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Patch Restoration Method: A new concept for concrete heritage

Jónatas Miguel de Almeida Valença *, Cláudia Andreia Fernandes Pereira de Almeida, Judite Lucinda Miranda Botas, Eduardo Nuno Brito Santos Júlio

CEris, DECivil, Instituto Superior Técnico, Universidade de Lisboa, Avenida Rovisco Pais, 1, 1049-001 Lisboa, Portugal

HIGHLIGHTS

- Patch Restoration Method (PRM), a method to support restoration on concrete heritage.
- A non-contact and easy to implement restoration approach using image processing.
- PRM validation using mortar specimens subjected to accelerated aging tests.
- PRM covers the entire intervention process, from inspection to monitoring.

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ABSTRACT

Concrete has been used to build some of the most outstanding constructions since the last Century. Some of these are definitely part of the World's heritage. In order to preserve this legacy, interventions must be performed according to very strict restoration requirements. However, when referring to concrete, there is an almost generalised lack of concern in this subject.

Thus, a method specifically designed for concrete heritage, called 'Patch Restoration Method' (PRM), was developed. PRM aims to encompass the whole process, from assessment to intervention, and have been developed to ensure the match between the repairing mortars and the concrete substrate, taking into account the effect of aging.

After the proof of concept, PRM was applied in an exceptional example of concrete heritage: the headquarters of Fundação Calouste Gulbenkian, in Lisbon, Portugal. Results obtained are presented and discussed, and conclusions are drawn. Finally, the tentative guidelines for the PRM are proposed.

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1. Introduction

Presently, the need for conservation of the built heritage is recognised worldwide. Since the second half of the XXth Century, concrete is the most used construction material. It was adopted to build some of the most outstanding constructions. Some of these, due to their architectural, historical and/or cultural relevance, are an important part of the World's heritage. In order to preserve this legacy, conservation and restoration operations have to be applied, using conservation methods for concrete structures but, simultaneously, taking into account intervention principles [1–3], settled for the built heritage.

The definition of a strategy for conservation of concrete structures, with minimum maintenance interventions during their lifetime, implies a continuous evaluation of their state of conservation. In this scope, monitoring material deterioration is one of the most important aspects to reach that goal. Some of the most frequent anomalies in reinforced/prestressed concrete structures are due to concrete carbonation and/or chloride penetration, leading to corrosion of steel reinforcing bars (rebars) and/or prestressing strands. Periodic visual inspections are common in large concrete infrastructures and, whenever a problem is identified, usually non-destructive tests, eventually complemented with laboratorial tests, are undertaken to make a clear diagnosis and prescribe an adequate repairing operation. Several methods are available as well as detailed standards. When local cracking due to rebar corrosion is detected, the 'Patch Repair Method' is usually applied [4]. This method consists in removing all deteriorated concrete from the detected (small) areas, cleansing rebars using a steel brush, applying an anti-corrosion painting on these, and replacing the void by a repairing mortar. However, the Patch Repair Method cannot be used straight forward in concrete heritage since, besides durability, material compatibility and structural perfor-

* Corresponding author.
E-mail addresses: jonatas.valenca@tecnico.ulisboa.pt (J.M. de Almeida Valença), claudiacafpa@hotmail.com (C.A.F.P. de Almeida), jmiranda@ipt.pt (J.L.M. Botas), eduardo.julio@tecnico.ulisboa.pt (E.N.B.S. Júlio).

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mance, it is also important to ensure both colour and texture matching between the original concrete and the repairing mortar [5–7].

In the last decades, new technologies have been applied to both structural and material assessment and, consequently, some of these are being increasingly used in the built heritage context. In concrete heritage, infrared thermography, ground penetrating radar, ultrasonic testing, and fibre optics microscopy are some examples of these new methods [8]. Regarding innovative vision systems, in spite of their high potential for structures evaluation [9,10] they are not yet close to experience a widespread use.

In this paper, a new method, herein called 'Patch Restoration Method' (PRM), is presented. It aims at fulfilling the aesthetics requirements, in terms of colour and texture matching in addition to all other requirements of the widespread Patch Repairing Method, based on innovative vision methods developed by the authors. Furthermore, PRM aims at covering the whole process, from the material assessment to the restoration operation and it includes the following steps:

(i) Evaluation of colour and texture in the neighbourhood of the damaged area, using digital image processing (DIP). Additionally, the roughness of the surface can be evaluated by analysing its texture using the 2D-LRA method [11];
(ii) Design and application of a customised repairing mortar with specific colour and texture requirements to match the substrate. It has to be highlighted that the effect of aging is also taken into account in this step, being the colour of the mortar adjusted in laboratory using DIP to match the colour of the concrete substrate for a time horizon where the former is expected to be stabilized (accelerated aging tests are supposed to be performed to settle this parameter); and
(iii) Monitoring the patch restoration operation, also using DIP procedures. The quantification of colour and texture parameters after the restoration operation provides information that allows defining more detailed procedures to be implemented in the future to ensure a perfect match between the restoration mortar and the concrete substrate.

In the following sections, PRM is presented in detail. First, in Section 2, DIP procedures are listed, as well as the restoration mortar requirements. Then, in Section 3, a study conducted with mortar specimens designed and tested in laboratory to calibrate and validate the method is described. Next, in Section 4, an example of concrete heritage – the buildings of Fundação Calouste Gulbenkian (FCG) in Lisbon, Portugal – is considered as case study to test PRM on site. Finally, in Section 5, tentative guidelines are provided aiming at standardising the application of PRM.

2. The Patch Restoration Method

2.1. Digital image processing

PRM is supported by DIP and comprises the following steps:

1. Image acquisition. The method can be applied using only the visible spectrum or including the infrared band. In the latter case, more detailed information about colour distribution can be achieved;
2. Identification of areas of intervention. In this step, a method previously developed by the authors, 'SurfCrete' – multispectral image analysis of concrete surfaces [10], can be applied to detect anomalies on concrete surfaces, e.g., cracking, delamination, detachment, crushing, among others, as well as previous interventions, inadequate in terms of restoration;
3. Characterisation of the concrete substrate. In this step, DIP is applied to define the colour and texture parameters of the surface. Other methods, such as the 2D-LRA method [11], previously developed by the authors, can also be applied to as complementary methods to assess the substrate surface roughness. This information is used to define the restoration mortar;
4. Assessment of damages and identification of environmental aggressive agents involved, aiming at defining the most adequate accelerated aging test;
5. Design and application of a customised restoration mortar, with specific colour and texture requirements to match the substrate;
6. Correction of the mortar mix, in terms of mechanical characteristics, compatibility with the concrete substrate, workability and consistency, but also taking into account its colour and the predicted changings of the latter with time;
7. Monitoring of the restoration intervention. Periodic surveys need to be performed to measure changes experienced by the restoration mortar with time. At this stage, it is mandatory acquiring all images under identical exposure and brightness conditions.

2.2. Restoration mortar requirements

Besides all the requirements of a standard repairing mortar, in terms of strengthening, durability, compatibility with the concrete substrate, and workability in fresh state to ensure the best application procedure, it is also necessary to adjust the colour and the texture of the restoration mortar to best match these parameters of the concrete substrate.

With respect to the mixture design of the restoration mortar, it should include whenever possible most constituents adopted in the original construction material, the substrate concrete. This will make it easy to ensure durability and to match the colour of the latter. Whenever, for some reason, this is not possible or feasible, a white commercial repairing mortar can be used and colour matching can be obtained by adding a small dosage of black pigment, calibrated by DIP, taking into account colour changes due to aging. Regarding texture, the ideal solution is to build a mould that reproduces the texture of the substrate. It must be stressed out that texture influences the human eye perception of the colour of a given concrete substrate.

3. Laboratorial study to calibrate and validate PRM

An experimental study was conducted to calibrate and validate PRM, namely, to study the viability of DIP to assess the colour of concrete surfaces and to qualitatively evaluate the influence of the surface texture on human eye perception of the colour of the latter.

3.1. Materials

The laboratorial tests were performed on prismatic mortar specimens with $100 \times 100 \times 20$ mm^3, considering different colours and textures. All specimens were produced with a white commercial repairing mortar, adopting five different percentages of black pigment: 0.0%, 0.1%, 0.2%, 0.3% and 0.4%. The specimens were cast using different moulds, aiming at inducing four texture types: (Rp) regular pattern; (Sp) spatterdash; (W) wood texture, and (S) smooth texture (Fig. 1).

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