NDT techniques for the analysis of anomalies related with durability - heritage buildings with masonry walls and confining concrete elements

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ABSTRACT

The anomalies related with durability of building masonry walls and their confining concrete elements are often related to the occurrence of cracking/detachment and with the presence of moisture. In many situations, it involves the cracking of masonry walls and the deterioration of concrete which, in cases of greater severity, results in the detachment of the walls render and in the local delamination of the concrete elements (columns, walls and beams), with the uncovering of the steel reinforcement and their consequent corrosion. Automated anomalies detection, in inspection of these anomalies, based on image processing techniques, can be done using the non-destructive testing (NDT).
The paper intends to identify the most common anomalies related with durability affecting the functionality and aesthetics and, in some situations, the safety of heritage buildings with reinforced concrete structure, seeking to typify the main anomalies related to the durability of materials and construction elements. A methodology of recognition of the most relevant patterns of these anomalies is briefly presented, in particular through image processing and features extraction of anomaly patterns in facade walls and on confinement elements of reinforced concrete, with the purpose of subsequent use within the framework of support to the inspection actions and consequent maintenance of this type of heritage buildings.

Key-Words: Durability; Anomalies patterns; Masonry walls; Concrete structure; Anomalies detection; Image processing; Feature extraction; Heritage buildings

1. INTRODUCTION

In the built heritage, the relevance of buildings built in the 20th century was being gradually recognized due primarily to its historical and cultural value and later to their public utility. Under the effort of conservation and protection of such heritage, it is important to promote the study of preventative and/or remedial interventions to meet the required performance level because of deterioration, without significant loss of its intrinsic cultural value and without losing the guarantee of maintaining adequate levels of security and functionality. In this set of buildings with reinforced concrete structure, it is growing the number of cases, where the respective facade walls and their confining concrete elements, subjected to external aggressive actions, present durability problems and therefore reflect the need of a pro-active conservation concerned with applying some form of treatment or taking actions prior a

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change in material property adversely affecting the ability of the structure, or parts thereof, to meet the required performance levels because of deterioration.

After the construction of the buildings, a progressive deterioration process reduces their functional performance and ability to fulfil their basic work construction requirements, as well as the needs and expectations of their users. Building facades are particularly exposed to the effects of environmental agents, namely related to the direct impact of sunlight, rain, wind, and atmospheric pollutants. These effects of environmental agents have negative consequences in terms of degradation of the facade due to anomalies related with durability that can occur in the different facade elements (concrete elements, masonry walls, etc., [2] and [6] to [9]). The anomalies related with durability of building masonry walls and their confining concrete elements are often related to the occurrence of cracking/detachment and with the presence of moisture. In many situations, it involves the cracking of masonry walls and the deterioration of concrete which, in cases of greater severity, results in the detachment of the walls render and in the local delamination of the concrete elements (columns, walls and beams), with the uncovering of the steel reinforcement and their consequent corrosion. These anomalies can have a strong negative impact on building service life and generally can force to significant maintenance costs associated to repair actions.

In a routine inspection, visual observations of anomalies depend on the knowledge and experience of the observer. Automatic image-based anomaly detection can be a complementary tool to visual inspection and the respective analysis can be based on the image processing techniques, eventually more objective and with more accuracy [1] and [5]. The automated anomalies detection, based on image processing techniques, can be done using the non-destructive testing (NDT) techniques available ([3] and [4]): ultrasound testing (US), infrared thermography (IRT) and photogrammetry (terrestrial/aerial survey using an unmanned aerial vehicle - UAV).

The paper intends to identify the most common anomalies related with durability, which can affect the functionality and aesthetics, and, in some situations, the safety of heritage buildings with reinforced concrete structure, seeking to typify the main anomalies related to the durability of materials and construction elements. A methodology of recognition of the most relevant patterns of these anomalies is briefly presented, in particular through image processing and features extraction of anomaly patterns in facade walls and on confinement elements of reinforced concrete, with the purpose of subsequent use within the framework of support to the routine inspection and subsequent maintenance of this type of heritage buildings.

2. RELEVANT PATTERNS OF ANOMALIES IN FACADE WALLS AND IN THE CONCRETE STRUCTURE RELATED WITH DURABILITY

2.1 General

The IRT method is based on the assumption that for temperatures above absolute zero all the objects emit energy from their surface in the form of thermal radiation. Thermography equipment captures the IR radiation and converts it to a thermal image (thermogram), which represents the distribution of surface temperature (Ts) of the object, without contact. IRT may be applied to the diagnosis of anomalies in renderings, evaluating the state of conservation of large areas of the facade and performing the diagnosis of their causes. IRT allows to relate observed situations of thermal inhomogeneity with an internal "picture" and state of the element, such as the characteristics of the materials as well as the occurrence in the wall renders of detachment, surface discontinuities and internal cracks and even the distribution of moisture on the wall.

The US method is based on the assumption that the cracking, the lack of cohesion and the detachment of the material (i.e., the state of preservation of the material) reduces the speed of the ultrasonic waves. This inspection technique aims the evaluation of the state of conservation of the construction elements based on estimation of mechanical resistance and deformability of constituent material and it allows the evaluation of the compactness and stiffness by determining the rate of spread of ultrasonic waves through the material. US testing when applied to concrete elements can be used for the determination of the uniformity of concrete, the presence of cracks and voids, changes in properties with time and in the determination of dynamic physical properties [3]. Depending on the distance separating the transducers it is possible to make use of this effect for locating flaws, voids or other defects greater than about 100 mm in diameter or depth, [3]. It may also be used to estimate the strength of in-situ concrete elements or specimens. However, it is not intended as an alternative to the direct measurement of the compressive strength of concrete.

The Photogrammetry is a technique that can be used in this context for obtaining the information about the building, namely from their facades (geometric information: position, size and shape) and their anomalies. Digital image processing (DIP) can be applied to single photos. Single photos have the disadvantage of having deformations due to the camera (from the lenses, the sensor, etc.) and due to the point of view (from where the photo was taken), making difficult to perform precise comparisons in studies made over time. Using photogrammetric techniques to build orthomosaics, the deformations are geometrically corrected, and measurements can be made, like in plans and maps. Orthomosaics, or orthos, can be created when surfaces are flat, like the majority of the facades, or when they are plannable. In this paper the analysis of the orthos by DIP is called IP2D. But, sometimes, when the surfaces can't be plannable, they cannot be represented by orthos. In this case a point cloud can be used to "bring" the surface into the computer. Although DIP cannot be applied directly to point clouds, one might use digital surface models derived from these clouds and apply to these DIP (IP3D). Due to the distances involved in photo surveys of buildings - a very few hundred meters, sometimes only some meters – these photogrammetric surveys are included in the close range photogrammetry. Some authors consider that 300 m is the frontier between a close capture (CC) and a far capture (FC). Here it is proposed the following anomalies signs of identification, which will condition the adequate methodology for capturing photos:

- Simply superficial zone with signs of degradation;
- Zone beneath the surface subjected to an active process of degradation/no signs of external degradation;
- Superficial zone with signs of degradation/ and also the zone beneath surface subjected to an active process of degradation;
- Anomaly concentrated in a localized zone;
- Anomaly developing along lines or band zones;
- Anomaly affecting the entire element.

In the following, it is presented examples of application of this methodology for concrete and for masonry walls elements.

2.2 Concrete elements

2.2.1 General

The most commons defects in concrete structures are cracks, being the reasons for them according to CEB (1992) the following: i) Cracks due to rheological concrete properties: drying shrinkage and plastic settlement of fresh concrete; ii) Cracks caused by load/imposed deformation: pure flexure, shear, pure tension, bond failure; iii) Thermal cracks: internal and external restraint; iv) Chemical cracks: reinforcement corrosion, alkali silica reaction, salt crystallization.

The most relevant durability problems in reinforced concrete structures are essentially related to the corrosion induced by chlorides and by carbonation (Table 1). The ingress of chlorides or carbon dioxide depassivate the steel in concrete, and in the presence of oxygen and water, the corrosion process is initiated; ingress of acids, alkalis and sulphates may lead to the chemical deterioration of concrete; moisture movement during freezing and thawing action can be responsible for deterioration of concrete.

2.2.2 Carbonation and the corrosion of the reinforcement

When carbon dioxide diffuses into concrete, in the presence of water, it reacts with calcium hydroxide to form calcium carbonate, and the pH of the pore solution is reduced; in case the carbonation front progresses until the surface of the reinforcement is reached, the passive layer of the steel surface will be dissolved, and the process corrosion of the reinforcement may begin. Corrosion in the form of rust formation and/or loss in cross-section of the rebars occur together with localized spalling or delamination of concrete cover (Fig. 1).

2.2.3 Corrosion due to chloride ingress

The mechanism of corrosion of steel in concrete containing chlorides is complex. Chloride ions are able to disrupt the passivating reaction that occur on the steel surface in the highly alkaline conditions in uncarbonated concrete. In carbonated concrete, smaller amounts of chloride will depassivate the steel and the corrosion processes are accelerated. The corrosion process for chlorides action is more aggressive than carbonation, being a localized corrosion and not general as in the case of carbonation (Fig. 2).

Figure 1. – Carbonation and the corrosion of the reinforcement (source: Duratinet).

Figure 2. – Corrosion due to chloride ingress (source: Duratinet).

2.2.4 Freeze thaw deterioration

The action of freezing and thawing usually occurs in horizontal concrete surfaces exposed to water or vertical surfaces that are in contact (permanent or almost permanent) with water. The water contained in the pores expands, when frozen, causing tensions within the concrete and cracks on the surface. The deterioration of concrete under the action of freezing and thawing may lead to disintegration of concrete (Fig. 3).

2.2.5 Alkali aggregate reaction

Certain aggregates containing reactive silica react with the potassium, sodium and calcium hydroxide cement and form a gel involving aggregates. This gel exposed to humidity expands and create tensions in the concrete, resulting in cracks around the aggregates. Moisture speeds up the alkali-silica reactions. This type of reaction may not be noticeable for a long time and suddenly turns into an advanced state of deterioration (Fig. 4).

Figure 3. – Freeze thaw deterioration.

Figure 4. – Alkali aggregate reaction (source: Duratinet).

Table 1. Examples of anomalies related with durability of concrete structural elements and the assessment of these anomalies characteristics through image processing

Characteristics signs of the anomaly	Type of cause of the anomaly	Description of the cause	Anomalies signs of identification					
			Simply superficial zone with signs of degradation	Zone beneath the surface subjected to an active process of degradation/no signs of external degradation	Superficial zone with signs of degradation/ and also the zone beneath surface subjected to an active process of degradation	Anomaly concentrated in a localized zone	Anomaly developing along lines or band zones	Anomaly affecting the entire element
• Rust formation • Loss in cross-section of the rebars • Localized cracking /detachment of concrete cover.	Carbonation and the corrosion of the reinforcement	Passive layer of the steel surface is dissolved	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	-	(IP2D, IP3D)
• Appearance of brown spots of iron oxide • Localized cracking /detachment of concrete cover	Corrosion due to chloride ingress	Chloride ingress in concrete with capacity to oppose the corrosion inhibiting properties of the alkaline cement paste pore solution	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	-	(IP2D, IP3D)
• Disintegration of concrete	Freeze thaw deterioration	Water contained in the pores of concrete expands, when frozen, causing tensions within the concrete and cracks on the surface	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	-	(IP2D, IP3D)
• State of deterioration of concrete	Alkali aggregate reaction	Aggregates containing reactive silica form a gel involving aggregates, which exposed to humidity expands and create tensions in the concrete, resulting in cracks around the aggregates	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	-	(IP2D, IP3D)

2.3 Walls

2.3.1 General

Facades building walls are subjected to environmental agents, which can cause visual degradation and negative effects on the heritage building aesthetic performance. Particularly, heritage building external renders, besides decorative protection attributes, perform an essential function of sacrificial layers, when exposed to climatic actions and mechanical and environmental impact (namely sunlight, wind, rain, and atmospheric pollutants). The most relevant durability problems in facade walls are essentially associated to environmental actions which main consequent anomalies have humidity related causes [7]: presence of rainwater or snow; wet-dry cycles; freeze-thaw cycles; vapour or high relative humidity action; cladding system's humidification; rising damp. Some examples of anomalies related to the presence of humidity are presented in Table 2.

In many situations, it involves the cracking of masonry walls, which, in cases of greater severity, results in the detachment of the walls (Figs. 5, 6 and 7, from [8]). In the visual observation and in the image assessment (photogrammetric and thermal images), the facade anomalies must be registered and classified. DIP can be used to enhance the deteriorated areas and to classify according to their condition level, for different types of anomalies in render (staining, cracking, detachment, etc.), or in the paint (blistering, cracking, etc.).

Figure 5. – Blistering and detachment of the render.

Figure 6. – Mapped cracking due to shrinkage and efflorescence's.

Figure 7. – Horizontal cracking following the joints.

2.3.2 Anomalies in cement based renders

In the following, anomalies associated with humidity in cement based renders are briefly analysed (presence of moisture on the surface or within the rendering), as well as the assessment of these anomalies characteristics through DIP (Table 2). These anomalies can affect the aesthetic aspect of the facade and the rendering's integrity (Fig. 8, from [9]). The cohesion and adhesion of external cement based mortars to the background can be weakened, along the time, due to environmental loads, and suffer some degradation as superficial cracks, detachments, etc.


a) Blistering of elastic type painting


b) Blistering near the edges


c) Blistering and detachment


d) Detachment of textured paint


Blistering


Blistering in "plastic paint"


e) Saponification / softening


f) Detachment of the paint


g) Detachment of the paint


h) Cracking in "Kerapas" type paint

Figure 8. – Anomalies in paints.

Table 2. Examples of anomalies related with durability of facade masonry walls and the assessment of these anomalies characteristics through image processing, [7], [8], [9]

	Type of cause of the anomaly	Characteristics signs of the anomaly	Description of the cause	Anomalies signs of identification					
				Simply superficial zone with signs of degradation	Zone beneath the surface subjected to an active process of degradation / no signs of external degradation	Superficial zone with signs of degradation / and also the zone beneath surface subjected to an active process of degradation	Anomaly concentrated in a localized zone	Anomaly developing along lines or band zones	Anomaly affecting the entire element
Cement based render (CBR)	Cracking of the render	Cracking along the connection between different materials coated in continuity [8].	Related to the different characteristics of the two materials (elasticity modulus, thermal dilatation coefficient, etc.), which have therefore different deformations, when subjected to thermal, hygrometric actions and to loading [8].	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D, IP3D)
	Cohesion loss/disaggregation and crumbling of the render	Rendering becomes fragile and easily disaggregated, exposing aggregates and the substrate layer [7].	Related to the loss of bond between the rendering mortar components, followed by a considerable loss of the composing particles. Rainwater is involved in the loss of cohesion process by granular disintegration [7].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	-
	Biodeterioration / biological colonization	Presence of a generally thin layer, usually greenish or blackened, of biological origin over the surface [7].	Related to the water on the surface, the lack of solar radiation and specific temperatures [7].	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	-	(IP2D)
	Efflorescence / cryptofflorescence	Crystalline deposit that arises on the concrete surface as a white stain [7], and, in case of cryptofflorescence, possibly together with cracks and detachment of the render	It results from the circulation and superficial evaporation of an aqueous saline solution. The hydrostatic pressure promotes the migration of water, superficial evaporation and, then, deposition of salts on the surface [7].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	-
	Wear or detachment of the finishing layer of ETICS	-	Non-compatibility of materials	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	-
	Warpage, swelling, deformations and other flatness deficiencies in ETICS	-	Thermal stress	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	-
	Detachment of ETICS areas	-	Humidity between ETICS elements	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	-
	Mapped cracking	-	Shrinkage of the rendering mortar, which is restricted by the support (block or brick masonry) [8]	(IP2D) [CC]	-	-	(IP2D) [CC]	-	(IP2D, IP3D)
Paint	Colour change	-	Lack of solidity of the paint due to pigments not suitable for exterior, or due to insufficient resistance against the attack by the alkalinity of the base [9].	(IP2D) [CC]	-	-	(IP2D) [CC]	(IP2D)	(IP2D)
	Change of gloss	-	Lack of resistance of the binder [9].	(IP2D) [CC]	-	-	(IP2D) [CC]	(IP2D)	(IP2D)
	Staining -appearance of areas with or without gloss	-	Due to rendering areas with different absorption (variable porosity); and to the application of paints with high PVC (volumetric concentration of pigment) [9].	(IP2D) [CC]	-	-	(IP2D) [CC]	(IP2D)	(IP2D)
	Blistering	Generally, blistering results in wider blisters, similar to small craters [7].	It can occur when solvents, or other volatile substances, are imprisoned by the paint coat. It is a frequent defect in water-based paints given the chemical connections that are established while drying, sometimes imprisoning water in the organic matrix [7]. It can occur also due to poor preparation of the base, insufficient thickness, humidity and temperature high during application and drying [9].	(IP2D) [CC]	-	-	(IP2D) [CC]	(IP2D)	(IP2D, IP3D)
	Cracking	-	Deficiently formulated product, hard and brittle coating [9].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D, IP3D)
	Detachment	-	Lack of adhesion, humidity, efflorescence, poor preparation of the base [9].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D, IP3D)
	Pulverulence, arenization, erosion	-	Lack of binder, weather action [9].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D, IP3D)
	Saponification / softening – dissolution of the binder	-	Paint not resistant to alkalinity of the base [9].	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D)
	Dirt retention	-	It can occur in areas less exposed to rain (especially in textured paints) [9].	(IP2D)	(IP2D) [CC]	(IP2D) [CC]	(IP2D) [CC]	(IP2D)	(IP2D)

2.3.3 Anomalies in render/ETICS

In Table 2, anomalies associated with humidity in render/ETICS are briefly analysed (presence of moisture on the surface of or within the rendering), as well as the assessment of these anomalies characteristics through DIP. The main anomalies are: wear or detachment of the finishing layer of ETICS; warpage, swelling, deformations and other flatness deficiencies in ETICS; detachment of ETICS areas.

2.3.4 Anomalies in painting surfaces

In Table 2, anomalies associated with humidity in paintings are briefly analysed (presence of moisture on the surface of the facade or within the rendering), as well as the assessment of these anomalies characteristics through DIP.

2.3.5 Maintenance actions

The correct evaluation of the state of conservation of a building and its elements constitutes essential information for the planning maintenance phase of the interventions to be carried out later. The standard UNI 10604 [10] refers to the existence of two levels of building inspections, preliminary and detailed, and, in the latter, it is intended to deepen the framework obtained from the general inspection (qualitative information), for quantitative information, in order to identify the requirements necessary to define the type of solutions to the problems identified. Detailed inspections are planned to use non-destructive and destructive tests. The use of NDT techniques allows a more objective diagnosis of the conservation status of the building and allows to define the criticalities of the identified anomalies and the priorities, the budgeting, execution time and type of contracting for the execution of the repair work (using in-house or outsourcing).

Anomalies are usually classified according to their severity (minor, serious and critical), their intensity (low, medium or is under development and high) and extension (function of the percentage of affected element). Based on visual inspection, it is not always easy to carry out this classification, so the use of IRT, US and IP2D methods, alone or together, is most useful because they provide more accurate information about what is visually perceptible and precise information about features of the element that are not visible and which may be relevant to the classification of the anomaly and to the technical specifications of the work to be performed.

The loss of performance of a building and its elements over time is a normal process and it is necessary to carry out periodic inspection, cleaning, small-scale interventions, major interventions and replacement to maintain the design requirements. It is a good practice to inspect annually the exterior walls to check for dirt, biological colonization and localized patches and cracking or adhesion problems of the cement based renders. Also, a water jet cleaning or other suitable cleaning method to the painting system applied should be periodically carried out, as well as a repainting.

3. METHODOLOGY OF RECOGNITION OF THE PATTERNS OF ANOMALIES THROUGH IMAGE PROCESSING AND FEATURES EXTRACTION

3.1 General

DIP can develop as follows (Fig. 9), being three the main steps: i) photo acquisition, which should follow some basic rules (camera axis perpendicular to the surface, high overlap, good lightning); ii) processing the photos to create orthos; iii) apply DIP to detect and enhance the anomalies in the orthos. For example, detected cracks can be separated based on the width of the crack.
One of the limitations of the anomaly detection is the size of the pixel in the photos (which has direct influence in the size of the pixel in the orthos). Large pixels (i.e., individual pixels covering large areas) do not allow the detection of small or thin elements. For this is important to use high definition cameras and, when necessary, UAV to allow the acquisition of photos near the surfaces.

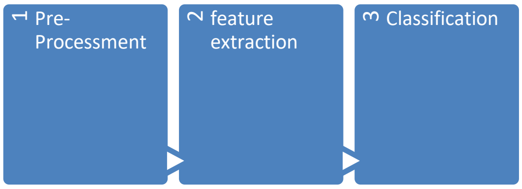


Figure 9. – Steps for a recognition system.

3.2 Experimental test

A test example of acquisition the images for photogrammetry and further recognition of the patterns of anomalies through DIP and features extraction (interest of extraction of a single mortar joint in each specimen - see details in Fig. 10) is described for two masonry specimens subjected to compression in a test machine: the test specimens were placed on a testing compression machine. In both specimens, each ortho was generated from two photographs taken by two digital cameras fixed on a horizontal bar (35 cm apart), attached to a tripod [3]. Information of the photos are described in Table 3.

Table 3. Characteristics of the photo surveys of two specimens

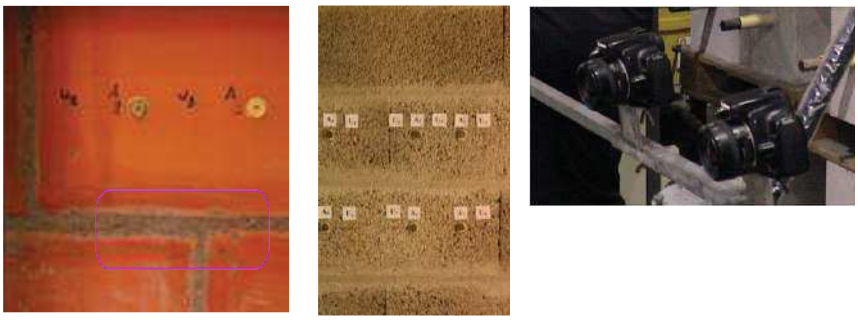
Specimen	Size of the pixel in the sensor	Size of the image	Distance to specimen	Size of the pixel in the specimen
A1	6.4 μm	8 Mpx	1.8 m	0.35 mm
A2	8.9 μm	4 Mpx	2.4 m	0.57 mm

3.3 Facade walls

A test example of acquisition the images for photogrammetry in two facade walls (called East and West) of a low building and further recognition of the patterns of anomalies through DIP and features extraction (interest of extraction of a single localized render crack and detachment zone – see detail in Fig. 11) is described. One camera was used, and it was made a terrestrial survey. Photogrammetry was used to generate orthos of each facade and a point cloud of the set [3]. Characteristics of the surveys are displayed in Table 4. It was applied DIP in the analysis of anomalies, for detection of cracking and detachment in the wall renders, and of cracks and repair zones in concrete elements.

Table 4. Characteristics of the photo survey of a facade

	Size of the pixel in the sensor	Size of the image	Distance to Facades	Size of the pixel in the facade
Terrestrial	6.1 μm	10 MPx	2.5 m: East 8 m: West	0.5 mm: East 2 mm: West



Specimen A1 *Specimen A2*

Figure 10. – Use of photogrammetry in the compression test of Specimen A1 and Specimen A2 [3] and [4].

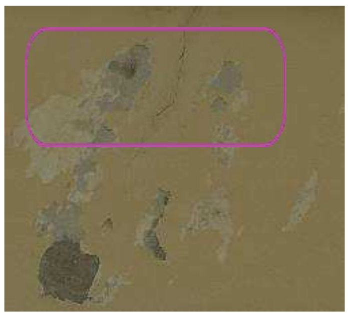


Figure 11. – Use of photogrammetry in North facade of a building [3]

4. CONCLUSIONS

This paper identified and typified the most common anomalies related with durability of materials and construction elements of heritage buildings with reinforced concrete structure. A methodology of recognition of the most relevant patterns of these anomalies has been briefly presented, in particular through image processing and features extraction of anomaly patterns in facade walls and on confinement elements of reinforced concrete. Such methodology is expected to be suitable for the purpose of subsequent use within the framework of support to the inspection actions and consequent maintenance of this type of heritage buildings. The loss of performance of a heritage building and its elements over time is a normal process and it is necessary to carry out periodic inspection, cleaning, small-scale interventions, major interventions and replacement to maintain the design requirements.

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