MULTI-SENSOR ANALYSIS FOR EXPERIMENTAL DIAGNOSTIC AND MONITORING TECHNIQUES AT SAN BEVIGNATE TEMPLAR CHURCH IN PERUGIA

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ABSTRACT:

In the contemporary world, human and natural calamities are challenging our capabilities to preserve heritage and develop innovative safeguard strategies that also address the requirement of sustainability for restoration purposes, still considering the connection between tradition and innovation. This work introduces non-invasive diagnostic practices that offer a new insight of the built environment by studying two different elements of the same architecture of San Bevignate Templar church: a thermographic mapping obtained with special post-processing procedures provided interesting information about the hidden wall pattern, while a prototypal laser scanner, called RGB-ITR, and a UAV survey supplied new insights on the precious paintings. The assessment of the masonry quality constitutes an *a priori* condition for a reliable estimation of its seismic vulnerability and for the planning of effective yet conservative interventions. The access keys to 'sustainability' therefore consist in the improvement of these contactless investigations, which can be performed both in passive conditions, in the case of thermography surveys, and in active ones, such as for the RGB-ITR scanner, as necessary substitutes for destructive or partial-destructive tests. The research achieved promising results for the characterisation of the architectural structure and the paintings, with the aim of a long-term monitoring of the structure and the decorative apparatus of a monumental heritage located in an area vulnerable to seismic and environmental events.

1. INTRODUCTION

In the definition of Cultural Heritage (CH) provided by UNESCO (UNESCO Institute for Statistics, 2009), many aspects and diversity of values of an *artefact, monument, museum, a group of buildings and sites*, are involved, *including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance*. In such a context, surfaces belonging to historical buildings are not limited to fulfilling architectural-structural functions but represent the creative and technical genius and a socio-cultural operation inaugurated at the dawn of humanity. Similarly, paintings and decorations of such surfaces often indicate an intent that goes beyond a mere ornament but has, as its purpose, the communication of a message or a story to be passed down through the centuries. This is the case of the structure and the paintings of San Bevignate church in Perugia which has an extremely high historical value being one of the most intact monumental testimonies among European Templar sites. Due to the considerable size of its architectural forms and the exceptional value of its iconographic testimonies of Templar subjects, San Bevignate church has become an important node of attraction for visitors and also the subject of scientific and historical studies. Moreover, due to the seismic area where the monumental complex is settled, non-destructive (NDT) analyses are necessary for monitoring and documenting the structure and the frescoes, also as a database for future evaluations on their conservative state.

In the last two years, different research projects were carried out in this monumental site by different institutions with several purposes. This work presents the preliminary results of an on-going research coming from the collaboration between ENEA and Università di Perugia focused on the analysis of the actual conservative conditions of the wall structure and the peculiar paintings by testing experimental technologies and methodologies. In particular, thermographic surveys in passive conditions were carried out by the Department of Civil and Environmental Engineering of the University of Perugia through the use of a thermal camera. The acquisitions involved the north inner façade of the church, with the main objectives to evaluate the frescoes' stratifications and the quality of the masonry texture without causing any damages to the wall paintings. With the same non-invasive and totally contactless approach, the 3D laser scanner prototype developed by ENEA, called RGB-ITR, was used for the coloured and three-dimensional digital transposition of the counter façade of the San Bevignate church (Guarneri *et al.*, 2015). Finally, as a complementary 3D technique and comparison method for the laser scanner data, a drone was used for the complete digitalisation of the selected wall of the church. The digitisation campaign was carried out within the framework of the "Save the Beauty" project, conceived in 2016 to enhance accessibility, digitalisation and protection of Cultural Heritage (*SavetheBeauty*, 2016), fitting in a wider concept of sharing the knowledge about peculiar Cultural Heritage through modern technologies (Guarneri *et al.*, 2020).

Interesting and challenging results were obtained by each technique, thus encouraging to start a joint action between the institutions aimed at safeguarding an important monumental complex in a seismic risk area. The results were combined to reach promising outcomes not only for research purposes but mainly for monitoring and documenting a rare example of

Templar iconography and structure. Future perspectives will include to carry out further diagnostic and structural measurements for seismic risk evaluations on the church, also by means of Finite Element Method (FEM), and to gather the obtained information to a HBIM model (Cardinali *et al.*, 2023; Liberotti and Gusella, 2023), enriching the knowledge of the site, also from historical and restoration points of view.

2. THE TEMPLAR COMPLEX OF S. BEVIGNATE

The San Bevignate church is one of the most intact monumental testimonies of the Templar Order in Europe, built on the site of an ancient Roman laundry, the remains of which are still visible today (Tommasi, 1981; Casagrande, 2008) (Figure 1a). The actual structure was founded in 1256 according to the request of the Templar friar Bonvicino, native of Assisi and a close collaborator of four popes. Built in agreement with the Bishop and the Municipality of Perugia, the church was dedicated to San Bevignate, a hermit whose body was housed in the past under the altar (Roncetti, Scarpellini and Tommasi, 1987; Merli, 2017a). Among the decorations of the churches belonging to the Militia Templi, San Bevignate’s are remarkable for the complexity and vivacity of the pictorial decoration (Scarpellini, 2008). The wall paintings of the inside of the church were accomplished in two phases between 1260 and 1283, narrating the story of the Order and depicting characters and episodes from the Umbrian Middle Ages, from Saint Bevignate to the flagellant movement. In particular, on the counter façade, a pictorial cycle relating to the mission to the Holy Land is depicted, by local craftsmen and dated back between 1265 and 1270. Arranged in three overlapping bands, it presents scenes of Knights Templar engaged in battle, monastic life and travelling to the Holy Land. The battle scene, represented in a violent and verisimilar style, has sometimes been identified with that which took place in Nablus in 1242, but it could also be a more generic reference to battle as the essence of the Templar mission in the Holy Land to defend holy places. Despite the extensive lacunae affecting the three levels in which the narrative is articulated, the frescoes are an exceptional artistic expression of historical narration in which the epic of the crusade against the 'infidels' unfolds, seen from the perspective of the exaltation of the mission of the *milites* Templi in *Outremer* (Figure 1b). The numerous cycles of frescoes are absolutely relevant not only as a testimony of the Templars venture in the Holy Land but also because they depict the mediaeval movement of the *flagellanti* or *disciplinati*, most likely born in Perugia in the beginning of the 13th century. The genesis of the movement is attributed to the Franciscan and religious reformer Raniero Fasani, as described in the late 14th century-text entitled *La lezenda di fra' Raniero Fasani* (Nicolini, 1987; Dickson, 1989). In this sense, the church of San Bevignate has a key role in the worldwide templar iconography: the frescoes in the apse are an extraordinary pictorial testimony - if not the oldest - of the birth of this Catholic movement, which remained active from the 13th to the 15th centuries. Dated back to the same period are the imitation stone ashlars of the inner walls, common feature in Templar churches and chapels aimed to recall the poverty of the holy land. In addition, along all the walls of the church, several saints and the twelve apostles holding large, jewelled crosses inscribed in roundels are represented. The apostles, which can be dated to the 1380s (ca. 1280-1283), are the work of a master or workshop of painters much more refined than those who created the frescoes of the first decorative phase such as the Templar battle. Their realisation is perhaps linked to the arrival in Perugia in 1283 of Guillaume Charnier, an important French Templar (Frugoni, 2008; Merli, 2017b).

The architecture recalls Gothic forms of Cistercian inspiration, sober and austere, made of sandstone, with external counterforts reinforcing the perimeter walls with ogival windows and with a single cross vaulted nave, with a peculiar internal play of masonry vaults.
The proof of the great worldwide relevance of the San Bevignate frescoes is also proved by the inclusion of such site to the European Cultural Route of the Templars (*European Cultural Route of the Templars*, 2012).

(a) (b)

Figure 1. San Bevignate church, Perugia: (a), external view; (b) the inside of the church on the counter-façade side.

The church is nowadays closed to the public, thus the outcomes of the diagnostic surveys and the digitalisation obtained in this work could be considered important and useful information for the future access and the valorisation to devotees and visitors.

2.1 The Templar iconography

The Templar monks were represented as warriors, fighting inner and outer battles with equal courage. Their beards were a sign of the penitential life as common in Eastern spirituality as it was rare in the West at the time. This principle of the Templar life was often depicted with a ferocious and, at the same time, defeated animal, a symbol of the perpetual battle against evil and inner temptations. Among the scenes depicted on the counter façade, there is one that shows a group of Templars dressed as monks inside a building, evocating the monastery, in which one of them is intent on removing a thorn from the paw of a lion, a reference to the hagiography of St. Jerome and mentioned in Jacopo da Varagine’s *Lezenda Aurea* (Santanicchia, 2016; Renzi and Alfi, 2023). The scenes in the frescoes were addressed to a poor audience that would probably never visit those distant lands, therefore the depiction was magnified. Such representations were intended to convey an idea of an environment full of dangers, exotic and mysterious, thereby also exalting the courage, valour and faith of those who fought in defence of the holy places or set out on pilgrimage (Santanicchia, 2020).

3. NON-INVASIVE TECHNIQUES

The non-invasive approach adopted for the study of the San Bevignate church was based on two steps: firstly, a thermographic analysis in passive conditions was carried out on the lower areas of the frescoes by using a thermal camera. Secondly, the 3D model of the counter façade was obtained with laser scanning and UAV. The scheme of the measurements is reported in Figure 2, where the red and green symbols represent the walls under investigation with the thermographic and 3D digitalisation surveys, respectively.

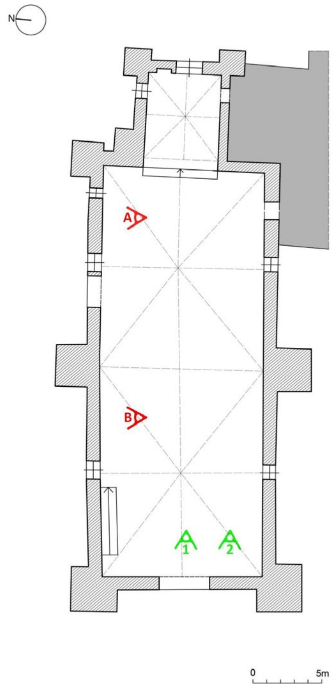


Figure 2. Survey of the Templar church with the photographic cones of vision: (red) the settings of thermographic shootings, (green) the laser scanning and UAV acquisitions.

3.1 Thermography

Calling to mind the well-known phenomena of heat transfer - conduction, convection and radiation - an infrared camera is able to record the amount of radiated heat from an object. Indeed, the heat transfer in any architectural element is affected by the presence of subsurface flaws or any other change in the thermal properties of each material, concerning both structural and decorative members. Localised energy differences on the historical surfaces are caused by the changes in heat flow and can be recorded using the infrared detector.
The interconnection between emitted radiation and surface temperature is given by the Stefan–Boltzmann equation

$$\varepsilon = \epsilon\, \sigma\, T^4 \qquad (1)$$

where ε is the energy radiated (W/m^2), T is the absolute temperature (K), σ is the Stefan–Boltzmann constant (5.67×10^{-8} Wm^{-2}K^{-4}) and ϵ is the emissivity (different for each material). Moreover, the relation between the wavelength of the maximum radiation intensity λ (µm) and the temperature is

$$\lambda = b/T \qquad (2)$$

where b is the Wien displacement constant (2897 µmK). For temperatures close to inner spaces' temperature, the energy is in the infrared region of the electromagnetic spectrum, with wavelengths ranging from 0.75 to 10 µm (Usamentiaga *et al.*, 2014). Thus, the temperature distributions are obtained by processing the measured infrared radiation from the investigated area and then recorded in the form of isotherm plots, also known as thermograms. The electronic sensor of the instrument records the value of energy stored by every single pixel and conveys an image, originally in grayscale, represented by black and white shades or in a combination of false colours levels. Laboratory tests verified the ability to assess the texture of masonry walls covered with plaster or frescoes using thermographic images (Gusella, Cluni and Liberotti, 2021) and this study tested the reliability of the proposed procedure on real artworks, underlining the role of this tool in NDT investigations on architectures. A thermographic camera, model 885-2 produced by the Testo company, with a sensor of dimension 320x240 pixels was used to acquire images in passive conditions on the north wall in correspondence of relevant frescoes for the assessment of the masonry's quality, stratification and safety, with particular attention to key factors in terms of conservation of the paintings. The most innovative aspects related to these activities are the definition of an appropriate survey protocol and the creation of a post-processing procedure on the thermal images, devised and adopted in the following steps (Gusella, Cluni and Liberotti, 2021):

• The temperature data acquired, relating to each image pixel, were represented as a scalar field (Figure 3b,d)

$$T_i = T_i(\mathrm{x,y}) \quad x = 1,2,\ldots,\mathrm{N} \quad y=1,2,\ldots,\mathrm{N} \qquad (3)$$

where N is the image width in pixels. It is assumed that the image has equal width and height.

• Assuming a threshold temperature (T_t), the previous field was converted to a binary function, which leads to black and white images where the mortar is represented by black regions of pixels and the bricks with the white ones (Figure 3c,e). In particular:

$$b_i = b_i\,(x,y) = \{0 \text{ if } T_i \leq T_t \text{ and } 1 \text{ if } T_i > T_t \qquad (4)$$

where the value 1 (black) is associated with mortar pixels and the value 0 (white) with brick/stone pixels.

• Moreover, the obtained binary images require specific treatments to improve their quality. At first, mortar (black) regions which are surrounded by bricks (white) pixels are removed. So, morphological operators were used to smooth the contour of the inclusions, which otherwise would be very fragmented due to the noise in the image acquisition phase. In the particular case of this sequence, erosion and dilation morphological operators were applied:

$$b_e\,(\mathrm{x,y}) = \text{maximum } \{b\,(s,t) \text{ for } (s,t) \text{ in } N^l_{(x,y)} \qquad (5)$$

$$b_d\,(\mathrm{x,y}) = \text{maximum } \{\, b_e\,(s,t) \text{ for } (s,t) \text{ in } N^l_{(x,y)}\} \qquad (6)$$

where $N^l_{(x,y)}$ is a square of side l pixels centred in the pixel at (x,y) coordinates. Moreover, it was pointed out that the use of sampling Kantorovich algorithm permits to enhance remarkably the quality of the thermographic images. Furthermore, a sensitivity analysis was performed considering two sources of uncertainties: the first was related to the parameters of the morphological operator, the second to the effects of the environmental conditions highlighting the robustness of the proposed approach (Cluni *et al.*, 2020). Starting from this strategy, the experimental outcomes were compared with the digital pics, highlighting the reliability of the procedure. Indeed, the results present a consistent separation of phases in terms of black and white image, i.e., each stone is surrounded by mortar joints and unrealistic conjunctions of inclusions are reduced as much as possible.

It is worth noting that passive thermography relies upon the naturally occurring thermal radiation received from the architecture. Indeed, with passive thermography, thermal contrast is observed with an infrared camera only if the target's temperature differs from the inner ambient one or from the external environment. Otherwise, the resulting thermal image will show little variations in colour or greyscale if there is not enough thermal contrast. From this it follows that the proposed technique has a great advantage, that of not requiring external sources of heat or radiation in order to be effective. At the same time, however, its applicability is strongly influenced by the environmental conditions, especially the external ones. A dependence that has proved to be not negligible, but which can be remedied by selecting, based on the seasons, the times in which the thermal gradient is most pronounced and therefore are the most suitable for carrying out the measurements. In this choice, the orientation of the individual building and the high thermal inertia of its masonries - and their influence - must also be taken into account in this reasoning (e.g. on a summer day characterised by good weather, twilight represents the most appropriate conditions to carry out the surveys).

The acquired data will be considered in the years to come as precious documentation for future interventions, especially considering that Umbria is a seismic region in which the preservation and safety of artistic heritage is always at risk due to frequent earthquakes (Giné, Ortega and Pons, 2019; Cianchino *et al.*, 2023).

3.2 Three-dimensional modelling

The detailed 3D colour model of the counter façade was achieved with a multi-sensor approach by using a laser scanner prototype and remotely-controlled drone. The laser scanner employed in this work is a prototypal system, called RGB-ITR, developed at the ENEA Research Centre of Frascati (Rome, Italy). This scanner belongs to the category of active methods for the digitalisation (Remondino and El-Hakim, 2006; Pavlidis *et al.*, 2007; Aubreton, Mériaudeau and Truchetet, 2016; Altuntas, 2021) and it is able to remotely (up to 30 m) collect both colour and structural information by using three monochromatic laser sources in the visible range (red, green and blue at respectively 660 nm, 517 nm and 440 nm) overlapped in a single light beam. The incident beam is focused with a suitable lens and scanned on the surface by means of a motorised mirror system (Ceccarelli *et al.*, 2018). The colour and the geometrical reconstructions of the investigated surface are obtained through, respectively, the amplitude and the phase-shift information of the back-reflected signals from the target. This is possible thanks to the use of the double modulation methodology of the laser sources, combined with the lock-in technique (Stéphane Poujouly and Bernard Journet, 2002; Mullen *et al.*, 2004; Ferri De Collibus *et al.*, 2005). Since the use of laser sources instead of the CCD technology, this technique presents several advantages in both acquisition and elaboration phases, among which the resulting textures are composed by white-balanced colours at every distance without being affected by ambient lights, avoiding the most common camera problems like glare and shadow effects (McCann, Vonikakis and Rizzi, 2017). The independence from the surrounding lighting conditions is a crucial factor for studies in CH, which often are characterised by peculiar environmental features, such as hypogeum sites, crowded areas requiring night acquisitions and also high illumination due to large windows (Guarneri, Ceccarelli and Ciaffi, 2019; Ceccarelli *et al.*, 2021), such as in the San Bevignate church which has a large rose window. It is worth to note that the RGB-ITR acquisitions were made without the use of scaffolds, digitising the entire surface of the counter-façade from the floor up to about 18 metres.

Concerning the post-processing phase, the elaborations on the laser images were performed in two steps:

1) White balancing and colours calibration for all the distance range.

2) Mathematical subtraction of the blue channel signals to the red ones in order to obtain information about the optical behaviour of the pigments. Thus, in the grey scaled obtained images, lighter areas indicate a red colour dominance, while darker areas denote a blue dominance.

Contextual to the laser scanner acquisitions, a DJI Mavic Mini drone was employed for UAV survey, collecting 190 photos with a 4:3 ratio and a resolution of 4000×3000 pixels, processed by Agisoft Metashape software. The UAV survey was carried out in three takes of 30 minutes of flying time each. The acquisition of UAV photos has the aim of quickly completing the missing parts of the 3D model obtained with the laser scanner and reconstructing a textured 3D model applying the photogrammetry technique. Due to technical issues caused by the GPS signal, working limitations constrained the drone to flight at 8 m from the floor and 5 m from the surface.

4. RESULTS AND DISCUSSION

The results allowed the study of both materials and colours of the frescoes, some of which are not easily visible and appreciable in detail from the ground, reaching about 18 metres. A multi-sensor approach was applied in the San Bevignate church by using 3D digitalisation techniques with laser scanning and UAV systems and a scalable and contactless thermographic method to identify and interpret the differences of temperature in wall surfaces. Such strategy enables the evaluation of the quality and regularity of the masonry texture covered by the frescoes, as the conservative status of the latter, representing an aprioristic element to be analysed (Galassi, 2023; Hejazi and Kaviani Dezaki, 2023) before any restoration intervention. In particular, the thermographic results were achieved by the surveys carried out in the lower parts of the north wall in correspondence of the depiction of the saints Magdalene, Stefano and Lorenzo (Figure 3) and of the drawings of overlapping ashlars (Figure 4).

Merging physical with digital photographs and measurements, and considering that in this first case the metre sticks were placed with a wheelbase equal to 2.70 m, it was possible to seize the quality of the masonry texture and also to characterise its dimensional features: a quasi-periodic texture made of stone blocks with different widths, ranging from 25 to 60 cm, but similar heights, of about 20 cm, was observed (Figure 3b-e). In addition, it was possible to contextually characterise the health of the frescoes, ascertaining the absence of detachments or infiltration phenomena. Moreover, the mortar distribution out of the joints suggests a trace of the fresco-makers' ancient technique: the surfaces of the previous frescoes were 'pitted' by the stonemasons in order to create a surface suitable for the adhesion of the new layer of mortar and painting, still visible today. Additionally, in the second part of the church analysed with the thermal camera (cone A in Figure 2), two interesting elements were pointed out, such as the different emissivity of the materials and the presence of an architrave made of another material of about 15 cm thick. Concerning the constructive phases and criteria, the peculiar workmanship is also observable on the abutments of the window, highlighting the traditional process of leaving alternate stone "teeth" for a better adjoining of blocks (Figure 3). This building technique is used when windows or doors must be opened from an existing wall by indenting, allowing the adjacent masonry to develop without having to adjust or cut the existing bricks.

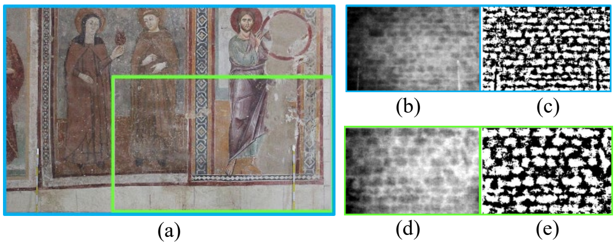


Figure 3. Thermographic results on the Saints Maddalena, Stefano and Lorenzo frescoes (a) corresponding to the B cone in Figure 2. Through the described procedure, the thermographic pics’ quality is enhanced revealing the masonry behind the painting level (b, d); binary image of the masonry texture where the geometry of the bricks is clearly appreciable (c, e).

Moreover, from the observation of the thermographic results obtained in the area of a window near the apse (Figure 4a), a recess (or niche) was identified, as can be seen from the thermal image, where the different emissivity can be clearly noticed (Figure 4b). The elaboration of such image with the above-mentioned approach allowed to better highlight the geometry of the hidden element and its material features. Indeed, the squared feature did not present any masonry texture as if it had been filled entirely with a sort of concretion material which has a thermal behaviour similar to the mortar between the bricks, confirming the different nature of the element with the respect of the surrounding masonry (Figure 4c).

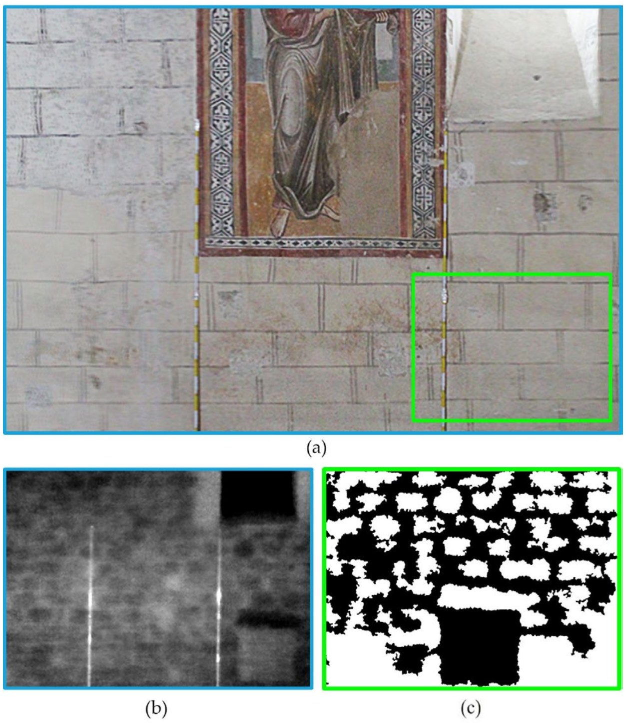


Figure 4. Thermographic results on the different area (a) corresponding to the A cone in Figure 2. (b) The thermal image with improved contrast where the structural peculiarities of the masonry wall are visible, including the niche which is better appreciable in the binary image close-up (c).

As a monitoring and analysis tool for the paintings, the 3D model obtained by the RGB-ITR scanner provides a detailed and accurate digitalisation of most of the counter façade of the church, integrated with the UAV survey, presented in this paper as preliminary outcomes. Figure 5 shows the comparison of two models obtained by the two different techniques: the image (a) reports the UAV model of the wall, presenting a good digitalisation of the structure (Figure 5b) with several details of the masonry (arrows in Figure 5c). The image (d) shows the integration of the UAV model with the RGB-ITR one, characterised by calibrated colours. In this case, the results on the structure obtained by the laser scanner (Figure 5e) provided sharper information on the wall’s bricks and in general on the masonry (Figure 5f).

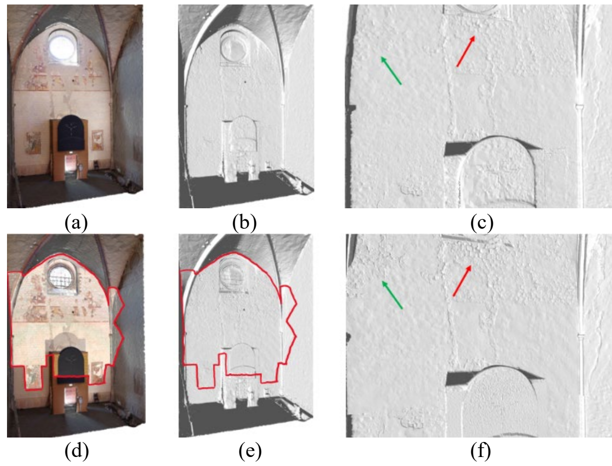


Figure 5. (a) 3D model obtained by UAV and its structure (b) with a close-up where the details of the masonry are visible(c); (d) 3D model colour-calibrated obtained by the RGB-ITR (area outlined with red line) integrated in the (a); (e) structure of the RGB-ITR 3D model and (f) the close-up where the red and green arrows highlight the detailed revealed with the two techniques.

Moreover, differences in terms of contrast and detail are also visible in the colour information collected by the two devices, as is shown in Figure 6, where close-up of the UAV (a) and RGB-ITR (b) acquisitions are reported in correspondence of the depiction of a lion. Even if the two images seem to be very similar, small differences in contrast and tone are evident. Moreover, for the observation of the RGB-ITR image (Figure 6b), details on the roughness of the wall can be appreciated, which are, on the contrary, completed smoothed in the UAV image (Figure 6a).

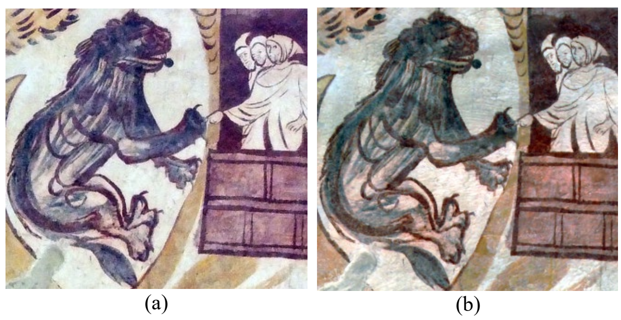
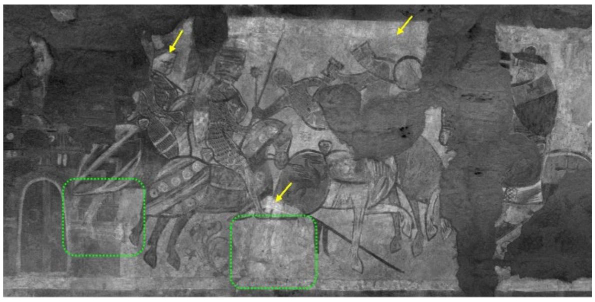


Figure 6. The lion detail digitalised by the drone (a) and the RGB-ITR system (b), where the differences in colours and roughness of the wall are visible.

As mentioned in section 3.2, some mathematical operations between the channels of the RGB-ITR images were applied in several parts of the digitalisation of the frescoes. In particular, from the elaborations in correspondence of the battle scene (cone 2 in Figure 2, Figure 7a), interesting elements were identified in colouring and artistic details (Figure 7b). Here, colour differences of some red areas are visible, with the respect to other red parts, appearing much lighter, or even not visible, in the grayscale image (yellow arrows in Figure 7b). Moreover, some horse legs appear to be depicted in a different artistic style, also lacking in the black contours that are instead present in all the elements of the pictorial decoration (green squares in Figure 7b). This information could be in accord with the two-phases realisation of the paintings, probably also with two artistic styles slightly divergent. Moreover, the retouching and the restorations carried out during the centuries on these frescoes could have resulted in features different from the original style of the decorative apparatus.

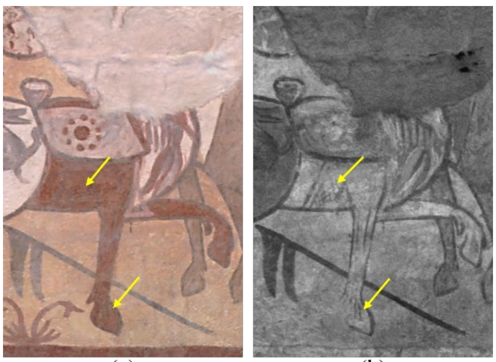
(a)



(b)

Figure 7. Details of the 3D models of the battle scene (cone 2 in Figure 2): (a) calibrated RGB-ITR image; (b) Subtracted image where the yellow arrows indicate a different colouring with the respect to other red parts and the green squared highlight the missing contouring of the horses legs.

From the observation of a close-up of the same area (Figure 8a), details of the red horse's saddle are recovered in the mathematical elaborated image (Figure 8b). Here, the pattern of the interlacing of the saddle strings are clearly evident, as well as the marks on the hoof. The darkening of the painting surface may have provided the loss of details, better appreciable in the elaborated laser image.



(a) (b)

Figure 8. Close-up of the red horse in the battle scene (cone 2 in Figure 2): (a) calibrated RGB-ITR image; (b) Subtracted image where the interlacing of the saddle strings and the marks on the hoof are clearly evident and indicated by the arrows.

Similar considerations to Figure 7 can be carried out in the rest of the battle scene, reported in Figure 9a. Although the area is particularly degraded with significant detachments, several horse heads can be discerned, showing comparable differences to those seen in Figure 7. In the elaborated image of Figure 9b, the two horses on the right (green circle) have clearly visible black outlines, like many other characters of the paintings in the church, while the two others on the left (yellow circle) lack this feature.

(a) (b)

Figure 9. Details of the 3D models of the procession in the battle scene(cone 2 in Figure 2): (a) calibrated RGB-ITR image; (b) Subtracted image where the different style of the horses can be seen between the outlined (yellow circle) and the not-outlined (green circle).

The differences revealed by mathematical processing of the laser images are probably related to the restoration actions that the church, and in particular the frescoes, have undergone over the past centuries. Furthermore, the thermographic survey provided the statement of a good conservation status of the mural structure.

5. CONCLUSIONS

The results presented in this paper show the efficacy of the complementary use of experimental techniques for diagnostic, monitoring and high-level documentation of the unique site of the San Bevignate Templar church. The passive thermographic approach highlighted interesting details related to the masonries' stratifications. Indeed, thanks to the application of properly developed post-processing procedure, the mean dimensions of the bricks were calculated and a hidden recess under a window was identified. At the same time, the 3D techniques, a laser scanner prototype and UAV, allowed the remote digitalisation of the counter façade and the visualisation of highly detailed features of the frescoes, some of which are not completely visible from the ground. Furthermore, the mathematical elaborations of the laser images highlighted interesting features, such as the recovery of details on the horse ornament and the lack of contouring in many parts of the battle scene. The latter element, as well as some differences in colouring in red parts, could be ascribed to the long history of the Templar architecture, which has undergone numerous restorations and retouching over the centuries.

The complementarity of the analyses enriched the knowledge about the templar decorations and architecture, providing valuable information for its protection and long term monitoring, but also in its visualisation and promotion, creating storytelling tools capable of attracting the user's attention, especially when the site is closed to the public.

As future perspectives, the results of the experimental campaigns described in this paper, together with other cognitive activities, are expected to be systemised and encoded by the development of a digital database. So, considering the peculiarities of the adopted techniques and their promising outcomes, an extended survey also in all the internal wall surfaces of the church could be settled in order to improve data for a more complete long-term monitoring, also considering further diagnostic techniques. In this perspective, all the collected information is assumed to be

classified in a HBIM model, considering a continuous improvement and update of the available contents of the database, also from historical and restoration points of view. Moreover, among the the next steps, the two 3D approaches will be fully integrated, with intent to build a high-detailed digital twin with a corrected colours digitalisation.
The work presented is embedded in a context of historiographical studies, both Italian and foreign, spanning at least fifty years. Thus, the results confirm the intention to clarify and expand knowledge of the artistic and structural asset of the important Templar site, opening the perspectives to the first, synergic use of new technologies for the monitoring, especially over the long term, the diagnostics and the communication of a distant but precious world.

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