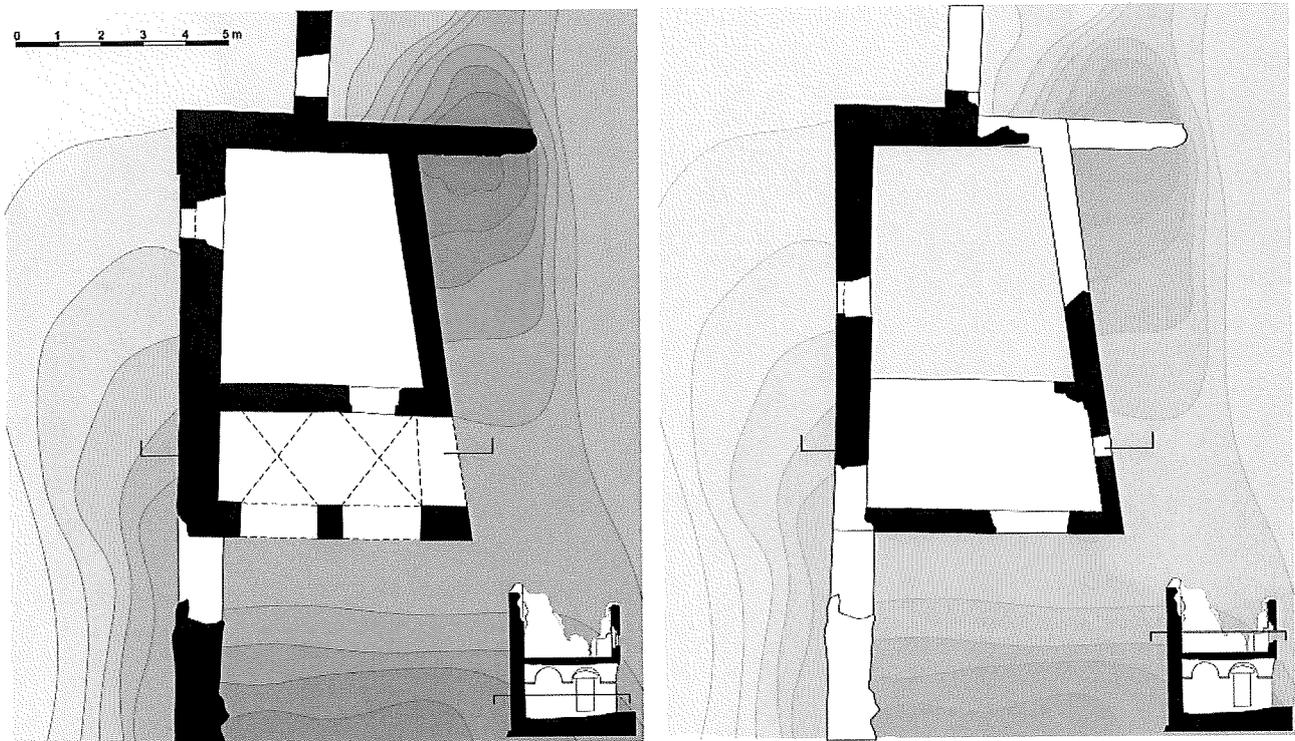


Fig. 9: Floor plan (on the left) and upper plan (on the right) of the Castle.

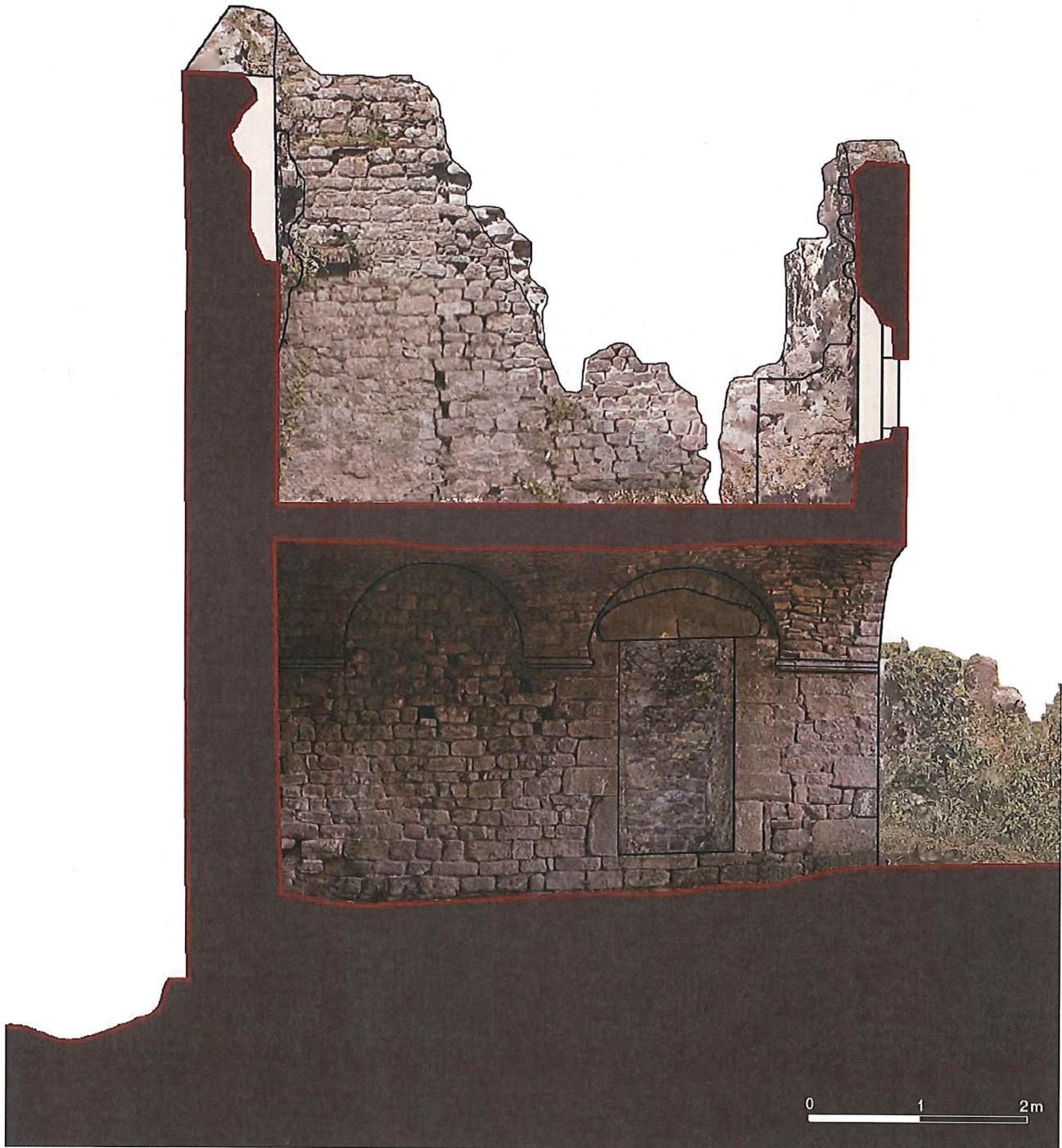


Fig. 10: Section of the Castle.

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