INFRA REDable. Thermography for the diagnosis and conservation of frescoed walls: the case of the Templar Church of San Bevignate

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Abstract
The importance of research that addresses the numerous themes of architectural and cultural heritage conservation is a fact that has now been acquired on the national and international scene. The objective of the ongoing research presented is the study and development of infrared thermography as an innovative technique for non-contact, and absolutely non-invasive, investigations for the diagnosis of ancient masonry walls with specific attention to frescoes. In parallel, the devised technique is applied to a case study of very high historical value: the cycles of mural paintings of the Templar Church of San Bevignate in Perugia. Such architectural complex also houses a relevant archeological site which consists of a roman fullonica, part of the museum itinerary. Starting from the thermographic data, both the state of conservation of the precious painting and the seismic safety of the masonry Church – tied to the quality of the brickwork texture – are evaluated. The comparison among thermographic results and the outcomes due to a restoration activity of the painted parts, that took place on 2019 and that is still in progress, are highlighted.

Keywords
Heritage, frescoes, restoration, thermal imaging, archeological contexts.

Damages to artworks induce invaluable losses from a social, cultural and economic standpoint. On this, art assets require special consideration because of their strong links with communities and their high vulnerability to different typologies of risks. Those treats can be tied to Natural hazards:
- Ageing of materials and the type of artifacts;
- Impact of climate changes;
- Earthquake damaging of monumental constructions;

and/or to Human hazards:
- Art crimes and vandalism;
- Negligence and rudeness of visitors;
- Lack of maintenance and site-specific prevention strategies.

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Complex of San Bevignate in Perugia: general view of the Church. Photos: authors.

Moreover, whatever the causes, a damage correlation between the museum structural systems and artworks housed in them represents a mandatory issue in order to safeguard unmovable art assets e.g. frescoes, valuable plasters or wall paintings, mosaics, paving and stuccoes (Marra 2021, Degli Esposti 2021, Ponte 2021, Satta 2021). In particular, the frescoes are in the highest risk condition, because the art good itself and the structural element (the wall to which it is connected) are part of a single entity. On this, the following critical features affecting the seismic response of historic masonry buildings must be analysed:

- masonry quality and texture;
- connections among structural elements;
- structural irregularities or defects;
- presence of damages and phenomena of degradation.

In this context the use of advanced close-range non-destructive techniques, such as Infrared Thermography (IRT) can already be profitably used for the detection of conservation issues (e.g., open fractures, unstable ledges) that can lead to deterioration phenomena (Hillen 2020, Meola 2016, Enshaeian 2021). These techniques, when combined with traditional methods (e.g. surveys, experimental tests, laboratory analysis etc.) and innovative technologies such as 3D mapping and image processing can provide fundamental data to implement strategies applicable for the sustainable conservation and restauration of different cultural heritage sites (Balocco 2020, Matracchi 2021, Kim 2021, Marín Ortega 2021, Barontini 2021, Picchio 2017, Jiang 2022, Pouraminian 2022, Martelli 2020, Gusella 2020). In this paper, the experimental results and conservation insights concerning the Templar Church of San Bevignate are presented, with the aim of evaluating the potential of the proposed thermographic procedure focused on the masonry quality detection. Moreover, the research is permeated by an interdisciplinary approach, aware of the historical and emotional certainties that the architectural heritage represents and attentive not only to its protection but also to its enhancement; therefore, in a future perspective connected to the central theme of the use of historic buildings, the development of digital means for museal storytelling of the results is also envisaged.

The Templar architectural complex of San Bevignate

History of the Church

In the countryside of the city of Perugia, in the seismic hazard-prone Umbria region (Italy), and more precisely near the monumental cemetery of Monteluce, stands the Templar architectural complex of San Bevignate. In particular, it is located strategically along the most important road axis that anciently crossed the area of the Perugian countryside pertaining to Porta Sole and towards the Tevere river. Currently the rue, that was one of the five royal access road axis to the city, is named Enrico dal Pozzo in the district of Monteluce: developed anciently as an extension of the historic center outside the medieval walls and characterized by the presence of necropolis since the Etruscan era. In particular, it is situated east of the historic center of Perugia in an area still characterized by a low level of urbanization. In those areas, from 1243, the Templars owned also a small Church dedicated to San Gerolamo. Therefore, together, the abbey of San Giustino d'Arna, San Gerolamo and the complex of San Bevignate actually constituted a single Preceptory (Nardelli 2010). The Church, sober and austere in its external appearance, is marked inside by the play of slender ribs and decorated with a

Fig. 1
General view of the nave.
Photos: authors.

pictorial cycle designed to remind the inhabitants of the mission carried out in the Holy Ground by the Militia Templi, a.k.a. the Templars, the religious-chivalric order created in Jerusalem around 1119 on the initiative of the French knight Hugues de Payns (fig. 1). Such exceptional artifact testifies the presence of the order of the temple in Perugia. Indeed, in 1256 the city's municipality granted the authorization at the Templar friar Bonvicino[1] to erect the religious building in place of a small Church dedicated to San Girolamo. Even though the Templars, at the time, were already present in the Umbria region at the abbey of San Giustino d'Arna, since such seat was decentralized with respect to the prosperous Perugia they requested a new one. For the inhabitants of Perugia – and for the Templars – devoting the Church to the figure of San Bevignate, whose history is still shrouded in mystery to this day, was important considering the popularity of its local cult back then: traditions tell that he was a hermit monk who lived around 500 AD in the woods of Perugia, his name, however, appears only after 1200 in a Templar manuscript from which it seems that he lived his youth in prison and then sought a life of redemption in prayer; in addition numerous miracles are attributed to him, including the resurrection of a boy torn to pieces by wolf attacks (Merli 2019).
There are other studies led by Father Ugolino Nicolini in the last decade according to which Bevignate might have lived around 1200 AD and took an active part in the order of the Templars. Actually, he was not proclaimed a saint by the Church of Rome but it was "laically" canonized only in 1453 by means of a decree of the Municipality of Perugia. The Templars could not see the cult of San Bevignate approved as the Congregation of Rites approved the Sanctification only in 1605, despite this they considered him already the first Templars' saint. On this, the Church contains very rare frescoes within which the deeds of the Knights Templar and the history of San Bevignate are represented, in which the latter was already depicted as a saint, about to receive an investiture by a bishop, complete with an aureole on his head (Nicolini 1987).

In addition, it is important to stress that the presence in the Church of the thirteenth-century frescoes constitute the first iconographic documentation of the motion of the flagellants, also known as the disciplined, founded in Perugia in 1260 by the friar Raniero Fasani. In this same year Bonvicino became interested in the Roman Curia, under the Pope Alessandro IV, for the canonization of San Bevignate, and thus indirectly his name was linked to homonymous mysterious hermit protagonist of the Lezenda[2] of Raniero Fasani itself.
In 1262 the construction of the Church was completed and also that of the Romanesque bell tower with a square plan, flanking the apse area, and of considerable size (7×7m). In addition to warehouses, deposits for equipment and shelters for animals, in the immediate vicinity there was also a chapel of more ancient foundation, dedicated to San Girolamo, documented as early as 1243 and mentioned by Lancellotti (Santanicchia 2016). It is also hypothesized that, given the extra-urban location of the preceptory, the area located in the southeast of the building was anciently protected by a wall and moreover was put in direct communication with the cenobitic area of the Church through a small door, now walled up (as well as other windows and accesses). A similar dating is proposed for the monumental octagonal stone well located behind the apse area (still visible today in the center of a garden of private property) and for the remaining buildings of the architectural complex now, as mentioned, used as a private residence. In 1312, with the suppression of the Templar Order, the monastery passed to the knights of San Giovanni of Jerusalem and in 1324 Ricco di Corbolo, a merchant of Perugia, bought the complex and established a female monastic community there, likewise placed under the rule of the Order of San Giovanni. In 1517, due to economic problems, the nuns were forced to abandon the monastery which returned to the fully possession of the Order of San Giovanni. From that date the Church gradually lost its importance and in 1860, with the suppression of various religious bodies, became the property of the Municipality of Perugia and was deconsecrated. In the last century had various uses, a wood storage, a kennel and even a fire station and such peculiar circumstances permitted to preserve – strikingly – the frescoes because they have been covered by plaster for decades. After a long and complex intervention plan of consolidation and restoration started following the 1997 earthquake, in 2009 the monumental complex reopened to the public and the original decorative apparatus have also secured; result of an agreement between the municipality and the superintendence of fine arts of Perugia. In addition, in 2021 another restoration plan concerning the frescoes of the counter-façade and part of the side walls was completed, with particular attention paid to restoring the original tones to the wall paintings (Vallerani 2004). To present day, a restoration work is still in progress concerning the cross vaults covering nave, subject to infiltration and degradation phenomena. The restoration activities – and the establishment of synergies with their perpetrators – confirmed what emerged from the historical-iconographic researches (to name a few, Santanicchia 2016, Merli 2008a): the paintings inside the Church (fig. 2) are realized with the fresco technique, ideal for making murals because it lends itself to a monumental style, is durable, and has a matte surface (result of pigments set with the freshly applied plaster to become a permanent part of the wall).

Fig. 2
Starting from the left, counter-façade and the apse after the restoration. Below, respectively, representation, among swaying palm trees, of a lion facing a group of monks, in a convent, dressed in white; the friar Bevignate depicted with a halo as if he were already a Saint and with the white habit consistently with the Templars in the counter-façade.
Photos: authors

Architectural features of the Church: the frescoes

The Church appears as a structure of considerable size made of sandstone and with a double sloping facade decorated with a simple oculus and a single round-arched portal, adorned with a marble frame with symbols typical of the Templars, while another small entrance door crowned with an ogive arch is located on the left wall. The Church is marked by the presence of architectural elements that recall the Gothic style (e.g. the ribbed vaults) but instead, analysing the portal and the frescoes themselves, emerges that the Church is influenced by the local architectures of the time such as the churches of San Francesco al Prato, Monteluce and the Upper Basilica of Assisi in which the Romanesque style prevails albeit borrowing some features from the Gothic one, as it is common in the Umbria region (Merli 2008a) The remarkable dimensions of the Church of San Bevignate (39.5×17.5×27m), introduce little known aspects in the Templar history and in their architecture. At the extremity of the façade two mighty buttresses are clearly visible and recall the others located on the perimeter walls. The building ends with a quadrangular apse interrupted by a mullioned window in travertine. Inside, the Church consists in a single nave divided in two large spans by pillars running along the walls – subdivision observable also on the gradients of the roofing – and by ogival-shaped ribbed cross vaults, delineated though a prismatic stone curb, whose weights are balanced by robust external buttresses on the perimeter walls. The square apsidal area, placed above the crypt and slightly raised with respect to the level of the nave floor, is marked by the presence of a grandiose ogival arch and covered, even then, by a cross vault. The Church is rich in valuable pictorial and, among them, the only certainly contemporaneous with the Templar period are actually those of the counter-façade and those above the apse (1260-1270). Above the main entrance, recently restored, it is observable an unusual iconographic choice that documents the Templar life arranged in two registers – one upper and one lower – inherent the efforts of the knights of the temple in defence of the holy sepulchre. To the left of the rose window can be seen a galley in navigation, of whose identity we are certain, due to the two beauceant[3] on the prow, with a clear Templar provenance; moreover pilgrims heading to the holy land enjoy the protection of three men who watch over from the top of the tree, on the right, there is a closed book held in claws by an eagle (interpreted as San Giovanni's protection). Under this representation, among swaying palms, a lion faces a group of monks dressed in white who are in the convent, and on this the reference to San Gerolamo seems evident. On the right under the rose window, the scene of the Nubles' battle is depicted: the Crusaders and the Muslims fight fiercely and there are shields and banners in the foreground (Curzi 2002). Concerning the apse and the decorations of the adjacent spans, geometric bands with the cornflower sign refer to the French origin of the Templar order and the presence of the nine stars surrounding the Templar cross in the fresco above the apse itself describes the nine Templars who founded the Order. At the top of the main wall of the apse and on the left wall of the Last Supper different scenes from the Gospels are portrayed. In these portions, some flagellants can be seen and this testifies to the fact that the monks of San Bevignate did not limit themselves to administering the Templar assets, but carried out functions of assistance and apostolate among the local inhabitants. At the end of the nave that leads to the apse, above a pointed arch and within a complex decorative theme, fragments of the story of a miracle attributed to San Bevignate can be glimpsed, in particular the event in which he revives a child torn to pieces by a wolf (Roncetti 1987).

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Fig. 3
Above, comparison of the Roman ruins at the time of their discovery and current state with the museum space. Below, details of the different types of floorings observed in the archeological site. Photos: authors.

Behind the altar, a portrait of San Bevignate with a halo merits special mention and in this scene, as described in the previous section, he receives the blessing of a bishop who seems to grant him the place in which to erect his Church.

The archeological site

In conclusion of this section, it behoves to bring up that at the same time as the restoration works following the '97 earthquake started, valuable Roman ruins were discovered by the Superintendency under the Church's floorings. The finds extend for almost the entire width of the nave and consist in an ancient fullonica[4]: an artisanal site characterized, in this case, by the presence of five basins. Two of them are connected to each other and have a brick pavement arranged with a herringbone pattern. In one of these, a bronze coin was also recovered, datable between the 3rd and 2nd centuries BC. Were also found channels similar to modern sewer systems. Indeed, anciently the area of San Bevignate was rich in water and in Roman times the fabrics were washed and dyed in this workshop, where the wool was processed for the use of both winter cloaks and armour. The system made of the various drains is still visible, as can be seen in the background the red colour used for dyeing (Merli 2008b). The discovery of the Roman ruins caused a change in the initial project: a new metal structure holding up the terracotta paving, at the floor area of the Church, was introduced under which a narrow walkway through the ruins for visitors was opened (fig. 3).

Such site represents a rare discovery, as there are few Roman fullonica remains in Italy; furthermore, its peculiarity is the location: far from the urban center, like the tanneries in medieval times, due to the bad smell they emanated. Moreover, on the other hand, a fragment of a mosaic with black and white tesserae was found, attributable to a previous Roman domus dating back to around the second half of 1st century BC. Finally, this archeological site includes also the crypt where was probably buried the Saint of which the remains were then moved in the 17th century to the cathedral of San Lorenzo, in the old town of Perugia, where they currently remain; such provision was sought at the time by the Bishop Napoleone Comitoli who, in this way, relaunched the cult of San Bevignate. To date, this archeological site – peculiar for the coexistence of several eras – is completely open to the public in a single museum itinerary with the Church: the exhibition starts on the ground floor with the Church where the wonderful cycles of frescoes stand out among the exhibits, then the visit continues at the ground floor where panel installations guide the visitors throughout the discovery of the fullonica, its ancient functioning and the social customs of the citizens of the ancient Romans; at tour's end the crypt of the Saint is visible. Due to its historical-architectural significance, the complex has also been included as a stage of the prestigious European project Templars Route European Federation[5].

From the thermographic results to restauration intervention

Materials and Methods of the Thermography technique

In recent times, thermal cameras entered into our daily lives as essential tools to mitigate the spread of COVID-19. Such contactless technology allows to measure localized differences of temperature on objects' surface, caused by changes in heat flow or in the materials' thermal properties. The measurement of temperature is a quantification of the electromagnetic energy emitted, in infrared spectrum, by the different construction elements. Consequently, temperature gradients are obtained by data processing from the measurements and are recorded as isotherm plots; on this the proportional relation between emitted radiation and surface temperature is given by the Stefan-Boltzmann equation. To check the capability to assess the texture of masonry wall covered with plaster or frescoes, by means of thermographic images, a research program started. In particular, three masonry samples, which differed for the textures, were built and covered with plaster.

The periodic texture was built with the running bond scheme and using bricks with the same widths and heights, in particular UNI bricks of dimensions 250×120×55 mm either used as a whole or split in two or four were employed. For the quasiperiodic texture, bricks with different widths but equal heights were used avoiding correspondences between the vertical joints. In the last case, the random texture, made using bricks with different widths and heights, was realized.

After a 10 mm-thick plaster application and the curing period, all the samples were exposed to direct sunlight in order to improve the heat flux through the bodies and a thermographic camera model 885-2 produced by the Testo with a sensor of dimension 320x240pixels was used to acquire the data. Moreover, to obtain the texture from thermographic experimental images, a post-processing procedure with the following steps was devised and used:

• In the first place, the temperature data acquired by the thermographic shots, relating to each image pixel, have been represented as a scalar field;

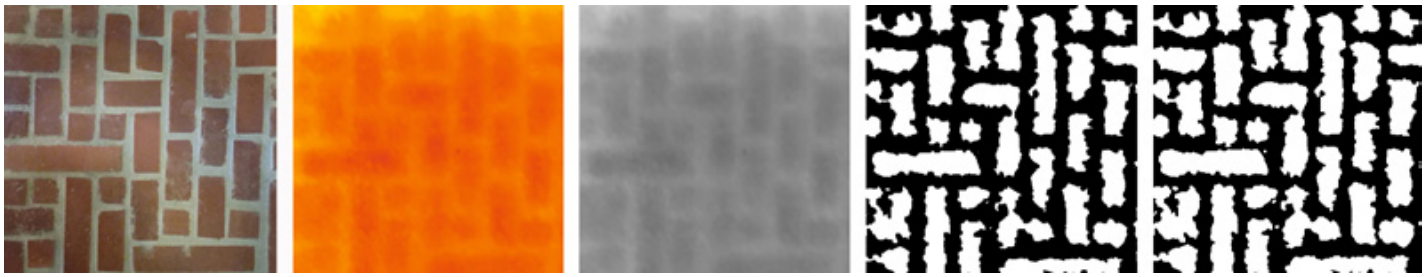


Fig. 4
Identified texture of random masonry sample. In the order, the improvements introduced by the proposed post-processing method: visible texture before the plaster application; thermographic image; surface temperature as greyscale values; black and white image after thresholding; identified texture after erosion factor; and identified texture after dilation factor. Photos: authors.

• Assuming a threshold temperature, the previous field was converted to a binary function, which leads to "black and white" images where mortar is represented by black regions of pixels and the brick's one by white pixels;
• Then, morphological operators – in particular erosion and dilation ones – have been applied to smooth the contour of the inclusions which otherwise would be very fragmented, due to different sources of noise in the acquisition phase.

With reference to the last point, the obtained binary image requires specific treatments in order to improve its quality. At first, mortar (black) region of pixels which are surrounded by brick (white) pixels are eliminated. Then the use of erosion and dilation operator, in the order, was required to smooth the contour of the inclusions which otherwise would be very fragmented, due to noise in the acquisition phase. It must be pointed out it how the use of sampling Kantorovich algorithm permitted to remarkably enhance the quality of the thermographic images. Furthermore, a sensitivity analysis has been done considering two typologies of uncertainties: the first, related to the parameters of the morphological operator and the second, to the effects of the environmental conditions that remarked the robustness of the proposed procedure.

Moreover, the influence of the fresco/plaster thickness in the correct assessment of the masonry texture has been analysed as a key factor: since it is made of a material very similar to the one the joints are made of – and it has usually a greater thermal conductivity than the stone – the plaster diffuses the thermal flux and might be because of an overestimation concerning the mortar presence. Applying the proposed procedure, the results shown in fig. 4 were obtained; the comparison with a digital image highlights the reliability of the post-processing procedure. In fact, the resulting black and white image has a consistent phases separation, i.e., each brick is surrounded by mortar joints and unrealistic conjunctions of inclusions are significantly reduced. For further details about the laboratory validation of the procedure and on the first experimental results please refer to Gusella 2021 (a, b). The aforementioned results, with reference to both the preliminary indoor testing phase and the first on site experiences, were promising and therefore the devised procedure was used during a new survey campaign – object of the present paper – propaedeutic to the last tranche of restoration works conducted lately on the valuable Templar Church of San Bevignate.

Masonry wall Texture and peculiar Characteristics of the Frescoes

The Church is one of the most important Templar Church in the world, since there is no such cycle of frescoes not even in the Chapelle des templiers de Cressac, a Templar chapel located in southwestern France that shows a valuable cycle of frescoes of reference on this theme. As mentioned in the previous sections, the main objective of the experimental investigations was the acquisition of information, without damaging the frescoes, about the non-visible masonry texture of the Church's walls. Concerning the survey methodology, thermographic "shots" were taken under passive conditions on different internal walls and thermal reflective elements – made of stiff wands – were placed to overlay, at a later time, the acquisitions and the ordinary photos in order to get dimensional information. This results in different responses from each construction or decorative material, in particular by identifying with black pixels the mortar and with the white ones the stone elements made of tuff, a soft reddish coloured rock – consisting of consolidated volcanic ash ejected from vents during a volcanic eruption – especially common in the area of central Italy where the regions of Lazio, Umbria and Tuscany meet (Raspa, 1987). Moreover, dealing with a real architecture, it was necessary to add to the procedure a new step to enhance the final binary image quality: an adjust contrast tool aimed at improving the black-to-white mapping of the thermographic greyscale image by which the recorded thermal images are preliminarily modified, consequently the differences between black and white appear sharper, filling the entire range of intensities [0, 255]. As mentioned, the restoration interventions in this last phase were concentrated only on the north wall of the masonry shell and in the same way – before the works started – the thermographic surveys were carried out precisely on its internal face[6] (fig. 5). Referring to the frescoes that decorate the examined wall, rows of overlapping ashlars are reproduced to imitate an austere wall face made of stone, a typical decoration of the Templar churches aimed to recall the poverty of the holy land. Above such decorations, the series of the twelve apostles stand out, distributed also on the other side wall, on the facade and on the back walls of the apse; such pictorial cycle was superimposed on the original decoration during a second phase, between 1283 and 1285. In particular, the last tranche of thermographic surveys was focused on some of the mural paintings concerning such cycle. Among the many examples, only the more substantial – with reference to the subsequent design of the restoration project – are described, starting from the triptych in which, in addition to one of the apostles, three saints were depicted: Magdalene, Stefano and Lorenzo. By means of straightening photographic and measurements digital techniques, and considering that in this first case the meter-sticks were placed with a wheelbase equal to 2.70 m, it was possible not only to seize the quality of the masonry texture but also to characterize 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, has been observed.

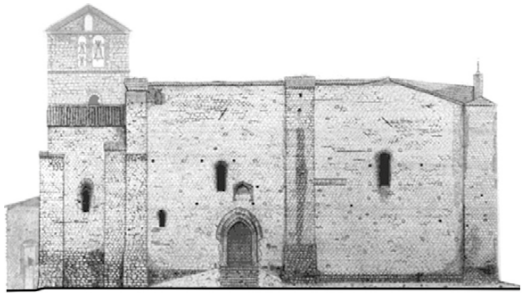
Such results match with what was surveyed in the apse in other instances, concerning the areas where the fresco peeled off and on the external facades. In addition, it was possible to contextually ascertain that there are no detachments or infiltration phenomena in place that can afflict the health of the frescoes. On this, recalling the historical-iconographical researches from which emerged that the Apostles' cycle was superimposed to the pre-existing ones, the mortar distribution and the presence of few fragments of mortar out of the joints (in those areas) suggests a trace of the fresco-makers' ancient technique: the surfaces of the previous frescoes have been "excavated" by hand

opposite page

Fig. 5
a Ortho-photo of the architectural complex of San Bevignate, the Church is outlined in red lines.
b Plan of the Templar Church with the photographic cones of vision of the survey: in red the settings of thermographic shootings, in green the digital photos.
c Survey of the north façade, object in its inner face of the thermographic survey campaign and of the last restoration interventions (elaborated from Raspa and Marchesi 1987).
Photos: authors.

Fig. 6
Experimental results on the fresco depicting Magdalene, Stefano and Lorenzo. See in fig. 5 the cone of vision 1 for the ordinary photo and, respectively, the cones A and B for the thermographic shots. The elaborations are reported, at two different scales, starting from the visible frescoes to the main phases of the post-processing method. Photos: authors.

a



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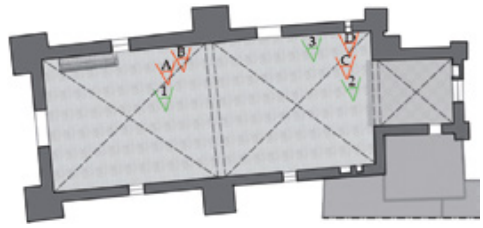

b

and without an exact pattern by the masons, allowing the fresh plaster (of the new fresco) to cling to the holes on the ancient mortar below (fig. 6). Finally, it must be pointed out that, in a previous publication antecedent to the design phase, the criteria and the numerical procedures conceived to correlate the masonry recognition to the mechanical properties identification have been described (Gusella 2021a). All these considerations found a match with the restoration activity that involved the frescoes during the just-passed year. In fact, the interventions, albeit oriented at restoring the original tones of the frescoes, through the use of different restoration techniques (Botticelli 1992, De Vita 2015; Caccia Gherardini 2020a), revealed the evidence of the different pre-existing layers of mortar, regarding not only the cycle of frescoes of the apostles. Also, the painted ashlar motif has been completely traced over the original one over at a later stage, today the scratches necessary for the successive additions are visible along with previously unknown engravings and mural paintings depicting animals, probably testimony of the outlines of preparatory drawings traced at first by the artist onto the wall and then covered. This, therefore, testifies the capability of the proposed thermographic method (Sec. 3.1) to gain information even about masonries subjected to various superimposed layers of plaster, considering also that fresco technique consists of three successive coats – two rough and the last smooth – of specially prepared plaster, sand, and sometimes marble dust trowelled as much of a wall as can be painted in one session.

Deficiencies and discontinuities identification

The role of the thermography tool for detection and qualification of deficiencies/discontinuities in the stonework is an important aspect. Through the analysis of another part of the same wall, closer to the apse, it was possible to discover the presence of a blind opening in the original masonry. At the time of the surveys such recess was totally bricked up and appeared by the thermographic survey with a size of 65x75 cm for the part walled up. Additionally, there was pointed out the different emissivity and the presence of an architrave made of another material of about 15 cm thick. Moreover, about the constructive phases and criteria, the peculiar workmanship, and the different material were also observable on the abutments of the window highlighting the traditional process of leaving alternate stone "teeth" for a better adjoining of blocks. A technique used (even nowadays) when windows or door openings must be made from an existing wall by indenting, allowing the adjoining wall to develop without having to adjust or cut the existing bricks. This scenario was confirmed by a closer thermographic picture and assuming a stratigraphic interpretation of the wall, the construction phases of the ancient site executed by different bricklayers arise: lower rows of a type of stone (which appears darker) of superior quality compared to that of the band between the recess and the window, where instead the masonry is composed of smaller elements thus making the presence of mortar predominant, are observable. Moreover, it is interesting to remark that the filling of the recess did not present any masonry texture as if it had been filled entirely with a sort of concretion material (fig. 7).

Even these observations found match with the results due to the restoration process that was carried out in recent months, in a seamless dialogue with the planning phase. The niche in question has been brought to light, confirming the presence of an architrave actually made of a different stone typology (even in the colour) and discovering the features very relevant from an archeological point of view (fig. 8). In fact, in addition to the presence of a fragment of a fresco, probably originally depicting animal fig-

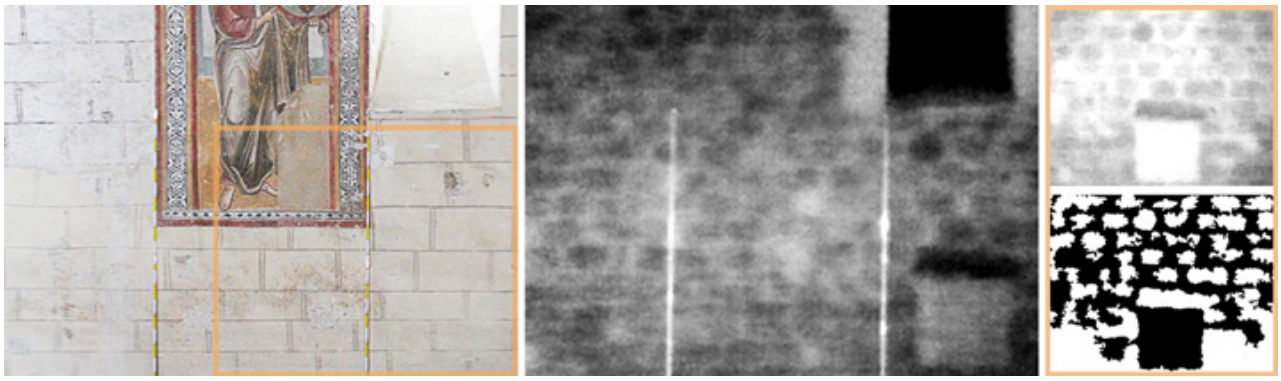

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Fig. 7
One the frescoes under investigation, in particular the one near the apse. In the pictures, the reflective meter-sticks located as reference points for the subsequent post-processing are observable in the visible image of the frescoes. To the right, thermal image with improved contrast in which are visible the structural peculiarities of the masonry wall, in the right corner is observable the former recess (see the cones of vision 2 and C in fig. 5) and cornered in orange, a zoom of the niche and its elaboration (see cone D in fig. 5). Photos: authors.

below
Fig. 8
Comparison before and after the restoration (consider cone 2 in fig. 5 for both shots). On the right column, starting from above: some of the animal mural paintings and engravings found in different areas of the wall under the non-original layer of the ashlar fresco (cone 3 of fig. 5); zoom on the niche where another drawing can be glimpsed at the bottom, perhaps of another animal figure; particular of the top of the "box" with peculiar engravings. Photos: authors.

ure in this case as well, peculiar engravings in the stone can be now observed by visitors. In this regard, in the upper internal surface of the niche, an incision which consists of two concentric discs containing alphanumeric signs, especially observable in the central part, arise. Indeed, it is well known that the Templars used a series of encrypted alphabets which included allegories and symbolisms. Therefore, it is opinion of the authors that such item – that leaves room for multiple interpretations – must be studied more in detail in the future (fig. 8).
This artifact might be the depiction of a cipher disk, an encryption device – based on the cipher designed by Leon Battista Alberti around 1467 – that consisted of two concentric discs containing an alphabet ordered for the text to be encrypted and a mixed alphabet for the encrypted resulting text (Ralls 2007). Otherwise, it could be a circular Sator[7], similar to the ones observable in other heritage sites like the Valvisciolo abbey, a church located in the Lazio region (Italy) and restored by the Templars in the 13th century (Testa 2021, Caccia Gherardini 2020b, Caccia Gherardini 2021).
In addition, it may be a representation of the sun or, given its subdivision which seems to consist of twelve segments, it could be a representation of the zodiac with other elements in the center of the innermost circle (Ralls 2007). The examples of restoration above mentioned, testify as the conservation of monuments and architectural heritage require critical reflections and careful analysis, especially related to site-specific methodological choices of survey and intervention, in a seamless mediation between architecture, restoration and engineering structural. In the case of San Bevignate, the synthesis of multiple knowledge, and their scientific and moral foundation, oriented and attributed intentionality to the subsequent plan, for example the choice of the Superintendence to unearth and preserve, as can be seen in fig. 8, only the original, and ancient, ashlar masonry decoration preserving the memory of the successive pictorial additions only in few parts of the wall.

Digital storytelling of the archeological site

In the last decade, several research groups visited San Bevignate and mustered different survey methodologies, for various purposes, including also the use of laser scanners and the collection of point cloud data. In virtue of this, and in a future perspective, the results of the experimental campaign in question and the ones tied to other cognitive activities are expected to be systemized and encoded by the development of a digital application to share and constantly update a database in the more general context of the masonry typologies and frescoes – with an estimate of their vulnerable conditions – belonging to the historical buildings of the territory of Umbria. This digital medium will therefore ensure an agile data transfer between the various players who contribute to the process of protection, use and management of prestigious historic buildings and first among them the architectural complex of San Bevignate. On this, such approach will involve also the new museum layout of the architectural/archeological site. Indeed, an open issue in the museums and galleries design is how the arrangement of space interacts with the art goods displayed within them with the aim to realise a specific effect, express the intended message or create a richer spatial structure (Caccia Gherardini 2020c, Belardi 2021a, Belardi 2022). Moreover, in the age of coronavirus (COVID-19), museums are facing unprecedented safe-related difficulties and economic uncertainty. The indefinite closures of the past years presented challenges, that museum professionals have accepted rapidly and creatively to keep

Fig. 9
Simulation preview of computer-generated imagery (CGI) and screenshots of the virtual reality experience designed for different devices in person and not. Photos: authors.

their audiences engaged remotely. National Gallery of Art, Museum of Modern Art, Frick Collection, Getty Museum, and museums of all kinds have mobilized the use of two new hashtags on socials to share collections, video gallery tours, and other educational and entertaining contents (Leoste 2021). In this scenario, and in the perspective of digital storytelling engagement, the merge between tradition and new technologies will allow to encode the mural paintings' message in a experiential and innovative cognitive process. The ongoing research program So a peculiar museum layout, in which the curatorial aspect and the research dimension meet, will be designed, including the use of Augmented Reality (AR) technology for mobile devices. Such technology, that has been around for years, nowadays it has become inexpensive enough to put into smartphones and tablets to superimpose the human field of vision with digital information and images, aprioristically scanning and redoubling by a 3D model the inner space of the Church.

The museum exhibition will face the way of seeing in AR with traditional procedures, like "trompe-l'œil" and the so-called "velo", to distinguish between what remains intact in the frescoes and what has changed during the different restauration conducted. In addition, examining this process as layering, the masonry texture behind each fresco will be revealed along with details about materials and the painting techniques. Moreover, the museum digital contents will be extended to the archeological site and its historical/constructive stratifications. Finally, all the museum tour will be further supported by the creation of digital avatars (examples in fig. 9) to facilitate the interactions between art goods and visitors (Martí Testón 2021, Belardi 2021b, Bechini 2022, Gusella 2020).

Conclusions

The proposed approach is intended to identify some principles that can inspire proposals for measures, of survey and vulnerability assessment, in several architectural and cultural contexts.
Under the assumption that the masonry quality/texture is an aprioristic element to analyse and eventually to improve, a method to identify and interpret the differences of temperature in wall surfaces was proposed and applied to a heritage architecture of great value; enabling the evaluation of the historical masonry texture covered by rare frescoes. The research was independent and prior to the restoration interventions described, but either way the evidences of the project itself confirm the experimental results, highlighting the reliability of the devised procedure and the necessity to adopt the proposed investigation strategy before conceiving any safeguard intervention. Moreover, the thermographic images have been very useful to detect deficiencies or discontinuities in the wall and besides to find characteristics of the frescoes in terms of realization criteria and actual conservation conditions. Without damaging the decorations by taking essays or samples, it was possible to obtain information not only on the risk factors concerning the restoration of the Church but also inherent to the seismic prevention, closely tied to the peculiarities and stratifications of its masonries. The new data will be used for the design of an innovative curatorial approach to the archeological and museum site.

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References

Marra A., Fabbrocino G. 2021, *On the SeVAMH survey protocol for safety and safeguard of artistic assets. Overview and validation at the Monumental complex of Santa Chiara in Naples*, «Restauro Archeologico», 28(2), pp. 4-17. <https://doi.org/10.13128/rar-8683>.
Degli esposti M., Bizzarri S. 2021, *From stone heaps to heritage landmarks. The excavation, restoration and reconstruction of prehistoric tombs at Salūt (central Oman) between experimental archaeology and site valorisation*, «Restauro Archeologico», 29(1), pp. 19-28. <https://doi.org/10.13128/rar-11389>.
Ponte M. et al. 2021, *Reduction of earthquake risk of the National Palace of Sintra in Portugal: The palatine chapel*, «International Journal of Disaster Risk Reduction», n. 60, 102172. <https://doi.org/10.1016/j.ijdrr.2021.102172 >.

Satta M.L. et al. 2021, *Remains of the ancient colonnade in the archaeological site of Pompeii, Italy: vulnerability analysis and strengthening proposal*, «Journal of Cultural Heritage», n. 52, pp. 93-106. <https://doi.org/10.1016/j.culher.2021.09.006>.
Hillen M.et al. 2020, *Cluster Analysis of IR Thermography Data for Differentiating Glass Types in Historical Leaded-Glass Windows*, «Applied Sciences», n. 10, 4255. <https://doi.org/10.3390/app10124255>.
Carosena M., Boccardi S., Carlomagno G.M. 2016, *An Excursus on Infrared Thermography Imaging*, «Journal of Imaging 2», n. 4, 36. <https://doi.org/10.3390/jimaging2040036>
Enshaeian A. et al. 2021, *A Contactless Approach to Monitor Rail Vibrations*, «Exp Mech», n. 61, pp. 705-718. <https://doi.org/10.1007/s11340-021-00691-z>.
Balocco C., Vicario M., De Vita M. 2020, *An experimental methodological approach aimed to preventive conservation and sustainable adaptive use of the cultural heritage*, «Procedia Structural integrity», n. 29, pp. 25-33. <https://doi.org/10.1016/j.prostr.2020.11.135 >.
Pietro M. et al. 2021, *The "Pieve di Santa Maria" in Arezzo (Italy). From the laser scanner survey to the knowledge of the architectural structure*, in «12th International Conference on Structural Analysis of Historical Constructions, SAHC 2020», Streamed from Spain, pp. 421-432. ISBN:9788412322200.
Kim B.et al. 2021, *Importance of Image Enhancement and CDF for Fault Assessment of Photovoltaic Module Using IR Thermal Image*, «Appl. Sci.», n. 11, 8388. <https://doi.org/10.3390/app11188388>.
Marín Ortega S., Barberà Giné, A. 2021, *Three different digitization techniques for works of art: RTI, photogrammetry, and laser scan arm. Advantages and drawbacks in the practical case of a Romanesque lipsanoteca*, in «Proceedings of the Arco 2020 1° Int. Conference on Art Collections Art Collections 2020», Art Collections 2020 Safety Issue, Florence, pp. 125-139. <https://flore.unifi.it/retrieve/handle/2158/1246497/617872/V2_Arco_2020_c_GV.pdf>.
Barontini A. et al. 2021, *Reducing the Training Samples for Damage Detection of Existing Buildings through Self-Space Approximation Techniques*, «Sensors», n. 21, 7155. <https://doi.org/10.3390/s21217155>.
Picchio F. 2017, Metodologie di rilievo integrato per indagini diagnostiche non invasive: la documentazione della Moschea Bianca di Al-Jazzar a San Giovanni d'Acri, Israele, «Restauro Archeologico», 26(2). <https://doi.org/10.13128/RA-22209>.
Jiang Y.-H., Yang N. 2022, Calculation method of effective modulus of stone masonry based on rve elements, «Gongcheng Lixue/Engineering Mechanics», 39(4), pp. 86-99, 256.
Pouraminian M. 2022, *Multi-hazard reliability assessment of historical brick minarets*, «J. Build. Rehabil.», n. 7, 10. <https://doi.org/10.1007/s41024-021-00148-9>.
Martelli M., Salvatici T., Garzonio C.A., De Vita M. 2020, *Assessment of residual effectiveness for Water-Repellent treatments for building stones. Water absorption tests on the monumental complex Cathedral of San Zeno and the Baptistery of San Giovanni in Corte*, in «Pistoia 2020 IOP Conf. Ser.: Mater. Sci. Eng.», 949 012022. DOI: 10.1088/1757-899X/949/1/012022.
Gusella V., Liberotti R. 2020, *Seismic Vulnerability of Sub-Structures: Vantitelli's Modulus in Murena Palace*, «Buildings 2020», n. 10, 164. <https://doi.org/10.3390/buildings10090164 >.
Nardelli S. 2010, *Le necropoli di Perugia. Vol. 2: Le necropoli di Monteluce*, Edimond, Città di Castello.

Merli S., Santanicchia M. 2019, *Gli Ordini di Terrasanta: questioni aperte, nuove acquisizioni (XII-XVI secolo)*, in «Convegno internazionale di studi», Perugia. <http://www.ordiniditerrasanta.it/>.
Nicolini U. 1987, *Le canonizzazioni "facili" del comune di Perugia: il caso di San Bevignate*, in M. Roncetti, P. Scarpellini, F. Tommasi (Eds.), *Templari e Ospitalieri in Italia. La chiesa di San Bevignate a Perugia*, Milano, pp. 39-45.
Santanicchia M. 2016, *San Bevignate di Perugia. Storia e iconografia. Lo Statuto degli Ortolani alla Biblioteca Vaticana e gli anni di Gian Galeazzo Visconti*, «Studi di Storia dell'Arte», n. 27, pp. 9-24.
Vallerani M. 2004, *Movimenti di pace in un Comune di Popolo: i Flagellanti a Perugia nel 1260*, «Bollettino della Deputazione di storia patria per l'Umbria», 101 (1). pp. 369-418. ISSN 0300-4422.
Merli S. 2008a, *Il patrimonio monumentale e artistico dei templari in Europa*, in «Atti del Convegno internazionale 'Milites Templi'», S. Merli (Ed.), Volumnia, Perugia.
Curzi G. 2002, *La pittura dei Templari*, Silvana editoriale, Cinisello Balsamo, pp. 39-51.
Roncetti M., Scarpellini P., Tommasi F. 1987, *Templari e Ospitalieri in Italia in La chiesa di San Bevignate a Perugia*, Electa/Editori Umbri Associati, Milano.
Merli S. 2008b, *La chiesa dei Templari in Medioevo*, De Agostini periodici, n. IX, Novara.
Gusella V., Cluni F., Liberotti R. 2021a, *Feasibility of a Thermography Nondestructive Technique for Determining the Quality of Historical Frescoed Masonries: Applications on the Templar Church of San Bevignate*, «Appl. Sci.», 11, 281. DOI: 10.1088/1757-899X/949/1/012022.
Gusella V., Cluni F., Faralli F., Liberotti R. 2021b, *Correlation of Vulnerability and Conservation Between Artistic Assets and Structural Elements*, in «International Conference Proceedings COMPDYN 2021», Athens, pp. 1216-1230. <https://2021.compdyn.org/files/uploads/general/2021_programme.pdf>.
Raspa P., Marchesi M. 1987, *Note sull'architettura di San Bevignate*, in M. Roncetti, P. Scarpellini, F. Tommasi (Eds.), *Templari e ospitalieri in Italia: la Chiesa di San Bevignate a Perugia*, Electa, Milano.
Botticelli G. 1992, *Metodologia di restauro delle pitture murali*, (Ediz. Ampliata), StreetLib, Loreto.
De vita M. 2015, *Architetture nel tempo Dialoghi della materia, nel restauro*, Fupress, Firenze. DOI: 10.36253/978-88-6655-768-5.
Caccia Gherardini S. 2020, *Connaisance et reconnaissance. Il restauro tra documento, interpretazione, tecniche*, in S. Musso, M. Pretelli (Eds.), Restauro, Conoscenza, Progetto, Cantiere, Gestione, Edizioni Quasar, Roma, pp. 79–84.
Testa S. 2021, *Abbazia di Valvisciolo tra storia, arte, simboli e testimonianze cistercensi a Sermoneta*, Youcanprint, Roma.
Caccia Gherardini S., Olmo C. 2020b, *The architectural Restoration on the road to the East [Il Restauro in viaggio verso Oriente]*, «Ricerche di Storia dell'Arte», n. 130, pp. 58-62.
Caccia Gherardini S. 2021, *The game of two charters. Theoretical codification for restoration*, «Restauro Archeologico», [Special issue], pp. 11-17.
Ralls K. 2007, *Knights Templar Encyclopedia: The Essential Guide to the People, Places, Events, and Symbols of the Order of the Temple*, Red Wheel/Weiser, Newburyport.
Caccia Gherardini S. 2020c, *"A careful, museum-quality restoration": Rethinking and Rebuilding the Canada Pavillion*, in R. Legault (Ed.), *The Canada Pavilion at the Venice Biennale*, 5 Continents Editions in association with the National Gallery of Canada, Mi-

lano, pp. 97-108, ISBN:978-88-7439-884-3.
Belardi P., Gusella V., Liberotti R., Sorignani C. 2021, *The Gipso|TECA of the University of Perugia: conversion of a heritage building in a plaster cast gallery*, in «Proceedings of the Arco 2020 1° Int. Conference on Art Collections Art Collections 2020», Art Collections 2020 Safety Issue, Florence, pp. 69-86. ISBN: 978-88-3338-152-7. <https://flore.unifi.it/retrieve/handle/2158/1246497/617872/V2_Arco_2020_c_GV.pdf>.
Belardi P., Gusella V., Liberotti R., Sorignani C. 2022, *Built environment's sustainability: the design of the Gypso|TechA of the University of Perugia*, «Sustainability», Natural and Anthropogenic Disasters Vs Cultural Heritage [Special issue], 14, 6857. <https://doi.org/10.3390/su14116857 >.
Leoste J. et al. 2021, *E-learning in the times of COVID-19: The main challenges in Higher Education*, in «Proceedings of the 19th International Conference on Emerging eLearning Technologies and Applications», Kosice, Slovakia.
Martí Testón A., Muñoz A. 2021, *Digital avatars as humanized museum guides in the convergence of extended reality*, in «MW21: MW».
Belardi P. et al. 2021b, *AR+AI = Augmented (Retail + Identity) for Historical Retail Heritage*, in A. Giordano, M. Russo, R. Spallone (Eds.), *Representation Challenges. Augmented Reality and Artificial Intelligence in Cultural Heritage and Innovative Design Domain*, Francesco Angeli, Milano, pp. 229-233. DOI: 10.3280/oa-686.36.
Bechini A. et al. 2022, *A News-based Framework for Uncovering and Tracking City Area Profiles: Assessment in Covid-19 Setting*, «ACM Trans. Knowl. Discov. Data». <https://doi.org/10.1145/3532186>.

Note

[1] A templar influential diplomat who had a close relationship Church of Rome, a role he held throughout his life (and in total he even served 4 popes) and himself sent a letter to the city authorities entitled "Super aedificatione ecclesiae Sancti Benvegnati" in order to materialise the Templar's plan.
[2] According to the anonymous author of *La lezenda de Fra Rainero Faxano*, Fasani was a Franciscan hermit who devoted himself to a solitary life of prayer between 1258 and 1260, after the holy hermit Bevignate and the *Madonna* apparition.
[3] It was the name of the war flag used by the Knights Templar in the 12th and 13th centuries. The source under consideration shows that it was bipartite, with a white gonfanon and a black chief.
[4] The Roman artisan workshop for washing and dyeing fabrics where the various stages of fabric processing were carried out. Here were carried out both the washing and stain removal of the already used clothes, as in modern laundries, and the preparation and treatment of new fabrics.
[5] *The Templars Route European Federation* is an European cultural and research project to whom the Municipality of Perugia participates and that has designated the Professor Mirko Santanicchia as Scientific Coordinator.
[6] It should be noted that these restoration activities were conducted by the Superintendency ABAP of Umbria region in the person of Dr. Giovanni Luca Delogu, as Construction Manager.
[7] It is a recurring Latin inscription, usually in the form of a magic square, consisting of the following five words: *sator, arepo, tenet, opera, rotas*. Their juxtaposition, in the order indicated, gives rise to a palindrome.