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NON-DESTRUCTIVE INVESTIGATIONS: A CASE STUDY OF A CONVENT IN LOMBARDY (ITALY)

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ABSTRACT

The use of investigation is a fundamental support to the knowledge of historical buildings, and a mandatory phase of planning any intervention. The investigations serve to ascertain the causes of damage, and to assess the residual performances of the elements/system of the buildings. Moreover, diagnostic allows to identify, locate and quantify the possible risks for the conservation of materials and features, and to set the necessary early actions to prevent further damages. The study case of Lavello complex is an example of the application of diagnostics at the beginning of the project, during the design of the definitive project, after the yard to monitor the executed intervention and set the conservation plan and maintenance activities. The paper reports the application of Ground Penetrating Radar (GPR) to locate ruins of previous buildings in the soil, underneath the church floor, IR Thermography to map the texture of the existing masonry underneath the finishing and the monitoring of moisture diffusion in the restored masonry.

Key words: archaeology, planned conservation, restoration, Serviti Fathers, Lavello convent, IR Thermography, GPR, Laser scanning

INDAGINI NON-DISTRUTTIVE: IL CASO DI STUDIO DI UN CONVENTO IN LOMBARDIA (ITALY)

SINTESI

La fase di accertamenti diagnostici e conoscitivi è un supporto fondamentale per la conoscenza degli edifici storici e una fase necessaria per la pianificazione e progettazione di ogni intervento. Le indagini consentono di accertare le cause di degrado e di riconoscere le prestazioni residue degli elementi/sistemi costruttivi degli edifici di antica formazione. Inoltre, la diagnostica consente di identificare, localizzare e quantificare i possibili rischi per la conservazione dei materiali e delle caratteristiche che connotano il manufatto, e per stabilire le azioni necessarie per prevenire ulteriori degradi. Il caso di studio del complesso monastico del Lavello è un esempio di applicazione di accertamenti diagnostici preliminari al progetto, durante la stesura del progetto definitivo, dopo la chiusura del cantiere con la finalità di monitorare gli interventi eseguiti e stabilire il piano di conservazione e le attività manutentive. L'articolo riporta le applicazioni di Georadar (GPR), utilizzato per localizzare i resti di precedenti edifici sotto il pavimento della chiesa, e di Termografia IR (IRT) per visualizzare la tessitura della muratura sotto gli intonaci e per monitorare la presenza e diffusione di umidità nelle murature dopo il restauro.

Parole chiave: archeologia, conservazione pianificata, restauro, Serviti Fathers, convent di Lavello, Termografia IR, GPR, Laser scanning

INTRODUCTION

The use of investigations, especially non-destructive investigations, is a fundamental support for obtaining knowledge of a building and a mandatory phase in the planning of any intervention.

Early detection is the first step towards the assessment of a building in the documentation process: both location and identification of the major damage areas allow further diagnostic steps to be addressed and economic issues required to support subsequent phases of the intervention project to be quantified.

The investigations serve to ascertain the causes of damage and to assess the residual performances of the elements / system of the buildings. Moreover, diagnostics allow the identification, location and quantification of possible risks for the conservation of materials and features and the setting of necessary early actions to prevent further damage (Della Torre, 2006, Rosina, 2007; 2008). The use of NDT in the preliminary phase of study is extremely helpful for obtaining a first assessment of the potential of a building for a new use and for addressing the choice of the new function according to both the potential and the limits due to the reduction of some performance metrics (Della Torre, 2006).

In the arena of NDT applied to Cultural Heritage, the investigation techniques (that are based on the analysis of images) have a prominent role, especially during the preliminary phase of the assessment.

The requirements of early detection obtain a correspondence with the characteristics of such tests: producing images does not require contact with the surface; the process is rapid and provides results in real time; a single sample can be repeated for further comparison and a time-based control; extensive surfaces can be scanned without much extra time; the images of an object, obtained using different spectra, supply different information, which can be collected in a unique informative system, as already shown in the recent scientific literature regarding this subject (Binda, 2001; 2002).

Moreover, due to the non-destructive nature of the tests, they can be applied periodically over the course of the monitoring activity, with the aim of studying the evolution of the damage phenomena and defining the materials and features thresholds which should not be exceeded in order to preserve the building.

During the initial multidisciplinary study phase of the documentation of buildings, early diagnostics is extremely advantageous for discovering, locating and connecting those details concerning the building that testify to the changes that have occurred over time. The archival documentation and stratigraphic survey carried out on the buildings comprise the milestone of the established methods for documenting the evolution of buildings: in addition, diagnostics provide a significant improvement for the historical analysis because it is helpful to be able to locate the transformations and to confirm their typologies and extensions (Binda, 2001; Rosina, 2006; 2009). The application of NDT techniques to historical buildings follows established techniques and procedures to investigate materials and building techniques and assess the state of conservation. Nevertheless, it is a complex area and reliable techniques available for testing ancient masonry are not numerous because of the non-homogeneity of the structures and materials employed.

The case study of Lavello Convent is a good example for demonstrating the application of recently established diagnostics (innovative at the time of their first application in 1998), which were used prior to the beginning of the project for the preliminary assessment, as advanced diagnostics during the design of the definitive project, and after the restoration for monitoring the executed intervention and establishing the conservation plan and maintenance activities.

This paper refers mainly to two non-destructive investigations, which were extensively applied especially to the church building at different stages of the project to develop and restore the building: the Ground Penetrating Radar (GPR) and Infrared Thermography (IRT).

In addition, the paper demonstrates the use of the laser scanner technique for surveying the archaeological remains: in Lavello church it served to obtain the measured drawings of the ruins, which were found in the soil on the basis of the historical research and the GPR application. The accurate documentation of the existing findings allowed the necessary information to be obtained in order to project the intervention for the optimized preservation and display of the ruins that remained hidden underneath the pavement and to design the supporting structure of the floor.

THE CASE STUDY

The monastery and abbey of Lavello in Calolziocorte (Northern Italy) has been the object of a conscious and coordinated restoration over the course of the last decade that restored the complex to the community life of the village and Lecco area.[1]

1 Spira firm (prof. G. Cruciani Fabozzi, Eng.L. Marrani, Florence) designed the restoration project and management, with the collaboration of arch. E. Maggi, S. Pozzi, G. De Michele; prof. D.M. Fontana, A. Breschi, C. Blasi (Comes firm) developed the structure and plants project. The project involved the local authorities (County of Lecco, Municipality of Calolziocorte, Parish of Foppenico, Valley of Saint Martin, Region Lombardy), and is was partially supported by the EU as Interreg III B Italy-Switzerland, and as RECITE II NCE (Network Culture Economy) project on three monasteries: the Kloster in Buch (Germany), Gussing Monaster (Austria) and Lavello Convent in Calolziocorte. The restoration started in 2002 and finished in 2007, and the final cost is approximatively 3,5 milion of euro. A report of the project and intervention is published in (Cruciani Fabozzi, 2004)

The new use includes the location of tourism and cultural activities at a European level; among these are included education, exhibitions and concerts in the monastery rooms and the use of the church for religious ceremonies and cultural events.

The aims of the restoration have been the elimination of the modifications due to inappropriate uses in the past and shoddy strengthening interventions; moreover, a non-secondary purpose has been to reform the monastic scale of the buildings and the functional pattern of the complex.

The documentation gathered for the restoration (Cruciani Fabozzi, 2004; 2008) and the conducting of the works on the building site has contributed to an enlargement of the knowledge of the history of the convent and the community life in the Lecco area between the 15th and 19th centuries.

GATHERING HISTORICAL DATA

Archival documentation

The team of designers of the restoration collected and analysed a considerable amount of archival and historical documentation (Cruciani Fabozzi 2008; 2011): the present paragraph briefly summarizes the available information. The abbey and convent of Lavello have represented a reference point for the territory since the early Middle Ages. The location on which the monastery was built has formed a strategic location since Roman times: the place is between Como Lake, the San Martino Valley and the River Adda, along the Roman military road connecting Como and Bergamo, very close to Olginate bridge (Aldeghi, 2005). It has thus comprised a border to various areas under different systems of political control. The earliest historical documents (dating back to 1014) refer to a castle and a chapel inside it, named after Saint Mary (Fumagalli, 1997). The available historical data (Borghi, 2002) report the reconstruction of the present church in 1480 after the destruction of the previous Medieval chapel, which occurred in 1380, due to Bernabò Visconti's struggles to strengthen his lordship over the territory of Milan. In 1480, the hermit Jacopino discovered the remains of the church and the miraculous source of water, where some extraordinary facts occurred. He constructed a small building on the ruins and the spring and in a short time the renown of the place had become so widespread that the number of pilgrims surged. In 1486 the Fathers of the Order of the Servants of Mary (from Saint Gottard branch) settled in the area. In 1510 they rebuilt the convent and 80 years later they reconstructed the church with a different orientation – only the northern side of the original remained due to its incorporation as perimeter wall of the new building. Between 1582 and 1585 the church was enlarged and in 1590 the skilled personnel (who came from Ticino Region, Switzerland) accomplished also the decoration of the two apses and the final refurbishment of the building. Minor modifications took place over the course of the next century as well as the transformation of the church and the convent into a hospital, between 1629 and 1638, which entailed the total whitewashing of the frescoes and decoration and the further enlargement of the cloisters. In 1772 the convent was suppressed and since that time the buildings suffered neglect and lack of maintenance until the time of the recent restoration.

The survey, assessment and preliminary analysis of the features and technical details of the monastery and church showed some evidences and traces of the transformations occurring between 1480 and the beginning of 17th century, which was a time of wider enlargement and changes. Nevertheless, many questions remained open, especially before the beginning of the building site and therefore the demolition of recent, shoddy additions, dangerous for the stability of the loggias, porches and several parts of the church and monastery.

The investigations provided the necessary data to be able to project the most suitable and compatible rehabilitation of the complex and allowed the display of the findings remaining in the soil under the church pavement to be designed.

… and Not Destructive Testing

Ground Penetrating Radar (GPR)[2] detection located the remains of tombs and the southern walls of the previous churches underneath the present pavement (Valle, 2004).

A preliminary set of measurements was performed both inside and outside the church in 1999, resulting in the location of the tombs and some longitudinal structures in the nave.

In 2002 the team of Politecnico di Milano and ISMES-CESI Inc. realized a further set of GPR 2D profiles inside the church, allowing the integration of previous measu-

2 Ground Penetrating Radar (GPR) is a non-destructive technique based on the use of electromagnetic waves to investigate the underground or internal structures of objects. It has been successfully used in investigating the non homogeneities, characteristics and damage of masonry and to inspect the soil for finding buried structures and objects (Marienjofer, 2001; Saisi, 2001; Leckebusch, 2003; Ranalli, 2004). The most common applications in the field of rehabilitation are the localization of large voids, inclusions of different materials (like steel, wood, etc.), and the survey of the section of stone or brick multi-leaf walls. Both applications are focused on the identification of the condition or damage of structures, presence and level of humidity and the monitoring or control of the effectiveness of repair by injection techniques.
Moreover, the recent code for the seismic rehabilitation of ancient buildings indicates the GPR investigation among the suggested tests, with the integration of destructive tests with the double flat jack and the stress measurements. The analysis of radar signal anomalies

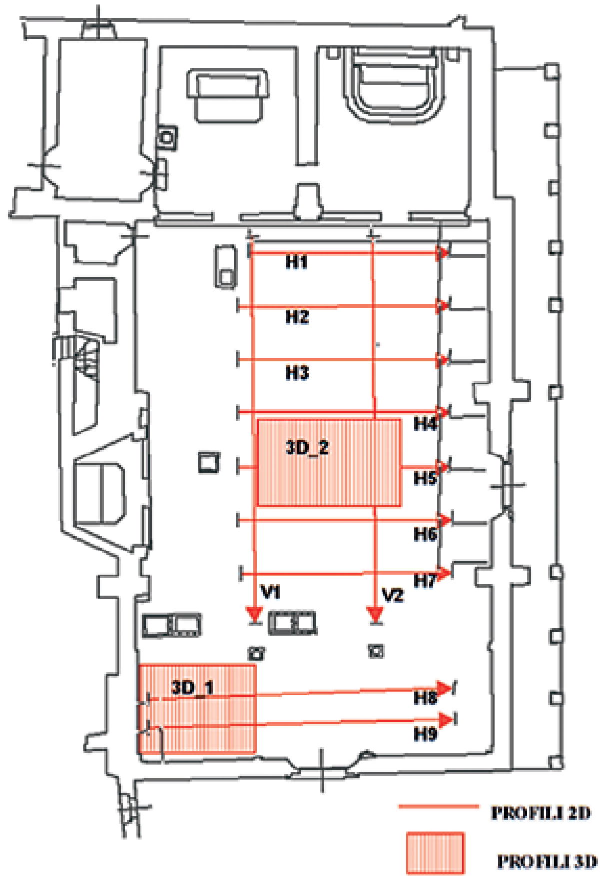

Fig. 1: Map of GPR profiles (2D and 3D) and the tombs underneath the pavement of Santa Maria del Lavello; the tombs location is the result of the investigation performed in 1998 (Courtesy of S. Valle, L. Zanzi, G. Lenzi).
Sl. 1: Karta georadarskih (2D in 3D) profilov in grobov pod tlakom cerkve sv. Marije v Lavellu; lokacije grobov so rezultat preiskave, izvedene leta 1998 (Z dovoljenjem S. Valleja, L. Zanzija in G. Lenzija).

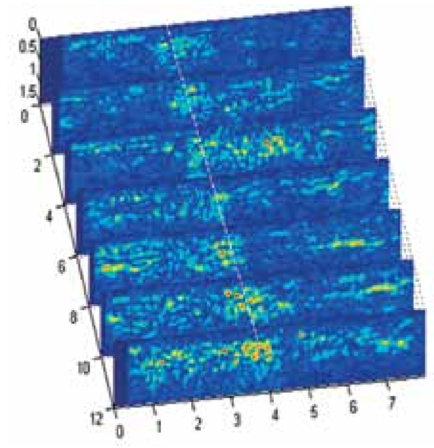

Fig. 2: Church of Santa Maria del Lavello. GPR Profiles H1,H2,H3,H4,H5,H6,H7 after the innovative post processing phase (Courtesy of Valle, L. Zanzi, G. Lenzi).
Sl. 1: Cerkev sv. Marije v Lavellu. Georadarski profili H1, H2, H3, H4, H5, H6, H7 po inovativni zaključni obdelavi podatkov (Z dovoljenjem S. Valleja, L. Zanzija in G. Lenzija).

Fig. 3: Santa Maria del Lavello, southern side, exterior.
Sl. 3: Sv. Marija v Lavellu, južna stran, zunanjost.

rements: the whole floor underwent investigation. On the basis of the results, the researchers developed a 3D investigation on two zones, where the 2D profiles indicated the presence of structures in the soil under the pavement. The innovative processing data in the 3D images provides a better signal-to-noise ratio and images that become more suitable and clearly supportive of the end-users' requirements. The improvement was due to the use of an algorithm based on time-space migration and the fundamentals of data pre-processing, allowing the researchers to achieve a good location and identification of the buried ruin.

Particularly, a longitudinal structure is clearly detected in all the 2D profiles across the nave, at 4 metres from the starting point of the profiles (white dotted line in Fig. 2). The structure is 50 cm in magnitude.

informs the interpretation of data and this part of the data processing seldom obtains a result on first reading. Therefore the data report must include the detailed reading key for the interpretation of the processed data.
In addition, the movements of the radar antennae could be a critical issue. The application requires the contact between the antennae and the object under investigation and sometimes the location, dimension and damage of the surface under investigation can preclude any contact. In the case of Lavello Abbey, the results of GPR application allowed the location of tombs and the main remains of the early churches of Santa Maria. Therefore the performed analysis allowed the archaeologists to organize the priority of the excavation and to manage the long time taking activities for documenting with the activities of building site in course. In December 1999, Giuseppe Lenzi (ISMES-CESI inc.) performed a detailed set of measurement by GPR, and the further data processing of Prof. Zanzi (DIS Dept., Politecnico di Milano) permitted the representation of the wall in the church plan, parallel to the southern side

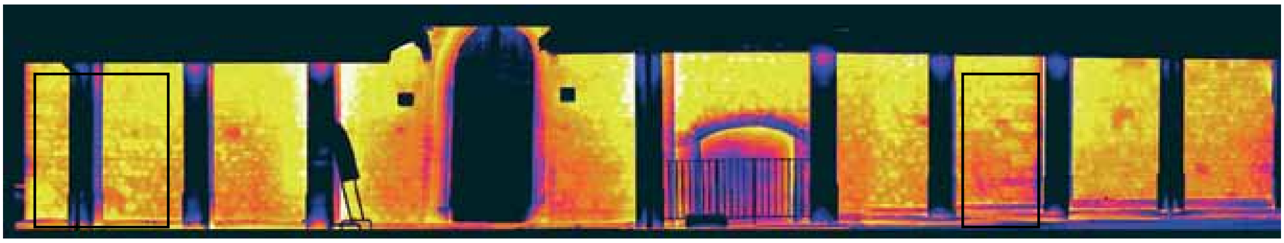

Fig. 4: Santa Maria del Lavello, composite of thermograms, southern side, exterior. Range of Temperatures: 15.5-19.5°C; ambient temperature: 11.5°C. The figure displays the shape of the masonry texture, according to the differences of the surface temperature during the cooling phase. The black squares contour the part of the masonry composed by squared ashlars, which differ from the more common cobbles spread in the rest of the structure.
Sl. 4: Sv. Marija v Lavellu, Sestavljanka iz termogramov, južna stran, zunanjost. Razpon temperatur: 15,5–19,5 °C; temperatura okolja: 11,5 °C. Slika prikazuje teksturo zidovja glede na razlike v površinski temperaturi, zaznane v fazi ohlajanja. Črna kvadratka orisujeta del zidovja, ki je sestavljeno iz klesancev, za razliko od preostalega dela konstrukcije, kjer najdemo bolj razširjene okrogle tlakovce.

The further excavations, based on the GPR information, showed an archaeological area extremely rich in findings: the remains of the sacred basins and the pipeline conducting from the miraculous spring to the exterior rooms and basin were also found.

The finding of the previous church bases and the tombs since the early settlement, allowed the establishment of the date of the foundation of the buildings; nevertheless, dating the elevations was much more uncertain, also because of some misleading details, such as the shape of the nave and the confusing dates written on the southern portal and inside the altar arch.

Infrared Thermography (IRT)[3] helped to detect the many details in the elevated masonry; the following paragraph presents the main results.

On the southern exterior side, IRT allowed the corner stones within the present masonry to be distinguished, revealing the edge of the first enlargement of the church (see Fig. 3, 4).

The surface temperatures differ depending on the thermal characteristics of the materials under such envi-

3 Infrared Thermography is a non-destructive, non-contact method to detect, gather and evaluate information about historic building conditions (Grinzato, 2001; Rosina, 2004; Avdelidis, 2004; Spodek, 2009). Using IRT, information can be obtained about the building elements, their location, shape material characteristics and state of decay that may not be noticeable from visual examination. IRT investigation is based on the principle that heat flowing in a material is altered by the presence of anomalies. The change in heat flow causes localized differences in the surface temperature. By mapping the surface temperature and understanding the conditions of heat flow, a map of inner anomalies in the material can be obtained.
The non-contact nature of IRT is advantageous for the investigation of delicate or sensitive surfaces. As long as a direct line of sight is available, data can be collected from a distance, eliminating the need for lifts or scaffolding. IRT can be repeatedly applied over time to monitor conditions, evaluate effects of treatments over time and observe anomalies over time and changing conditions.
The objectives of an IRT investigation are the detection and evaluation of thermal anomalies corresponding to discontinuities because of decay and / or hidden elements of a building. Its primary application to historic buildings concerns the investigation of inner layers and structural elements a few centimetres underneath plaster or stucco and in masonry construction.
Although it has been shown that it is theoretically possible to overcome the depth limitation of a few centimetres beneath the outer surface, practically, obstacles remain to the extensive application of IRT for the detection of layers that are deep inside the wall during field-testing. The difficulty is primarily due to the application of a proper thermal solicitation of the surface in order to obtain a return signal from the surface that can be detected by the thermocamera and which could be unequivocally related to the researched defect instead of any surface anomaly. Determination of the correct time and duration for performing testing is critical because buildings are subjected to slow and varying boundary conditions and different heat fluxes may interact with each other causing detrimental or additive effects which significantly compromise the thermal signal. Solar heating is a powerful heating source that can cause heat flux through the structure. In order to obtain uniform heating of a vertical surface it is optimal to start irradiation at the same time for the entire surface, or at least for a large part of it. Therefore, the building's orientation and relationship to adjacent structures, trees or building elements that may cast shadows, are crucial factors to be taken into account in the investigation plan. For detection of structural elements beneath plaster, cut stone or bricks joined by lime mortar, the pattern is characteristic of the age and the placement on the building. The texture of the masonry depends on the size and thickness of the element. The best IRT results are achieved in case of stone coated with lime mortar. In the case of Lavello, IRT was successfully used in the preliminary phase of obtaining knowledge about the Abbey and the main results had been the localization of rising damp, water leakages from the roof and thermal unbalance in a part of the frescoes, which are the main factor of risk for the conservation of the finishing. In the advanced stage of the project, IRT helped to create a mapping of the different masonry textures in the complex and therefore to integrate the historical research with the project of rehabilitation of the structures and decoration. During the building site, the integration of IRT and microclimate monitoring served to reduce the risk of damage of the finishing during some work requiring the change of RH balance inside the church, and to lead a gradual optimization of the microclimatic conditions after the turning on the new heating plant (Rosina, 2007). At the conclusion of the restoration, IRT integrated by gravimetric tests, allowed the intervention to eliminate rising damp and water infiltrations to be to monitored and tested.

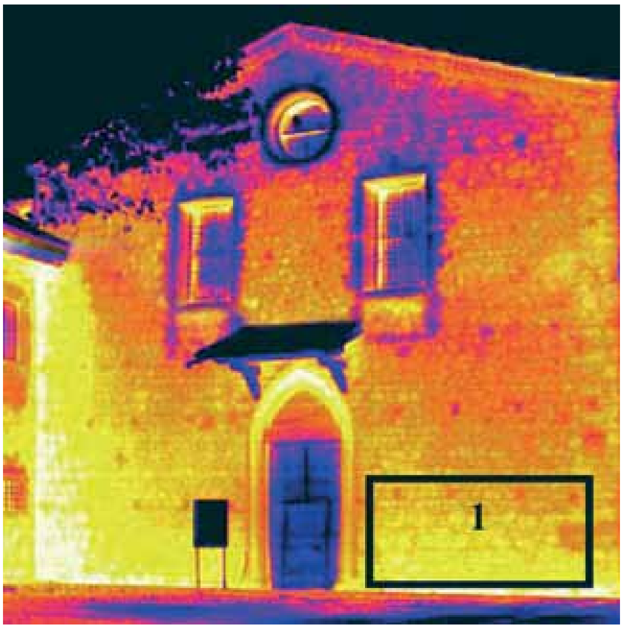

Fig. 5: Santa Maria del Lavello, composite of thermograms, the façade of the church. At thermal Infrared, the pattern of the masonry appears clearly: note in square 1 the regular size of the squared ashlars, the same in the right corner. The small dark spots, regularly disposed in the structure, are the scaffolding anchorages, which were infilled after having built the façade. The dark rectangles below the windows at the first floor are the signs of the previous opening, partially closed in 1706 because of the interior modification of the church. Range of Temperatures: 12-17.2°C; ambient temperature: 11.5°C.
Sl. 5: Sv. Marija v Lavellu, Sestavljanka iz termogramov, cerkvena fasada. V infrardeči termografiji je vzorec zidovja jasno viden: v kvadratu 1 je opazna enakomerna velikost klesancev, enako v desnem kotu. Manjša temnejša mesta, enakomerno razporejena po konstrukciji, so sidirišča za gradbeni oder, ki so bila zapolnjena po izgradnji fasade. Temna pravokotnika pod oknoma v prvem nadstropju nakazujeta, do kod sta okenski odprtini segali prej, preden sta bili leta 1706 med prenovo notranjščine cerkve delno zaprti. Razpon temperatur: 12–17,2 °C; temperatura okolja: 11,5 °C.

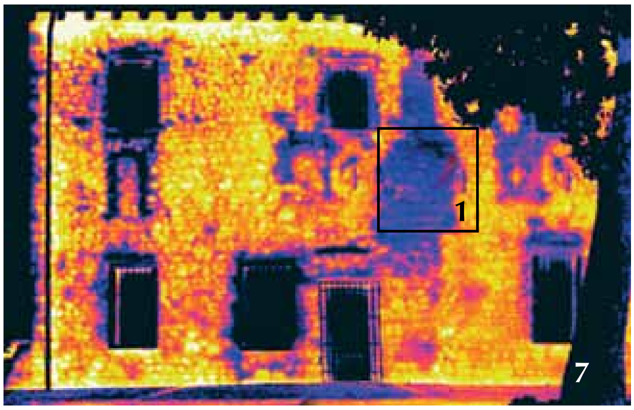

Fig. 6: Santa Maria del Lavello, the southern side of the monastery, left part.
Sl. 6: Sv. Marija v Lavellu, južna stran samostana, levi del.

Fig. 7: Santa Maria del Lavello, composite of thermograms of the southern side of the monastery, left part. IRT allows an extensive stucco patch having a higher thickness than the rest of the elevation to be located. The increase of thickness of the stucco changes its water absorption capability. In addition the close trees prevent any direct sun irradiation of that zone for many hours a day, despite of the orientation. Therefore the result is the damage of the restoration stucco, because of the almost permanent retention of water in such a porous material. Range of Temperatures: 14.3 -17.3°c; ambient temperature: 11.2°C.
Sl. 7: Sv. Marija v Lavellu, sestavljanka iz termogramov, južna stran samostana, levi del. Infrardeča termografija je omogočila odkritje obsežne zaplate štuka z večjo gostoto, kot je v preostalem delu zidu. Zaradi povečane debeline štuka je sposobnost absorbiranja vode na tem mestu spremenjena. Poleg tega bližnja drevesa preprečujejo neposreden padec sončnih žarkov na to mesto po več ur dnevno, kljub legi cerkve. Končna posledica je škoda na restavracijskem štuku zaradi skoraj nenehnega zadrževanja vode v tako poroznem materialu. Razpon temperatur: 14,3–17.3 °C; temperatura okolja: 11.2 °C.

Fig. 8: Santa Maria del Lavello, the southern side of the monastery, right part.
Sl. 8: Sv. Marija v Lavellu, južna stran samostana, desni del.

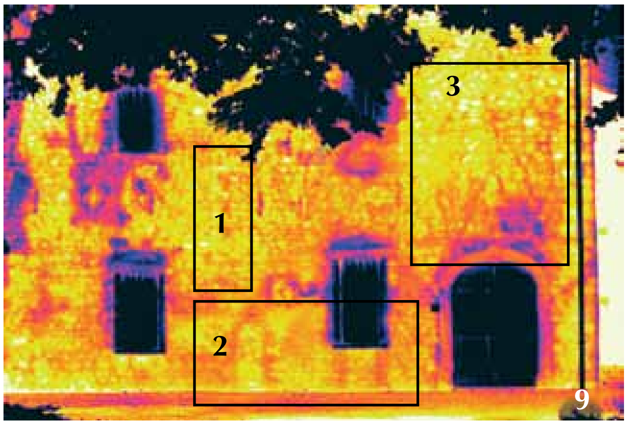

Fig. 9: Santa Maria del Lavello, composite of thermograms on the southern side of the convent on the right hand side. Range of Temperatures: 12-13.5°C; ambient temperature: 11.7°C.
Sl. 9: Sv. Marija v Lavellu, sestavljanka iz termogramov, južna stran samostana, desni del. Razpon temperatur : 12–13,5 °C; temperatura okolja: 11,7 °C.

Fig. 10: Santa Maria del Lavello, the interior towards the apses (Courtesy of G. Cruciani Fabozzi).
Sl. 10: Sv. Marija v Lavellu, notranjost cerkve proti apsidam (Z dovoljenjem G. CrucianijaFabozzija).

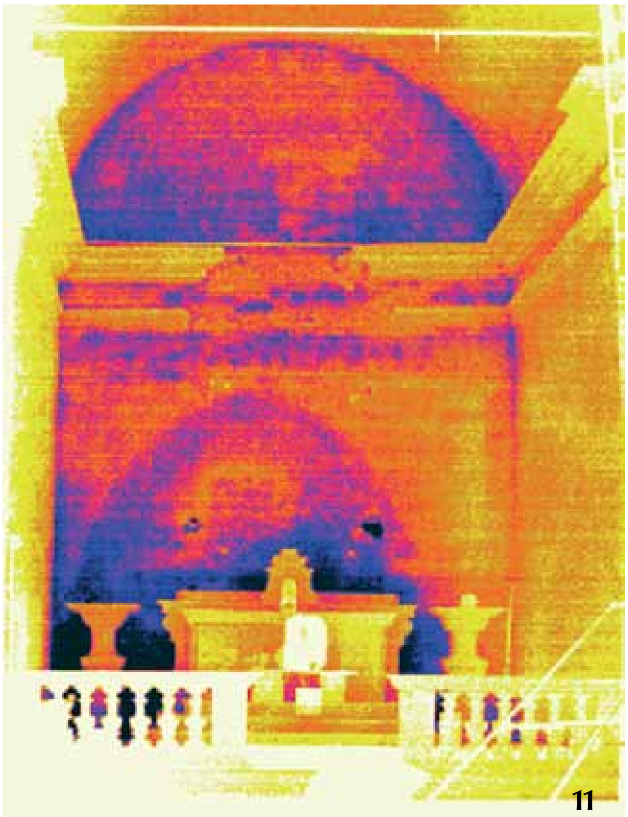

Fig. 11: Santa Maria del Lavello, composite of thermograms of the eastern side of the right apse. Range of Temperatures: 10.8-12.5°C; ambient temperature: 14.6°C.
Sl. 11: Sv. Marija v Lavellu, sestavljanka iz termogramov, vzhodna stran desne apside. Razpon temperatur: 10,8–12,5 °C; temperatura okolja: 14.6 °C.

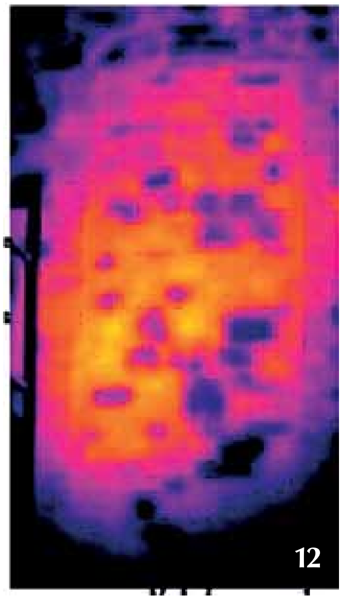

Fig. 12: Santa Maria del Lavello, composite of thermograms of the northern side of the right apse. Range of Temperatures: 19-22.3°C; ambient temperature: 12°C, the recapture has been obtained by active approach after a heating of 45 minutes by two halogen lamps.
Sl. 12: Sv. Marija v Lavellu, sestavljanka iz termogramov, severna stran desne apside. Razpon temperatur: 19–22,3 °C; temperatura okolja 12 °C. Posnetek smo pridobili z aktivnim pristopom po 45-minutnem ogrevanju z dvema halogenskima svetilkama.

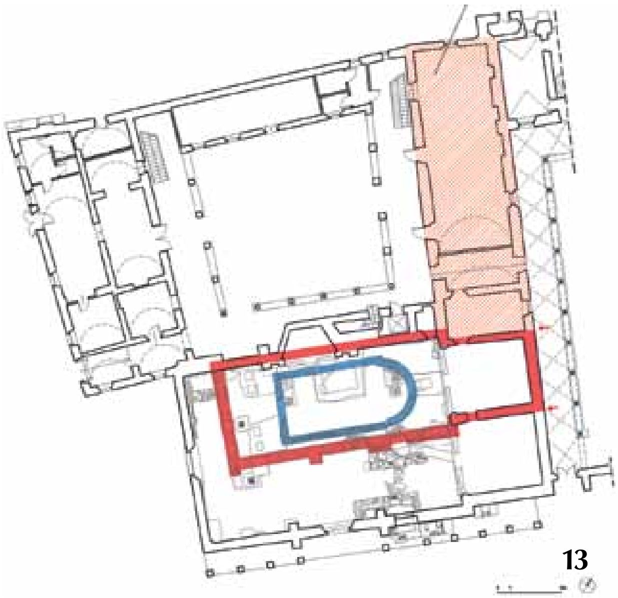

Fig. 13: Santa Maria del Lavello, plan of the monastery and Abbey, display of the three overlapped churches and the original settlement of the middle age castle, on the base of the tests, archaeological excavation, findings during the restoration (Courtesy of G. Cruciani Fabozzi).
Sl. 13: Sv. Marija v Lavellu, načrt samostana in samostanske cerkve, prikaz treh prekrivajočih se cerkva in izvirne naselbine srednjeveškega gradu, izdelan na podlagi preiskav, arheoloških izkopavanj in ugotovitev med restavriranjem (Z dovoljenjem G. Crucianija Fabozzija).

Fig. 14: Santa Maria del Lavello, the excavation of the archaeological remains and the location of the target of the topographical survey (Courtesy of G. Cruciani Fabozzi).
Sl. 14: Sv. Marija v Lavellu, izkopavanje arheoloških ostankov in lokacija cilja topografske raziskave (Z dovoljenjem G. Crucianija Fabozzija).

ronmental conditions. Considering a masonry composed by stones and lime mortar, the thermal behaviour of the two materials is different during the heating exchange with the ambient, therefore the temperature of the surfaces is lower or higher according to the speed of cooling of materials having different density (Ludwig, 1997; Grinzato, 2001; Rosina, 2002; Ludwig, 2005).

IRT allows the map of surface temperature under investigation to be visualised and the areas of non-homogeneous distribution to be localised. In case of good adhesivity of the finishing to the substrate, the pattern of temperature distribution displays the location of different materials underneath the plaster.

Analysing Fig. 4, the shape of the corned stones appears very clearly: the left edge coincides with the corner with the façade, where it was expected to be located; while, on the opposite side, the right edge concludes the nave, not the apse, thus confirming that the apses were added after the completion of the main building.

The thermography of the façade shows the same corner ashlars (right side), confirming the important structural function of the squared stones as "framing" the cobblestone masonry (Fig. 5); in addition a reduction of the size of the windows results from the thermal imaging, due to the insertion of an interior balcony in 1706.

On the southern side of the monastery, IRT demonstrated the numerous changes that occurred in that wing of the complex. Historical documentation reported only that in 1706 that side, used as storehouse until that date, underwent a complete refurbishment. The new use was as a hostel and required large vaulted rooms to be built, partially using the exterior walls of the existing buildings. Because of the poor condition of the buildings and the minimal importance of their use, neither description was kept in the archive files.

Infrared Thermography allowed many interesting details of this masonry to be discovered. Figs. 7 and 8 show the results.

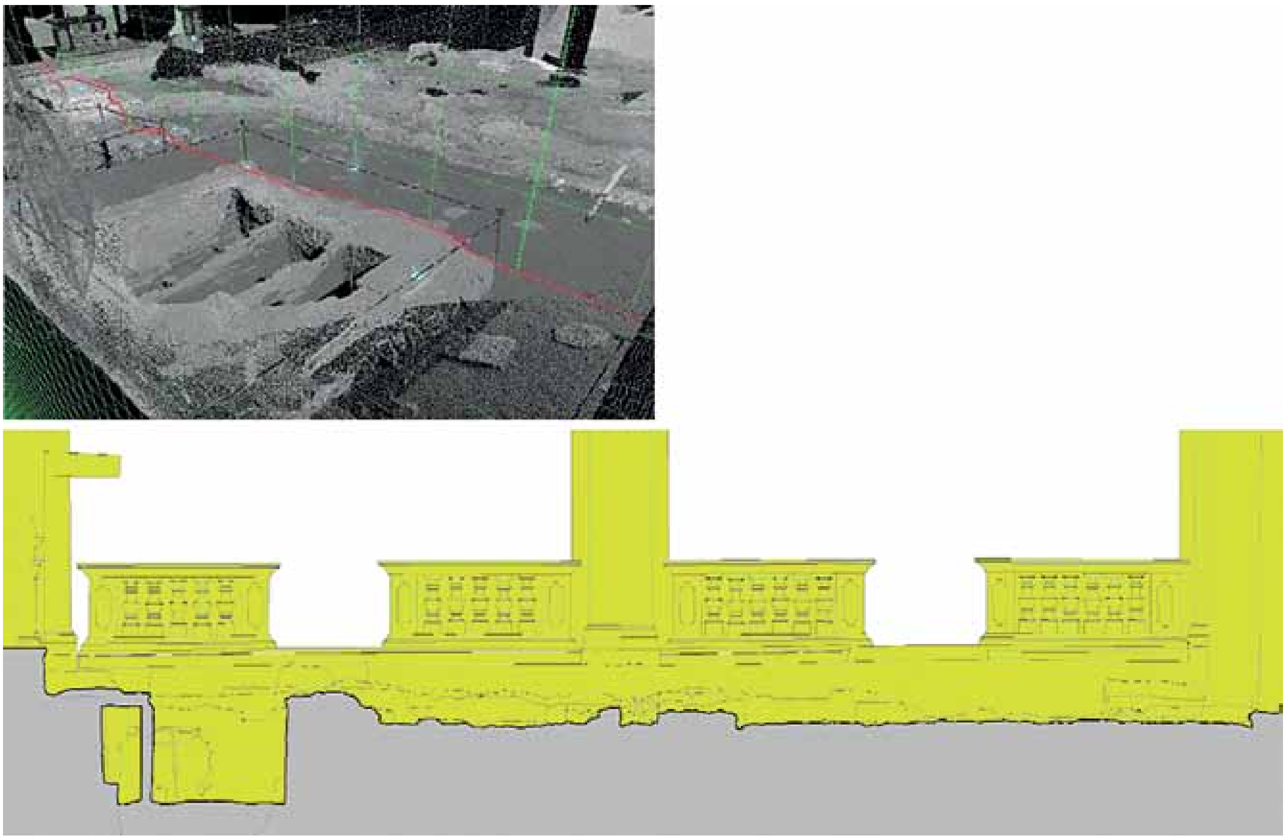

Fig. 15: Santa Maria del Lavello, cutting of the cloud of points along the sections alignment provide the profile of soil and remains. Bi-dimensional drawings are extracted from "slices" of the points cloud model (Courtesy of G. Tucci).
Sl. 15: Sv. Marija v Lavellu, prerez točkovnega oblaka po poravnavi odsekov prikaže profil prsti in ostalin. Dvodimenzionalne slike so pridobljene iz »rezin« točkovnega oblaka (z dovoljenjem G. Tucci).

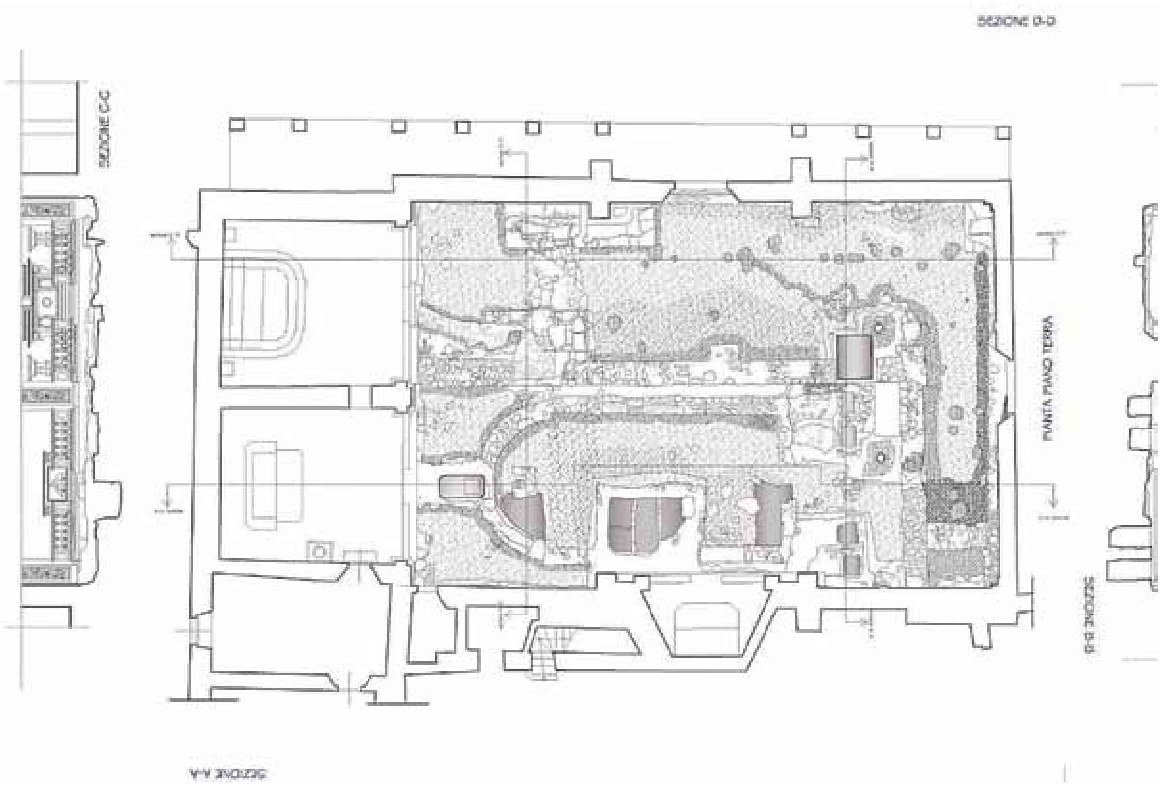

Fig. 16: Santa Maria del Lavello, materials and state of conservation of the archaeological remains, underground level (Courtesy of G. Tucci).
Sl. 16: Sv. Marija v Lavellu, materiali in stanje ohranjenosti arheoloških ostankov, podzemni nivo (Z dovoljenjem G. Tucci).

Fig. 17: Santa Maria del Lavello, the foundation of the pillars in the opaque part of the pavement (Courtesy of G. Suardi).
Sl. 17: Sv. Marija v Lavellu, temelji stebrov v neprozornem delu tlaka (Z dovoljenjem G. Suardi).

First of all, it is possible to locate the corners of two original buildings, thanks to the squared corner ashlars vertically lined in square 1, Fig. 9. That alignment marks the left edge of a building which had many modifications after the placement side by side of the second building (at the left), especially at the ground floor: see the original arched doors and window (square 2, Fig. 9), infilled at the time of the connection between the two buildings. The size and height of the opening does not fit with the use of the building in the 18th century as facility. Also the distance of the original arched windows at the first floor (both in Fig. 7 and 9) allows to hypothesise a shorter height of the rooms in the original structure: probably the first use of the two buildings was as bedrooms, and later, with the enlargement of the wings in the main cloister, the building became a storehouse. Furthermore, the thermal analysis allows also information regarding the structural behaviour of the masonry to be to gathered. In Fig. 9, square 3, it is possible to detect many vertical and oblique cracks over the portal, which were infilled during the restoration. Nevertheless the location of the several cracks and their size, allows the opening the large portal that contributed to weakening the masonry over it to be considered.

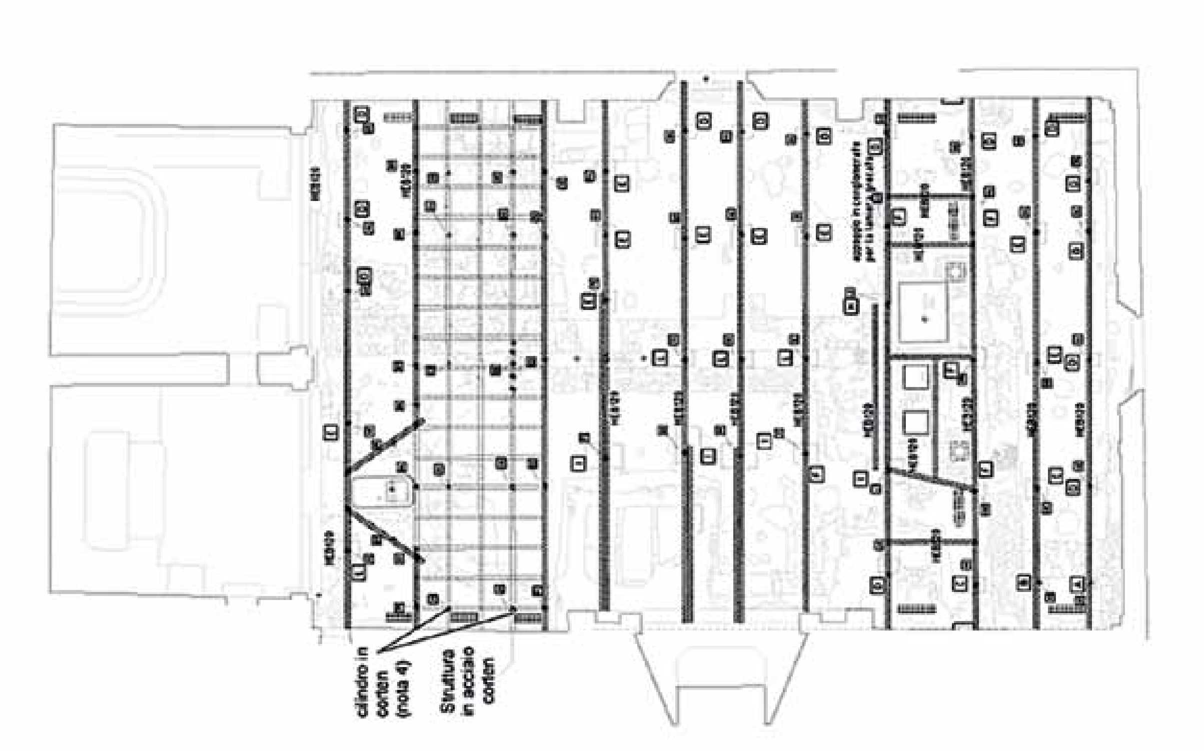

Fig. 18: Santa Maria del Lavello, the plan of the supporting structure of the pavement (Courtesy of G. Cruciani Fabozzi).
Sl. 18: Sv. Marija v Lavellu, načrt za podporno konstrukcijo tlaka (Z dovoljenjem G. Crucianija Fabozzija).

Fig. 19: Santa Maria del Lavello, the new pavement, partially opaque and partially realized with supporting glass tiles (Courtesy of G. Cruciani Fabozzi).
Sl. 19: Sv. Marija v Lavellu, novi tlak, delno neprozoren, delno pa izdelan iz podprtih steklenih plošč (Z dovoljenjem G. Crucianija Fabozzija).

Also, internal IRT permits the location of modifications that were not reported in the archive documentation.

In Fig. 11 the composite of thermograms shows an arched structure of the masonry in both the apses, as it was a structural texture for a better distribution of the stress. Another hypothesis is that the arched structures existed at the time of the refurbishment, and this second hypothesis could make more sense, according to other details that IRT shows. The temperature of the masonry that is located inside the arch is lower than the temperature of the surrounding wall: the cause could be a greater thickness of the plaster coating the structure inside the arch, than elsewhere on the wall. Therefore, the masonry is not planar inside and outside the arch as it was built at two different times.

Again, concerning the wall that separates the two apses, Infrared shows an infilled large window (Fig. 12). The decoration is not interrupted; therefore the window could be a part of a structure built before the refurbishment of the 17th century. During the restoration building site, at the first floor of the western side in the main cloister (the adjacent building to the apses), the dismantlement of recent ceilings allows the project managers to discover the traces of middle ages frescoes. All these facts allow the hypothesis that the apses of the church were built on the remains of the original castle walls, mentioned in the first historical document (dating back to 1014). Therefore their masonry is not homogeneous and underneath the last frescoes traces of previous apertures / structures remain.

Laser scan survey[4] was extremely successful in documenting the archaeological excavation, both in terms of the remains and the morphology of the surrounding land itself (Bonora, 2006; Bonora 2008). As shown in Fig. 14, the remains and the soil had very irregular geometry and profiles. The project purpose was to keep the remains available for further studies also after the reconstruction of the pavement. The new structure creates a crawling space for the ventilation between the bottom of the excavation and the floor structure. This solution is a "floating floor", inspired by the constructive concept of the ancient hypocausts. It also takes into account both the needs to insert radiant heating panels and the customer's request that a significant portion of the archaeological findings remain visible. The floating floor is supported by pillars, whose foundation, size and location were designed to take into account the presence of the remains in order to not put the old structures in contact with the new ones and prevent any possible damage. A part of the new pavement was realized with supporting glass tiles, to allow the view of the ruins. The aim of the survey was to provide the most reliable geometric information to design the foundation of the supporting structure inside the free spaces, where the archaeological findings were not located. The researchers obtained useful measured drawings of the sections of the underground level by "cutting" the cloud of thousands points measured by the laser scan survey (Fig. 15). The final result was a complete documentation of all the findings, their materials and state of conservation (Fig. 16) that allowed the planning of the intervention necessary to restore them and to ensure their optimal conservation in the future. In addition, the documentation was used to support the required information to design the new floor. The floating floor included also the heating plant, a warm water system, and its activation allows the microclimate in the church and underground space to be optimally maintained for the conservation of frescoes, ruins and masonry.

4 Laser scanning technique uses various scanning technologies to provide a 3-D record of a surface. In a nutshell, a low-powered laser is used to measure the position of a point on an object in 3-dimensions. As time progresses, many measurements are taken, building up a complex and highly accurate 3-dimensional map of the surface of the object.
Applications in archaeology and architecture have recently become common for the documentation both of the excavation site (and its stratigraphic layers) and the structures and object findings (Tucci, 2003; Musso, 2004; Doenus, 2005; Brizzi, 2006; Getty Conservation Institute, 2007).
Surveys are carried out to document the findings while the excavation proceeds. The removal of the upper layers of material in order to bring to light the underlying ones – requires a common reference system for the measurements taken in the different phases of the excavation to be considered. According to (Tucci, 2008, 276) "It is therefore important to identify and appropriately materialize a large number of reference points in areas that will not be affected by the excavation procedures; these reference points, both natural and artificial, constitute the local reference system onto which later acquisitions and / or acquisitions obtained using different techniques can be superimposed and thereby made directly comparable. The graphic representation obtained from the metric survey, like the other documents pertaining to the building, is then arranged chronologically thereby facilitating a diachronic interpretation".
This method of survey is accurate and reliable and is generally considered to be the first diagnostic step in historical buildings, especially for detecting the geometric irregularities that belong to a pathological state, such as leaning / rotation / deformation of structural elements, spalling of finishing, cracks, non planar surfaces, etc. Three dimensional laser scanning helps the project of conservation also as a tool for monitoring decay and supporting conservation decisions. In the archaeological areas, laser scan surveying has the additional advantage of realising the data regarding both the findings and their surroundings.
In the case of Lavello, it played a fundamental role in acquiring the necessary measurements for the project of the new supporting structure of the floors, joining the aim to design the foundation without touching the remains, with the aim to protect and display the ruins remaining under the new floor by realizing a part of the floor with glass. Moreover, the laser scan survey was a source of rich and accurate visual material to illustrate areas of the site which remained under the opaque floor, therefore no more visible after the restoration, thereby to enhance the visitors experience.

CONCLUSIONS

The presented diagnostic techniques for the analysis of archaeological findings and historical buildings are a valid support to the knowledge of the transformation of architectures in time; as shown in the study case, the process of knowledge starts with the "archaeological" survey of the buildings themselves, as well as findings in the soil.

The integration of experimental techniques and traditional methods for the survey of findings allows a tremendous improvement in the amount and quality of the information to be obtained and the provision of a complete documentation to be used to effectively project the rehabilitation of the historical building with the aim of preserving as much as possible of the materials and features of the remains. In fact, the knowledge of the technical issues related to the conservation of the materials of the building and findings informs the restoration project, especially in terms of the project choices regarding the new use and the necessary least transformation of the existing building. Matching historical research and technical testing / survey allows an overall view to be attained, consisting of a synergic and holistic comprehension of both the historical and materials characteristics of the buildings since the beginning of the project. Therefore it is possible to choose the most compatible use and intervention from the first steps of the decision-making process. The documentation phase has a prominent role in the conservation process, which has the goal to protect the Cultural Heritage over the entire lifespan: hence, the implementation of tools and methods, the widespread communication of results and their exploitation by means of a multidisciplinary approach, the updating of filling methods, contributing to a facilitation of the collaboration between the historians, technicians, scientists along with the designers and planners, this being the most desired requirement for obtaining the most effective preservation of the cultural heritage itself.

NEDESTRUKTIVNE PREISKAVE, ŠTUDIJA PRIMERA SAMOSTANA V LOMBARDIJI (ITALIJA)

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POVZETEK

Uporaba preiskav, zlasti nedestruktivnih, predstavlja temeljno podporo pri spoznavanju stavb in obvezno fazo v načrtovanju kakršnegakoli posega na njih.

Namen preiskav je ugotoviti vzroke za poškodbe in oceniti stanje preostalih elementov/sistema stavbe. Poleg tega diagnostika omogoča opredelitev, lociranje in količinsko določitev možnih tveganj za ohranjanje materialov in značilnosti ter določanje potrebnih zgodnjih ukrepov za preprečevanje nadaljnje škode. Uporaba nedestruktivnega testiranja (NDT) v predhodni fazi preučevanja je izjemno koristna za pridobitev predhodne ocene potenciala stavbe za novo obliko uporabe in izbiro nove funkcije tako glede na potencial, kot glede na omejitve zaradi zmanjšanja določenih metrik učinkovitosti.

Na primeru samostana Lavello je učinkovito prikazana uporaba pripravljalne diagnostike, ki je zelo koristna za zbiranje podatkov o obstoječih težavah v stavbi pred začetkom projekta; napredne diagnostike, ki se uporablja na kritičnih mestih med oblikovanjem končnega projekta; in nadzorne diagnostike, ki služi preverjanju izvedenega posega ter določanju konservatorskega načrta in vzdrževalnih ukrepov.

Avtorica v prispevku še posebej podrobno poroča o uporabi georadarja (GPR) in infrardeče termografije (IRT), pojasni metode njune uporabe in pridobljene rezultate pri lociranju arheoloških ostalin v zemlji pred izkopavanjem ter ocenjevanju razvojnih faz kompleksa. Ključna rezultata sta bila lociranje ostalin zgodnje poselitve v zemlji s pomočjo georadarja in odkritje različnih vzorcev zidave zaradi prizidkov/preoblikovanj, ki so bili izvedeni na obstoječih stavbah, z metodo infrardeče termografije. Informacije smo pridobili brez vzorčenja konstrukcije ali strganja zaključnih površin: preiskavi z georadarjem in infrardečo termografijo sta nedestruktivni in z njuno uporabo je moč pridobiti podatke o notranjih plasteh neke strukture, pod njeno površino. Prispevek poleg tega obravnava nadzorovanje naraščajoče vlage v samostanu po posegu ter posledično določitev vzrokov in smernic za konservatorski načrt. Nedestruktivno testiranje igra pomembno vlogo v vseh fazah projekta in posega, saj je z njim mogoče ponavljati teste v različnih okoljskih pogojih ter pridobivati podatke in oceno o konstrukcijah sproti (torej v realnem času) in brez uničevalnega vzorčenja. Uporaba diagnostike je tako razkrila informacije, ki so temeljnega pomena za prizadevanja, da bi zagotovili dolgotrajne učinke restavriranja. Zahvaljujoč njej lahko pozornost posvetimo ranljivosti stavbe in vzpostavitvi ukrepov pregledovanja in nadzorovanja, da bi preprečili nadaljnje širjenje škode in zagotovili zgodnje odkrivanje dejavnikov tveganja pri ohranjanju gradbenih materialov in značilnosti.

Ključne besede: arheologija, preventivno konservatorstvo, restavriranje, servitski redovniki, samostan Lavello, infrardeča termografija (IRT), georadar (GPR), lasersko skeniranje

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