

Procedure for NDT and Traditional Methods of Ancient Building Diagnosis, by Using Thermograph, Digital Images and other instruments data Analysis.

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Abstract

The authors of this paper belong to an interdisciplinary research group, developed at the Polytechnic University of Valencia, financed by the Ministerio de Fomento, 2004, in order to evaluate the efficiency of different destructive techniques and non destructive methods applied to the analysis and diagnosis of ancient buildings. The results of this project and the experience gained applying its conclusions to the knowledge of ancient buildings inspired this paper, which is focused to determine a methodology to undertake this sort of surveys. Within the difficulties involving the data compilation about the historic buildings architectonic and structural development, and the necessary accurate results, there are other requirements to observe: to reduce time consuming in the task and to develop more simple and economic methods, applying reduced number of instrumental, avoiding a massive destructive testing of all building materials and construction elements at the Laboratory. The aim of building conservation is to be respectful with the material belonging to the historic building, including the surveying phase of the job. Using a few instrumental easily carried to the building site, considering the difficulties derived of the lack of accessibility that may exist in this sort of buildings, and taking into account not to produce damage to the object, maximizing results by minimizing the samples/testing/data taken from the building the data gathering phase is focused, looking for its complementarities, coincidences and correlations.

The techniques applied are a) metric rectified digital images to obtain accurate and fast drawings of the building elevations; b) thermograph images analysis for the identification of different building materials, coatings and discontinuities in the masonry walls; and c) ultrasonic, micro drilling and wood hardener for timber structural elements assessment. This method was applied to several case studies, reaching accurate results. As a conclusion, a procedure was developed, that is presented in this paper.

Keywords: historic buildings, NDT assessing, thermograph images, micro drilling, ultrasonic, digital images, wood penetrometer

1. The objective of the research project

The research project “**NDT Methods of Ancient Buildings Assessment and Diagnosis of Building Materials and Construction Systems for its Conservation**”, developed at the Polytechnic University of Valencia 2004-2007, involved three main aspects:

- Evaluation of different methods for ancient building assessment including NDT ones.
- Comparison between the data coming out from the diverse NDT instruments applied and traditional methods, looking for correlations between them.
- Finally, establishment of a procedure to apply for ancient building assessment, allowing organizing and systematizing the previous studies necessary for planning the conservation process.

The work was focused to find simpler and advantageous data gathering methods at the building site, employing a reduced number of instrumental, taking into account the difficulties found many times at the buildings, such as risk for the surveyors, security aspects and accessibility problems, frequently present at this buildings, due to its bad conservation conditions.

Besides, the previous experience of the research group in ancient building assessment based on traditional methods of inspection, several buildings were selected to apply gradually this proposed method, presenting different site characteristics, architectonic typology, building materials and construction systems.

A complementary research was done at the Laboratory to obtain more data in order to contrast the results.

2. Building historic research and plan drawings

A documental and historic survey is necessary to prepare an architectonic and constructive analysis of the building. This phase of the analysis can be done at the same time with the plan drawings. These must contain not only metric information, but also distribution of the different spaces, construction system, building materials and all other characteristics.

The data necessary for this purpose may be obtained by different methods. High digital images for metric restitution have been proved as a reliable system to apply for this purpose (Fig. 1). It must be taken into account that in some cases there are on site difficulties to fix the reference points necessary for the properly metric transformation of the captured digital images, in order to obtain accurate restitutions^[1].

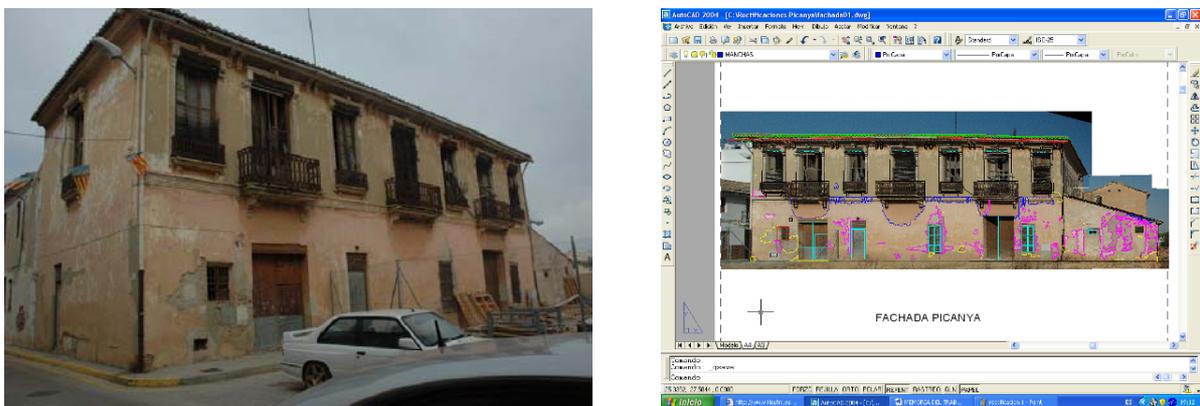


Fig. 1. Digital image and metric restitution. (Ancient building at Picanya, Valencia).

The elevations obtained by applying this method were used as a starting point for the data compilation and later comparison with IRT images, establishing an analogue process of image restitution with both technologies (Fig. 2).

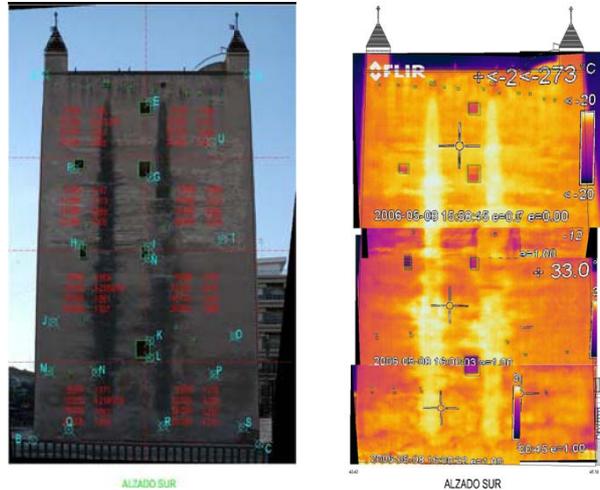


Fig. 2. Comparison of digital and IRT images of a façade (Medieval Tower at Torrent village, Valencia)

3. IRT image analysis

Digital images were compared with IRT images, trying to find the corresponding information of both, paying attention to the additional data given by this technology. IRT camera was FLIR ThermoCAM B2.

It was especially interesting to verify that IRT images of the façades allowed discovering hidden openings in the walls, repairs, changes in the walls building materials and its renderings, presence of dampness and other pathology (Fig. 3). In all cases this analysis gave completely new information, some times endorsed by comparing the images with old photographs, engravings or drawings [2] [3] [4] [5] [6] [7] [8] [9].

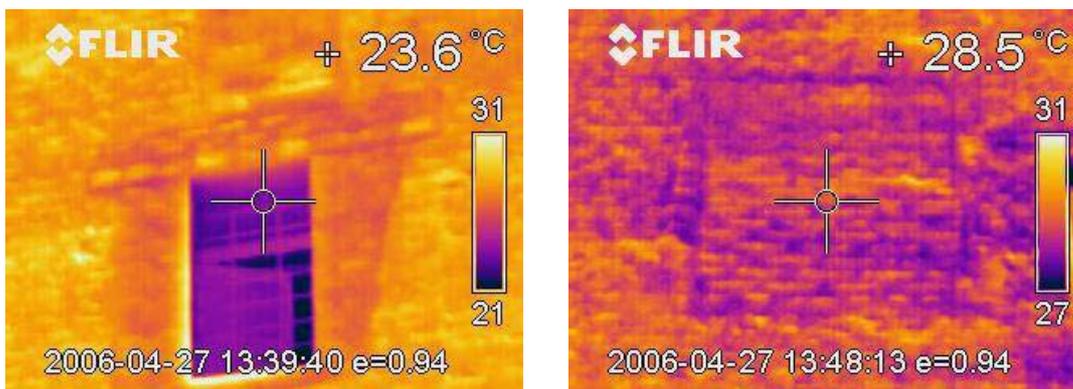


Fig. 3. IRT images showing former repairs and changes in walls, and shape and size of openings (Castell d'Alaquàs, Alaquàs village, Valencia)

IRT images show different thermal emissivity of the diverse building materials, allowing its identification. In some cases it was detected temperature changes in the same façade of 10°C, due to the different composition and density of the walls materials and finishing.

By means of this technique, different walls composition were identified such as bricks, stones and masonry hidden under the mortar coatings, especially when the construction elements were made of very diverse materials (Fig. 4).

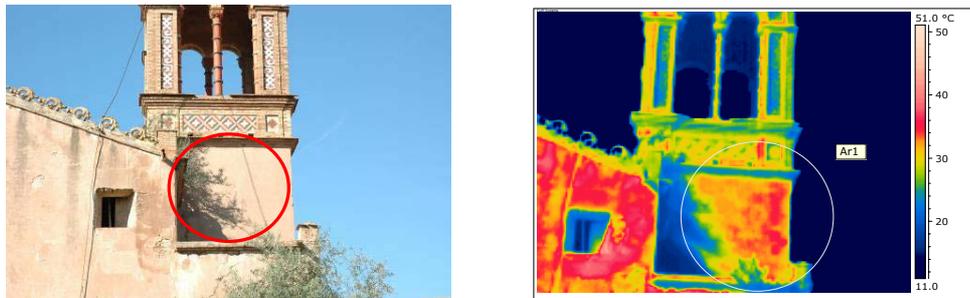


Fig. 4. IRT images where can be identified a brick wall beneath the mortar rendering

Several mortar probes were prepared at the Laboratory with different conglomerate such as cement, lime and gypsum, varying its thickness (1, 2 and 3 cm). Later were analysed with IRT images, coming out a clear different emissive temperature between them. These differences were clearly recognised with rendering thickness of 1 and 2 cm, but not in those 3 cm thick.



Fig 5. Comparison of mortar probes prepared at the Laboratory with mortar

These probes were also applied directly to the building walls of one of the cited buildings, at the Picanya village, in order to identify the mortar rendering type through IRT image analysis (Fig. 6). In all cases, the depth of the rendering must be measured, to make possible this method of identification.



Fig. 6. Probes made on site (left), later analysed by IRT images (right) for its identification.

The presence of damp areas was also clearly recognized and other pathology such as discontinuities and cracks in the walls.

4. Timber elements analysis

Timber was used in historic buildings at the Valencian Community for the construction of floors and roof structures. Generally the timber used was *pinus sylvestris*. These structures may be decayed by root and insect attack. Many inspections were made by this research group for timber structure assessment, employing traditional methods besides a hygrometer, ultrasonic and wood hardener (Pilodyn) testing as NDT methods applied [10][11][12][13].

This research project included the use of a microdrilling device, Rinntech 3450, to improve the data gathering method in order to obtain more accurate results in order to evaluate the timber structure. After the necessary previous testing of the microdrilling device in 5 probes of old timber at the Laboratory, and comparing these results with those coming from the other devices quoted before for NDT, also applied at the same probes, it was possible to systematize a procedure of data gathering at the building site [14][15][16][17][18].

A visual inspection must be the first step to do for the data compilation of each timber element. Record cards were done for each element, previously identified with a proper code, including all the information obtained on site: sizes of the square sections, moisture content, splices, defects, grain deviation, number of knots and its size in reference to the face in which those are contained, decay, and other characteristics that are necessary to define the structural quality of timber and its decay. Afterwards the NDT was applied, but after the previous experience at the laboratory and various case studies, a procedure to apply them in order to optimise the results and time consuming came out. The procedure is as follows:

- Ultrasonics, to make an approach to the MOE (Dynamic MOE was obtained, being the static MOE is 95% of that value for the spice cited before), of all elements.
- Wood hardener tester, to determine surface consistency (alterations, density), of all elements
- Microdrilling, to give a “view” of the timber element interior, one each three and in all elements where alterations were detected

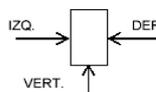
MELIANA - ROOF

ROOM	JOIST	MOISTURE %				WIDTH (cm)	HEIGHT (cm)	PILODYN ENDING			ULTRAS. (µs)	MICRODRILLING (ENDING)	PATHOLOGY	
		ENDING		VERT CENTRE	VERT			RIGHT	LEFT	INFERIOR ENDING			SUPERIOR ENDING	
		VERT	RIGHT											LEFT
3A NORTH	1A	-	-	-	-	12	22	-	-	-	-	-	-	-
	1N	24,6	25,3	23,8	14,2	12	20	10	-	15	-	orden 110 vert	-	-
	2N	15,2	24,8	16	11,8	10	20	12	14	14	63,5	-	REINFORCED IN 3/5 CENTRAL PRTMETALLIC PROTHESIS. TL	TR
	3N	23,9	16,5	19,3	12,6	12	21,5	11	11,5	12	64,5	orden 111 vert	-	-
	4N	21	22,5	19,1	13,1	11	22,5	11	13	13	53,5	-	FEW KNOTS	-
	5N	12,2	12	13,7	13,6	12	21	13,5	15	14	67,1	-	MANY KNOTS. RESINOUS TERMITE ATTACH	TL
	6N	10,4	12,6	10,2	13,6	10,5	22,5	18	12	14	52,9	orden 112 vert	ROT ENDING	-
	7N	14,9	12,7	12,2	13,9	12	21	12	16	17	-	-	BROKEN JOIST	-
8N	13,8	14,8	16	13,1	11	22,5	13,5	14	17	52,7	-	TL. COMMON BEETLE ATTACH	TL	

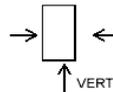
SPECIE OF WOOD
PINUS SYLVESTRIS

QUALITY
STRAIGHT GRAIN
KNOTS Ø 5 cm, SEPARATED 35-40 CM
WHITE WOOD ON UPSIDE OF THE RAFTER
COMMON BEETLE
LONG HORN BEETLE
WOOD ROT IN ENDINGS

MOISTURE CONTENT



PILODYN



TWISTED LEFT



TWISTED RIGHT



Fig.7. Example of data card, gathering results of visual and NDT results

In this way an approach to the resistant values can be done, the extension of the damage can be defined and the general state of the timber structure conservation can be predicted.

5. Proposal of a general procedure for NDT method of assessment

As could be seen, each NDT device gives a series of data, which are in relation between them. For each case study a general procedure is proposed, that may change depending on the building characteristics.

Phase	Works to be done/NDT device	Data obtained
Building general aspects definition	Compilation of historic documental and graphic information	Original configuration, former repairs, refurbishments and enlarging process
	Analysis of this information	Building type and construction system identification
	Visual detection of pathological areas	Problems detection
Graphic analysis	General planning for the on site data gathering	Points of view and supporting points. Selection for captured images metric rectification.
	High resolution digital images capture	
	Building general layout. Sketches of construction system	Construction system and building materials identification.
	Software digital images adjustment or metric rectification	Drawing of plans, sections and elevations
	Metric rectified images analysis	Different materials and finishing, damaged areas, and general pathology identification
IRT analysis	IRT images capture. Measurement of temperature and dampness	Surface temperature. Definition of discontinuities and heterogeneous areas
	Evaluation of information given by digital and IRT images	Identification of hidden openings, repairs, different wall materials, and pathology
	On site comparison with IRT probes images	Material identification. Conclusions
Timber analysis	General structure and jointing analysis. Timber element identification. Photographs of each element ending and any other alteration detected	Description of the structure, geometry, its orientation. Preparation of timber elements record cards
	Visual inspection	Defects, decayed areas detection. Timber structural quality definition
	NDT devices: Hygrometer, ultrasonic, microdrilling and wood hardener.	Moisture content measurement, MOE approximation, density, external consistency, internal observation of the element. Conclusions.
5 Final report	Compilation of all data and conclusions of different phases	General conclusions of the different methods applied
	Data and results presentation	Information summarize
	General conclusions	Proposals for repairs

6. Conclusions

Some conclusions came out from this research project.

Graphic analysis:

- (1) Architectural drawings can not be substituted by any other instrumental method to refer the information about a historic building. Accurate information has to be reflected in plans, sections and elevations
- (2) Digital images metric rectification for the elevations, is a way to reduce time consuming for the surveyor

IRT analysis:

- (3) IRT image of a building façade will be significant if it has reached with enough uniformity a minimum temperature. For this reason, the IRT image should be obtained after the heating process of the surface, and in different moments of the cooling down process to evaluate the different thermal inertia effect of its elements.
- (4) The differences between emissivity of different coatings of various compositions at the same temperature are clearly identified in an IRT image at a temperature high enough
- (5) This work opens an interesting line of research in IRT images of historic buildings analysis based on the comparison of IRT images with qualitative sample images of materials or elements previously studied.

Timber analysis:

- (6) There is correlated information about some of the results of many testing and research works that allow us to adopt them as an approach to semi-quantitative values about a single timber element resistance.
- (7) Wood is, generally, in good state of conservation, except some elements. Those are identified in drawings, indicating position and extension of the damage According to that resume, repair measures are designed as a conclusion.
- (8) Based on visual inspection, Pilodyn values confirm what have been observed, giving an approach to its density and consistency.
- (9) Resistograph graphics printed out, and later analysed by means of data bases reveals what happens in the interior of the timber element, being possible to precise the extension of the damage. Some media values about the mechanical characteristics of timber may be obtained by comparing the results.

In general aspects:

- (10) Sequence must be followed in order to know the possibilities given by each NDT and traditional methods applied for the assessment of a historic building. Data coming out from one specific method applied may be in relation with the following ones.
- (11) Documental research and visual inspection can never be avoided

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