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The Role of Thermography in the Non-Destructive Evaluation of Historical Architectural Surfaces

Some observations about the method and its purpose

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***Abstract*—Infrared-Thermography (IRT) has become a supporting tool for the investigation of historical structures and facades. Using the non-destructive testing method for the detection can give a profound knowledge about the current status of the object and the state of decay, about different kinds of discontinuities at historical facades, of construction details and of thermal bridges in the facades. Different case studies of thermographic surveys on some Sicilian monuments are presented and discussed to illustrate how the method can offer applicable information about the investigated objects and demonstrate its reasonable integration into conservation projects.**

Keywords*—restoration, conservation, monument, historical surfaces, plaster, diagnostics, infrared thermography*

I. Introduction

Ancient plasters and superficial patina are significant expressions of the character of monuments and buildings. The alteration of the façades and the superficial envelope can determine the drastic loss of architecture identity and, as a result, a loss of the old districts atmosphere that still characterizes the contemporary city.

The diagnostic investigations offer different kinds of analytical tools to study the architectural materials, the structures and evaluate the necessity to plan the restoration intervention or program the periodic maintenance. The examination by the IRT method can support an effective maintenance and conservation of ancient buildings and their historical surfaces. The investigation by IRT has become a reasonable tool to study the covering surfaces of ancient architecture and it allows editing and compiling the conservation state diagnosis. Thermal evaluations are particularly useful to appraise the relationship between interior and exterior plaster and covering materials, the microclimatic exchange in the architecture surfaces and the related alteration of materials. Also a common absence of documentation about historical construction details can sometimes be solved by the technique in a non-destructive way.

The contribution of the scientific surveys can determine a sustainable conservative evolution in the field of architectural planning.

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II. IRT - Method

The technique is based on the temperature measurement while the infrared camera is recording the infrared radiation that is emitted from the heated surface. On the basis of the distribution of different temperatures at the surface of the tested object it is possible to get diverse information, which are often invisible and usually obtained with destructive tests, unsuitable for historic architecture. The infrared images stored by the thermocamera are processed with software, which eliminates the perspective distortions and applies filters to increase image quality parameters. The experimental method is useful to get a metric thermal image to be edited with the photogrammetric image of the architectural surfaces simultaneously. The received graph can be imported in CAD-software as raster image and becomes the base to improve the design of the thematic maps that constitute the restoration project.

The IRT becomes more frequently applied in the architectural examination and the preventive maintenance of buildings. For the location of the following problems in the near surface area the thermal method can give usable results: voids and other irregularities behind plaster, plaster delaminations, and detection of moisture in the surface region. Potentialities of the technique are the contactless, non-destructiveness, the inspection of large areas in relative short time and the real time data on the instrument's display. Beside the advantages there are limits to declare expressed in the dependence of the weather during the external investigation, the pour resolution of each thermogram, the accessibility to the surface and their form-factor, the variety of historical materials and the absence of information about the emissivity.

To obtain more detailed information the interaction with other non-destructive diagnostic instruments is sensible operated; thermography, radar and ultrasonic test, in synergy with other diagnostic surveys, can offer many essential information about structures and coating materials status that once was possible to reach only through direct investigation, altering the integrity of layers: it is possible to study the degradation entity in those superficial portions or thickness to be consolidated, or verify the quality of treatments already carried out.

III. Investigation - case studies

Some application examples of the diagnostic methodology to building surfaces in Sicily are introduced and critically commented to understand the potentialities and the limits of the technique and its role in the discipline of the restoration

and conservation of cultural heritage. During the investigations, a micro bolometric thermal camera with a 9,2 mm lens angle has been used; the data analysis has been processed by Flir, images editing, c.a.d. and T.r.u.e. software, the last one developed by the LIRBA Lab (University of Palermo).

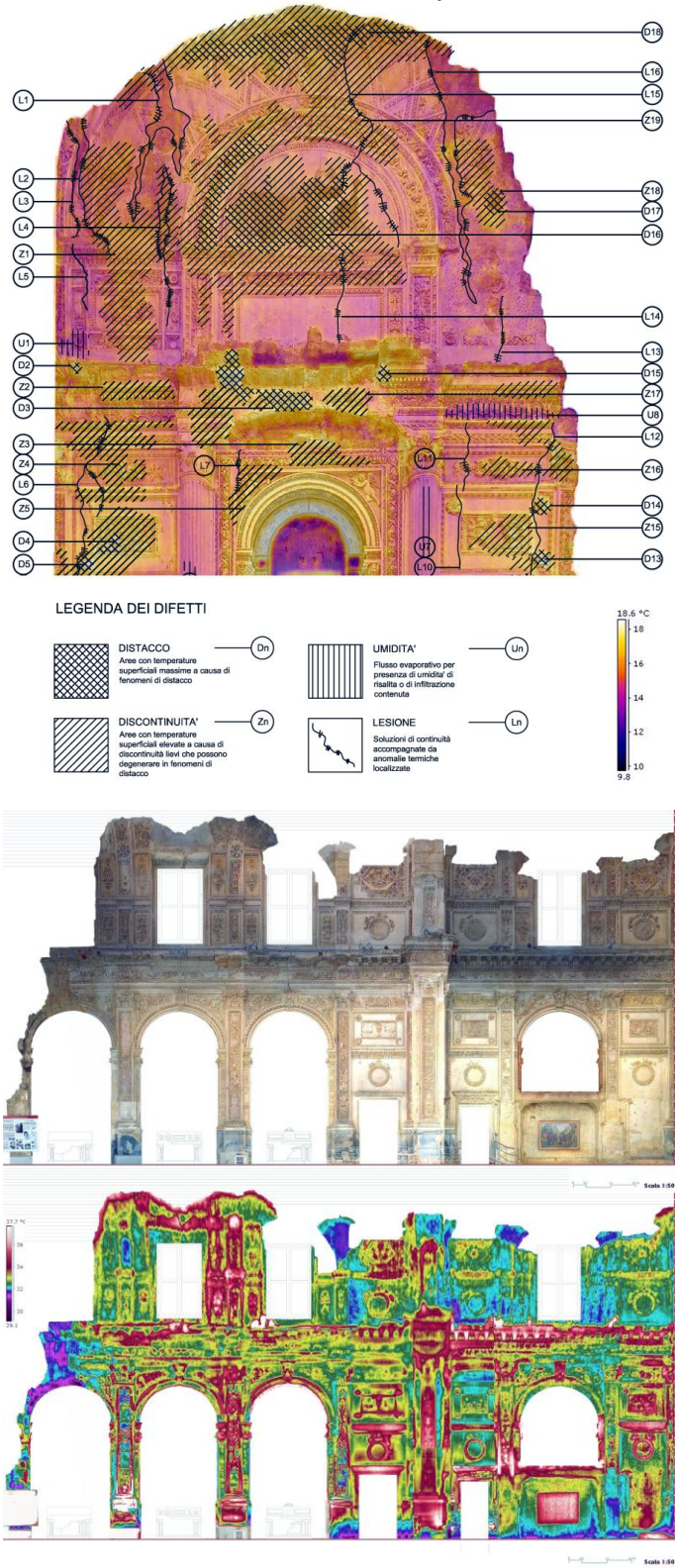
A. *Former Mother Church of Santa Margherita di Belice*

Infrared thermography has been made inside the former church before and during the conservation works in progress. The diagnostic verifications have been carried out at the points where the defects were diagnosed earlier, to verify the quality of the interventions and, therefore, raise the quality levels of yard. One of the main aspects in the restoration of the former Mother Church was the consolidation of the stucco that line the inner surfaces of the two walls not collapsed during the earthquake of 1968. The restoration has been difficult due to exposure of the interior finish surfaces to the elements for more than forty years. The condition of degradation reached in the years and the need to assess the state of conservation of the stucco and the level of adhesion to masonry required a careful investigation campaign. After the earthquake, in fact, the church (built in the late seventeenth century) remained without coverage in ruins, until the recent construction of new roofs with a project funded by the City of Santa Margherita di Belice.

The thermographic survey was carried out with the "active method" on the side and apsidal walls. The achievement of adequate thermal levels has been possible with the use of two convectors, who sent a stream of hot air on the surfaces in a uniform manner. Meanwhile, activating the thermal camera and measuring the superficial temperature of the stucco, the thermal state was continuously monitored. Reached the optimal temperature levels, the filmmaking process started; the thermograms were recorded along regular routes until covering the areas to be investigated. To simplify the graphic processing of thermal maps, the large wall surfaces of the former mother church were divided into sectors.

The thermal investigation offers a model of interpretation of the degradation state that is based on the evaluation of the distributive geography of the temperatures on the deteriorated surface; in fact, the presence of lesions or adherence loss between superficial layers can influence the emissivity levels and determine anomalous thermal distributions. But every single thermal image contains the measure of the temperatures in a small area and it's characterized by a perspective deformation that prevents the effective location of the areas to be restored. For such a reason, the result of the investigation is not diagnosis yet: it is simply a data set of mere measurements that doesn't determine a cognitive close examination that results specific for the planning and the execution of a restoration.

The computer processing of the thermal IR images has been developed in the laboratory and it was composed by some different phases, from the setting right of the infrared images to the elaboration of the thematic maps directly on the



Figures 1-3. Santa Margherita di Belìce (Agrigento), maps of the restoration project concerning the degradation analysis on thermal anomaly.

thermal mosaic of images (Fig. 1-3). The result of the investigation achieves therefore a global character and becomes a thermal and metric image (in reduced proportions and measur-

able). From this phase the "measure" can be unified with the architectural mapping and acquire the potentiality to be integrated to the project too. The synergy between photogrammetric and thermographic survey and the fusion of their corresponding maps supported the clear demarcation of the detached superficial areas where consolidation was to be carefully accomplished. The thermal images were assembled or completely collaged upon the metric visible image in order to get the thermal (and simultaneously metric) maps of the stucco façades. The final result of the computer processing phases is a system of overlapped images, perfectly corresponding and without distortions.

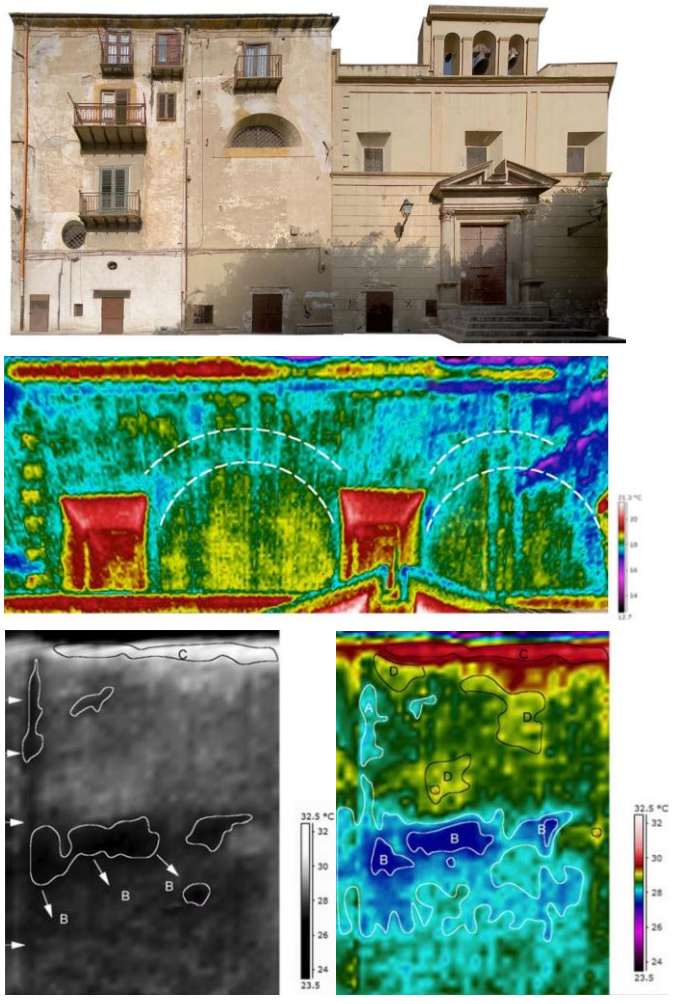
B. *Facade of San Giovanni dei Napoletani Church in Palermo*

The thermographic measurement was applied to a facade of the 16th century San Giovanni dei Napoletani Church in Palermo, to get a profound knowledge of the present status and the state of degradation of plaster in the near surface region. The alignment to the south-east of the facade was helpful for the used passive approach, because the warming up of the facade by the sun throughout the day was necessary for the investigation of the emission of heat during the cooling down phase. The appearance of the facade is composed of two esentially different types of facade, whose structure has often been modified, renewed and transformed in their structure. That also applies to the plaster surface because of the diversity, the age and its present state.

In three studies from September to November 2007 it was possible to test the efficiency of the method to get reasonable results. The aim was to observe the influence of different climatic conditions and of different times of day during the thermography measurements. Generally for the investigation it was necessary to warm up the facade by the sunlight, which made it possible to start the thermography-measurement with to detect the emission of radiation, using the cooling down phase when sun warming was finished. The thermographic measurement took place scanning the whole facade successively in several single shots, that had been saved as Infra Red images. As a basis for the complete proceeding it was necessary to develop an exact deformed overmeasure by using the photogrammetric survey. The montage of the gathered photo images and the Infrared images created thermograms, which represent the basis for the inspection and analysis of any distortions.

The thermograms in different scales and variable transparency indicate humidity on the surface, which may have been caused by the eaves gutter. Another reason could be the interfusion of the humidity from the inside to the outside, where it evaporates. In the infrared picture the humid parts on the surface have the lowest temperatures and are shown in the darkest colours. The thermograms also show the extent of humidity in the whole lower area of the detail more clearly, which appears to be in good condition in the visual observation. There is also humidity near the gutter. In contrast flaking plaster, cavities and non adherent plaster are most probably in the hot parts, which can be seen in the warm colours and the high temperatures. Non-adherent plaster and cavities act as thermal barriers. These non-intact areas are like failings, which have a lower thermal conductivity under the surface area. This is the reason why the surface above these areas keeps warmer longer, which can be seen in the thermogram in the warmest colours and hottest temperatures.

The application of preliminary studies by non destructive investigation in combination with the visual study generated some very interesting and utilizable results in the determination of the status and damage of plaster and masonry. The achieved results offer the opportunity to check specific areas, fin later examinations for example by putting precise minibore holes into the plaster layers or into the masonry, also as the humidity measurement of the surface. To get a basis for the future procedures for later maintenance NDI can be helpful. In the field of historic research the investigation appeared structural alteration beneath the facing of plaster. Former semi-circular arcs between the windows, pilaster strips and jutties have been made visible due to the thermographig survey, because of the differency of the thermal conductivity of the materials.



Figures 4-7. Palermo, San Giovanni dei Napoletani Church. Humidity phenomena (B), adherence loss and cavities (C, D).

C. *Di Pisa Palace in Palermo*

Thermography is very suitable for evaluating the conservation status of the "artificial stone" plasters. The digital thermograms are processed to obtain mosaics with the correction of perspective distortion bringing them over photogrammetric images, elaborated earlier after the relief of external facades. The final graphs are metric multilayer mappings of temperature distribution, which can be used for positive diagnostic evaluations.

A wide campaign of investigations by IRT has been recently carried out on the Art Nouveau architecture in the city of Palermo. La Casa Di Pisa, for example, is one of the most expressive Sicilian architecture of modernism, influenced by the school of the architect Ernesto Basile. The survey has allowed the visualization and localization of abnormalities in levels of adhesion, rather extensive and sometimes severe. Evaluating the graphs, diffuse thermal anomalies are observed, in particular, under the balconies of the last level, and slight discontinuity in the upper part of the façade (Fig. 8-10).

The thermogrammetric survey methodology is applied to get digital images that are the basis to support and develop the design of the restoration project and, therefore, the implementation of the conservation techniques (consolidating injections, for example) in the practice of worksite, with positive effects on the timing and costs of architectural design and yard operations. The metric mosaic (scaled and measurable) allows, in fact, the exact location of each defect. The elaboration of metric defects maps is essential to provide operators with the correct data to locate the portions of plaster on which the compatible techniques of restoration are to be applied.

IV. Concluding remarks

The infrared surveys here introduced confirm that the final graphs are to be considered as specific project maps and underline, with metric precision, the degradation of materials and the areas to be treated during the restoration yard. The maps can be subsequently elaborated in c.a.d. software as raster images to estimate the costs of the conservative treatments, with positive effects in terms of sustainability, management and overhead.

The non-destructiveness would be a great advantage in the preservation of monuments by getting useful results of the preliminary testing of the object. However – while aware of the appreciation of the diagnostic tests – the correct method of survey is not common and difficult to put into practice if the operators do not have the proper training; just as the readability and evaluation of the results needs a lot of experience as well as the prompt propagation of the various findings. We also have to critically consider the substantial quality of the diagnostic findings also if the thermographic measurement in exterior areas is limited to thickness surface (stimulated by the sun or artificially heated).

Figures 8-10. Palermo, Di Pisa Palace, the facade covered with artificial stone plaster; rectified photography and metric thermography highlighting areas characterized by higher emission levels (white areas).

The Sicilian experiences of research allow us to hypothesize some perspectives of the future search. Also if the infrared thermocameras become more and more sophisticated, it clearly appears that a real positive evolution can be determined only if the interdisciplinary dialogue is increased between the architects/designers and the industrial researchers. The evolution of the instruments seems to advance autonomously, without appraising the comparison with the applications in the field of architectural restoration/conservation. We can today purchase very sophisticated and expensive tools of recent evolution, but it is still impossible to note the contemporary evolution of the application methods. It may be wrong to set too many possibility of regulation in the tools because they became difficult to be used and, accordingly, expensive; the native software are lacking and cannot support the processing of the final diagnosis: images are limited and distorted.

The most interesting developments in the works of applied research are probably the ones characterized by the synergic use of photogrammetric survey, thermal measurements and laser scanner: this integration produces the metric precision that is requested for the restoration planning.

References

[1] F. Tomaselli, G. M. Ventimiglia, "Scientific investigation to maintain our architectural heritage", Palermo, 2014, in press.

[2] G. M. Ventimiglia, "Role of diagnostic surveys in the conservation of the former mother-church of Santa Margherita di Belice in Sicily: preliminary tests and restoration site checks", in Built Heritage 2013 Monitoring Conservation Management, International Conference, Milano, 2013, pp.1003-1011.

[3] F. Tomaselli, G. M. Ventimiglia, "Superfici materiche nella percezione della scena urbana", in Madonie Madonie, Palermo, 2013, pp. 36-43.

[4] G. M. Ventimiglia, "L'intonaco Li Vigni nell'architettura del XX secolo a Palermo. Nuove conoscenze e applicazioni diagnostiche per la manutenzione", in Filosofia della conservazione e prassi del restauro, Napoli, 2013, pp. 373-381.

[5] G. M. Ventimiglia, "Finte Pietre. Architettura dell'apparire e conservazione dei valori culturali", Roma, 2012.

[6] G. M. Ventimiglia, Città, intonaci, colore. Problematiche inerenti al restauro degli intonaci storici, Roma, 2012.

[7] C. Franzen, P. Baldracchi, C. Colla, E. Esposito, G. Gaigg, R. Pfluger, A. Troi, "Assessment of Historic Structure by IRT, In proceeding of European Workshop on Cultural Heritage Preservation", EWCHP, Berlin, 2011.

[8] G. M. Ventimiglia, "IR tecnology and conservation of monument: experimental application on architectural surfaces", Fondazione Giorgio Ronchi, Firenze, 2011, pp. 805-817.

[9] J. Spodek, E. Rosina, "Application of Infrared Thermography to Historic Building Investigation", Journal of Architectural Conservation Vol.15, Nr.1, 2009.

[10] R. Ollig, G. M. Ventimiglia, "Zerstörungsfreie Untersuchungen von Mauerwerk und historischen Putzen", in Restauro, IV, Berlin, 2009, pp. 252-258.

[11] A. Aveta, "Diagnostica e conservazione. L'insula 14 del Riona Terra (Pozzuoli)", Napoli, 2008.

[12] R. Ollig, G. M. Ventimiglia, "Non destructive investigation of historical plaster and stonework in San Giovanni dei Napoletani Church in Palermo (Italy): evaluation of the Exchange between architecture and environment by thermography and radar survey", Art2008, Jerusalem, 2008, pp. 129-134.

[13] F. Tomaselli, G. M. Ventimiglia, "Teaching Restoration Methodology: Role of Scientific Contributions in the Conservation of Architectural Heritage", in Teaching Conservation/Restoration of Architectural Heritage, EAAE ENHSA, Genova, 2008, pp. 229-236.

[14] G. M. Ventimiglia, Palermo, "Palazzo Diana di Cefalà", III Mostra Internazionale del Restauro Monumentale, ICOMOS, Firenze, 2008.

[15] F. Tomaselli, G. M. Ventimiglia, "La Chiesa di Santa Maria della Catena a Palermo e il restauro degli affreschi nella cappella maggiore. Conoscenza, diagnosi e consolidamento dei dipinti murali", Scienza e Beni Culturali, Bressanone, 2007, pp. 129-140.

[16] F. Tomaselli, G. M. Ventimiglia, "La metodologia T.R.U.E.", SIAE, LIRBA, Palermo, 2006.

[17] E. Rosina, "La percezione oltre l'apparenza: l'architettura all'infrarosso", Firenze, 2004.

[18] F. Tomaselli, G. M. Ventimiglia, "Le indagini diagnostiche per il monitoraggio e la verifica della conservabilità degli intonaci a finte pietre del Novecento", Scienza e Beni Culturali, Bressanone, 2004, pp. 729-738.

[19] M. Milazzo, N.Ludwig, "La termografia nella diagnostica delle strutture architettoniche", Napoli, 1998.

[20] N. Ludwig, R. Marchesi, E. Rosina, "Telemetric measurement of emissivity in the thermal analysis on building materials", Budapest, 1995.