Assessment of real aging in selection process of replacement materials for stone monuments conservation.

Nicolas Concha-lozano[1] Dominique Lafon[2] Olivier Eterradossi[2] Pierre Gaudon[1]

[1] Centre des Matériaux de Grande Diffusion (CMGD). Ecole des Mines d'Alès, Alès, France
[2] Lab. Propriétés Psycho-Sensorielles des Matériaux (2PSM). Ecole des Mines d'Alès, Pau, France

Resumen:

En el ámbito de la sustitución de piedras en los monumentos, frecuentemente se plantea el problema de la selección de las piedras de reemplazo. De hecho, la reconstrucción debe ser estéticamente duradera, es decir, la piedra sustituida debe envejecer como la piedra original. Este estudio presenta una cadena de procesamiento de imágenes, desde la adquisición hasta la visualización, que permite comparar imágenes de piedras en varias etapas de su envejecimiento: recién extraída de la cantera, envejecida en edificios antiguos, y decapada con arena en monumentos recién restaurados. Esta herramienta incluye: (1) una calibración de cámara digital, (2) una transformación de adaptación cromática y (3) una etapa de redimensión. Para testear el método propuesto, un estudio de caso se llevó a cabo para evaluar la compatibilidad de tres tipos de caliza. Esta herramienta gráfica puede ayudar la selección de materiales de reemplazo con envejecimiento complejo como la piedra natural.

Palabras Clave: *COMPATIBILIDAD, PIEDRA, CALIBRACIÓN, COLOR, PATRIMONIO*

Abstract:

Reconstruction of monuments often raises the question of stones replacement. It must be aesthetically durable, which means the stone must age like the original one. This study presents an image processing chain, from capture to visualisation, to compare stones at different states of aging: recently extracted from quarry, weathered on old buildings, and cleaned on monuments recently restored. This tool includes: (1) a digital still camera calibration, (2) a chromatic adaptation transform and (3) a resizing process. To test it, a case study was conducted to assess the compatibility of three types of limestone. This graphical tool helps the selection of replacement materials by visual comparison between several possible stones in order to select them by aging properties and visual resemblance.

Key words: *COMPATIBILITY, STONE, CALIBRATION, COLOUR, CULTURAL HERITAGE*

1. INTRODUCTION

Monuments and other historical buildings built of stone deteriorate over time. When the level of stone decay threatens the survival of the monument, the deteriorated parts of the masonry need to be replaced with new stones. It is common that the quarry that provided the original stones is unknown or no longer in use, thus, the question of stone selection for replacement is raised.

Deterioration changes the appearance of stone, and may cause aesthetic incompatibility. To ensure a long-lasting restoration, stone replacement should remain consistent over time, even during the early stages of deterioration. Limestones develop a patina composed by biological colonization and soluble species which could precipitate inside the stone porosity. Whereas biological colonisation can be cleaned by conventional methods such as sandblasting, hydro blasting or laser, precipitates forms thick indurate layer on the surface that cannot be removed easily.

An effective evaluation of compatibility for stone replacement requires a comparison stage that consists in observing the replacement stones in various states of aging with the same lighting conditions. It is also necessary to evaluate the effect of shooting distance in the visual perception of stone texture with respect to the original stone wall [CHORRO 2007].

Current selection methods rarely consider long term appearance change. It is mainly due to a lack of representative samples at various stages of deterioration. Furthermore, it is difficult to evaluate in-situ the lighting and observation distance effect: these are crucial in the visual perception of high specular reflective stones or multi-scale textures. A portable image acquisition of colorimetrically calibrated image would create an image collection of the same stone in different stages of aging e.g. new, old, or cleaned. Calibrated image coupled with a Color Adaptation Transform (CAT) can display images as if they were seen under the same lighting.

Deterioration of stones has already been monitored by photographs based on a relative greyscale calibration [THORNBUSH 2003, 2008]. In the same purpose, this study uses an alternative method of image comparison based on an absolute calibration in XYZ tristimulus space.

This study presents an image processing chain, from capture to viewing, including: (1) a known in-situ colour measurement method based on calibrated Digital Still Camera (DSC), (2) a Chromatic Adaptations Transform (CAT), (3) and an algorithm to simulate the observation distance based on CIE XYZ tristimuli mixture. To evaluate the relevance of this graphical tool, measurements were made on three limestone historically used for construction and restoration of monuments in the region of Languedoc-Roussillon in southern France.

2. MATERIALS AND METHODS

1.1. In-situ measurements

The DSC that is used for this study is a CANON® D7 in raw mode with 60mm fixe focal lens, shutter speed and f-number. Photographs were taken under a slightly overcast sky for a diffuse illumination that avoids specular reflections. For each shot, a white reference is fixed on the stone surface (fig. 4).

For each type of stone, three locations were chosen to find an unaltered surface, a weathered surface and a surface cleaned by sandblasting on old monuments recently restored (tab. 1).

1.2. DSC Calibration

To use the DSC as an in-situ measuring tool for the comparison of stones visual appearance in various lighting conditions, it is first necessary to calibrate and to transform RGB components according to the lighting reference. The calibration allows converting DSC sensor response in physical values (XYZ cd.m^2). The CAT provides simulated images as if they were seen in the same lighting condition.

TABLE 1, LOCATION OF PHOTOGRAPHS DEPENDING ON THE TYPE OF STONE AND AGING CONDITIONS

	In quarry	weathered	sanded
Barutel (micritic)	Quarry, Nimes	Old quarry, Nimes	Maison carrée, Nimes
Pompignan (sparitic)	Quarry, Pompignan	Pompignan's church	Anduze's Temple
Lens (oolitic)	Quarry, Moulezan	St Perpetue church, Nimes	Maison carrée, Nimes

Calibration of the DSC uses a spectrophotometer (Photo Research® PR650 in CIEXYZ 1931 2° mode with spectral resolution of 8 nm between 380 à 780 nm) and a GretagMacbeth® color chart.

An image of the color chart is taken with the DSC, and simultaneously the radiance spectrum of the 24 squares of the colors chart is measured with the SPR. In order to obtain diffuse natural day lighting, the scene is illuminated by indirect sun radiation under a slightly cloudy weather [THORBUSH 2003].

A linear transform model is used to fit 12 parameters of $M_{3\times4}$ matrix [LEON 2006].

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \end{bmatrix} . \begin{bmatrix} R \\ G \\ B \\ 1 \end{bmatrix} \quad (1)$$

Where {R, G, B} is the raw response of the camera and {X, Y, Z} the CIEXYZ 1931 tristimulus.

In this study the solution is computed using direct least squares based linear regression method of the over determined system of equations with MATLAB (2008a, The MathWorks) software.

2.3. Chromatic adaptations transform (CAT)

The XYZ tristimulus is converted to LMS space by $\mathbf{M}_{\mathbf{CAT02}}$ linear transform used the CIECAM02 model [FAIRCHILD 2000]:

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = M_{CAT02} . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{bmatrix} . \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (2)$$

Then a Von Kries–Ives CAT is applied on the LMS data. This colour transform is based on independent gain adaptation of each retinal cone [BRILL 1995]. Each color component is then multiplied by the ratio between LMS components of a reference white $\{L_{wr}, M_{wr}, S_{wr}\}$ and the reference used for the photograph $\{L_w, M_w, S_w\}$.

$$\begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} = \begin{bmatrix} \frac{L_{wr}}{L_w} & \frac{M_{wr}}{M_w} & \frac{S_{wr}}{S_w} \end{bmatrix} . \begin{bmatrix} L \\ M \\ S \end{bmatrix} \quad (3)$$

Equation (2) is reversed to obtain the image in corrected {X_c, Y_c, Z_c} components:

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = M_{CAT02}^{-1} . \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \quad (4)$$

The conversion to standard sRGB space for standard monitor display [STOKES 1996] is given by:

$$\begin{bmatrix} R_l \\ G_l \\ B_l \end{bmatrix} = \begin{bmatrix} 3.2410 & -1.5374 & -0.4986 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.0556 & -0.2040 & 1.0570 \end{bmatrix} . \frac{1}{K} . I \begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} \quad (5)$$

With K the normalization factor taken equal to Y_{WR} and I the unit matrix. The conversion between linear and standard is made according to following condition:

$$As = \begin{cases} 12{,}92\ A_l & if\ A_l \leq 0.0031308 \\ (1+0.055)A_l^{\frac{1}{2.4}} - 0.055 & if\ A_l > 0.0031308 \end{cases}$$

(6)

Where Al and As are respectively the $\{R_l, G_l, B_l\}$ and $\{R_s, G_s, B_s\}$ components.

Four images of a reference limestone where taken under different natural illumination in order to estimate the CAT error. The error estimation used is ΔE CIELab distance.

2.4. Resize method

If two images have different shooting distances, a scale factor f can be calculated:

$$f = R / R_f \qquad (7)$$

Where R and R_r are respectively the spatial resolution of stone image and of a distance reference in [pixel.m^{-1}]. Each image is resized by XYZ tristimulus average of f×f pixels. Resizing using XYZ space is perceptually justified as apposed to decimation or interpolation in RGB space [CHORRO, 2007]. For non-integer values of f, the average is performed on pixels portions.

3. RESULTS AND DISCUSSION

The correlation coefficients obtained with the linear calibration model are close to 1 for each of the three components (fig. 2). However it is possible to achieve better performances using a quadratic model or neural networks [LEON 2006].

Images of the same limestone surface with and without CAT correction are show in figure 1. The corrected images should have a difference of color (ΔE) around zero. Here the maximum color difference is 2.50 ΔE. This value is higher than the theoretical color discrimination threshold (that is equal to 1) but the visual difference between these images seen on screen is hardly noticeable.

The images of the Barutel, Lens and Pompignan stone are shown in Figure 3. At the freshy extracted state, Barutel and Pompignan stone are visually closer. Nevertheless in sandblasted state Barutel stone is closer to the Lens stone. The radical change in appearance of the Barutel stone requires profound alteration that is retained after cleaning. This "memory effect" makes the stone a complex aging material. Indeed, Barutel and Lens stones develop a thick indurate layer at the surface that allows long-term homogenization of visual aspect. Weathered state images are more difficult to interpret because a single image is not representative of the diversity of alteration type observed on these stones.

In the same way comparison can be achieved between a replacement stone and a building that needs to be restored. In the following example (fig. 4), the image of sandblasted Barutel stone surface has been scaled by taking the R_F (equ. 7) and white reference of the frontage image (equ. 3). This virtual replacement allows estimating the compatibility of a textured surface in its future environment.

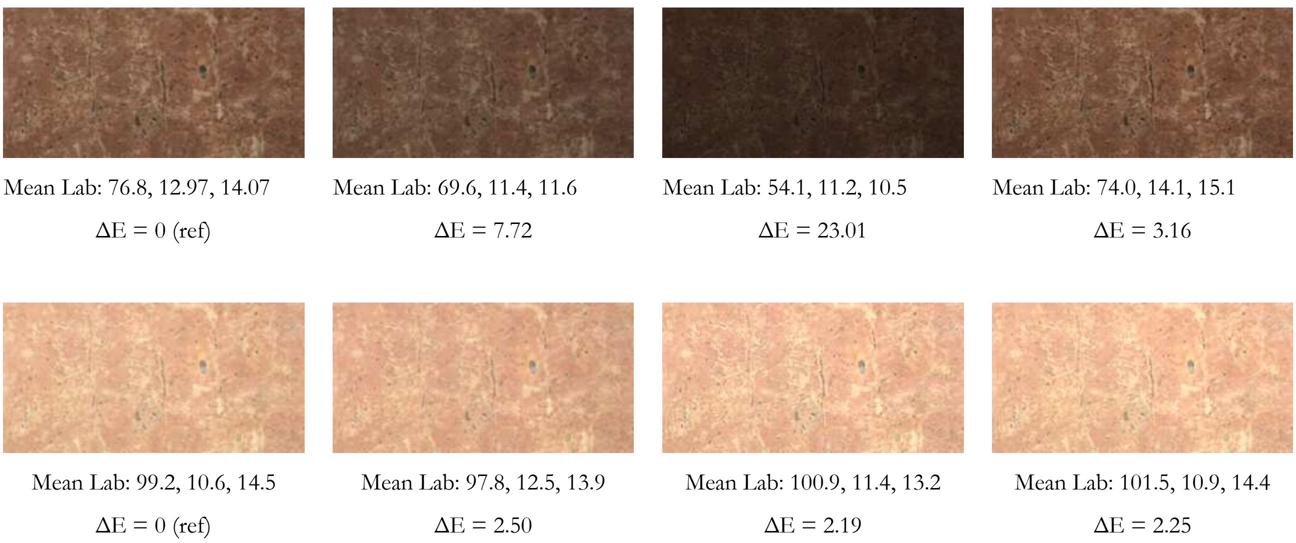

Figure 1, Above images without cat, below images with cat correction

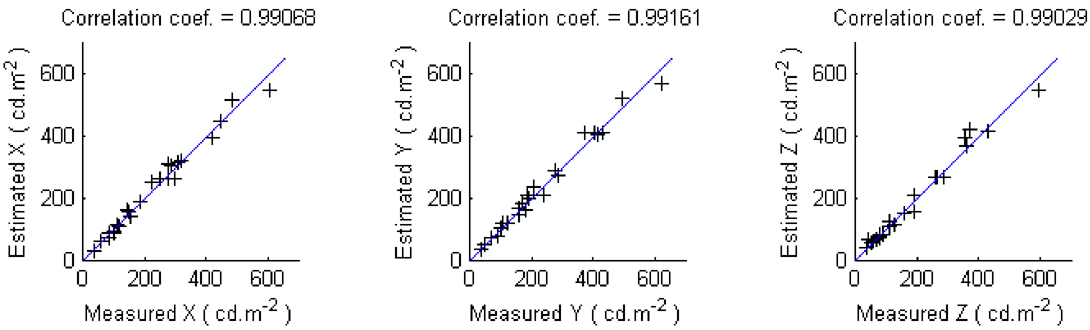

Figure 2, Measured and estimated tristimuli values by the linear calibration model.

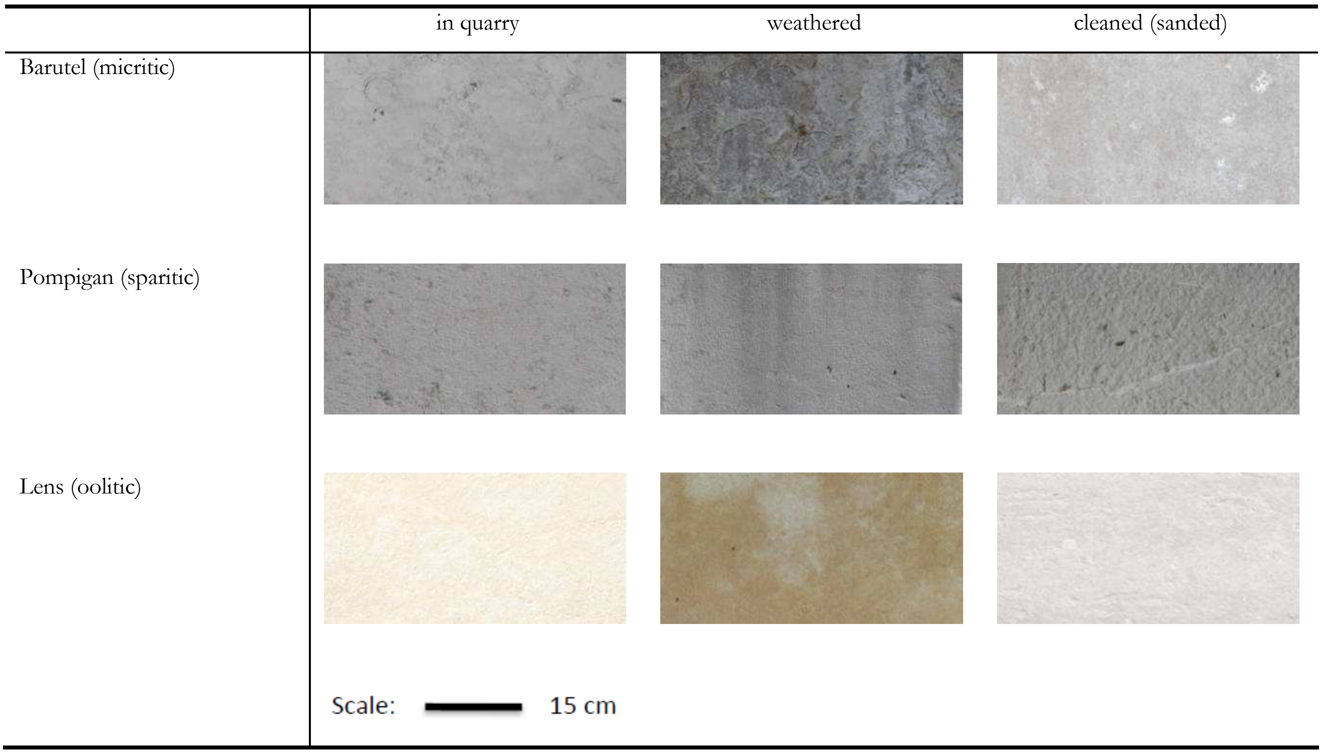

Figure 3, Visual comparison of stones in different aging states after size and cat correction

Figure 4, Example of virtual stone substitution

4. CONCLUSION

This capture method has been tested in order to compare stones surfaces at different aging states. A simple linear calibration allows to convert raw sensor response to CIE 1931 XYZ component with a coefficient correlation higher than 0.99. Then a Von Kries colour adaptation transform correct lighting differences with an estimated error lower than 2.5ΔE.

Comparison between recently extracted from quarry and old sanded stones reveal the "memory effect" of Barutel and Lens stones.

Adapted resizing allows virtual replacement to be displayed on a computer screen.

This graphical tool helps selection of replacement materials by visual comparison between several possible stones, in order to choose one as aging complex as the original. Also, this tool could build a database that would improve the research time for matching stones, thus simplifying the work of restorer

ACKNOWLEDGMENT

I wish to thank J.S. Bidoret and R. Cres for their instrumental and technical support and P.E. Le-Marec and M. Lazaro for their editorial support.

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