LIGHTS ON

cultural heritage and museums!

Paula Menino Homem [Ed.]

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LIGHTS ON…

CULTURAL HERITAGE AND MUSEUMS!

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INTRODUCTORY *NOTULA*

Paula Menino Homem[1]

Facing serious times of change, museums and other cultural institutions, discuss and reflect, in a deeply and interdisciplinary way, about their role in resilience, sustainability and quality of life of the XXI century society.

The XXI century is seen as the Century of Light, as light and light-based technologies are recognized as major economic drivers with the potential to revolutionize it. In that sense, UNESCO proclaimed 2015 the International Year of Light (IYL2015), also noting "that 2015 coincides with the anniversaries of a series of important milestones in the history of the science of light, including the works on optics by Ibn Al-Haytham in 1015, the notion of light as a wave proposed by Fresnel in 1815, the electromagnetic theory of light propagation proposed by Maxwell in 1865, Einstein's theory of the photoelectric effect in 1905 and of the embedding of light in cosmology through general relativity in 1915, the discovery of the cosmic microwave background by Penzias and Wilson and Kao's achievements concerning the transmission of light in fibres for optical communication, both in 1965" (United Nations, A/RES/68/221, 2014).

Such revolution happens and has significant impact on cultural heritage and museums. Aware of the process, we joined the international initiatives on the IYL2015 and organized the International Congress **Lights On… Cultural Heritage and Museums!**

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(https://lightsonchm.wordpress.com/), held in Porto, Portugal, on July 20th, 21st and 22nd 2015.

The congress adopted the concept of light in its broader meaning, that is, not only the form of energy associated with the visible portion of the electromagnetic spectrum, but also all other invisible radiation such as X-rays, ultraviolet, infrared, among many. It aimed to raise and enhance awareness for its potential and crucial role in cultural heritage and in inclusive museums.

Assuming a multi and interdisciplinary character, it strengthened the cooperation bonds between professional, scientific and educational communities and generations. It provided a platform for sharing experiences and knowledge about important scientific and technological advances in the field, featuring Thematic Sessions, with Invited Speakers and Oral Presentations, Poster Session and Workshops. The official language was English and the focus was on the following topics:

1. Science of vision. The perception of colour as a function of illumination
2. Lighting systems in museums / historical buildings / monuments. Requirements and scientific and technological developments
3. Built environment. Solutions. Energy resources and sustainability
4. Study and safeguard of heritage associated with the production of energy and electric lighting
5. Scientific examination of heritage and analytical applications using different radiation. Research on i. Materials, technologies, functions and producers

ii. Alteration processes and diagnosis

6. Technologies of communication and mediation

7. Curative conservation and restoration

8. Integrated risk management. Preventive conservation

We are pleased to share with you a selection of the contributions, hoping the reading may be fluid and pleasant and the thoughts and information useful.

SCIENCE OF VISION. THE PERCEPTION OF COLOUR AS A FUNCTION OF ILLUMINATION

Bernardo, L.M. (2016), Physical principles on the illumination of displayed museum objects. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.4-17

PHYSICAL PRINCIPLES ON THE ILLUMINATION OF DISPLAYED MUSEUM OBJECTS

Luís Miguel Bernardo[1]

ABSTRACT

The illumination of displayed museum objects must fulfil basic requirements such as the established conservation rules, aesthetic values and the visitors' viewing expectations. Therefore, choosing the right intensity and spectral colours of those objects' illumination is a very demanding task to curators, light designers and engineers. For a correct decision, the basic principles of white light composition, the light interaction with the materials, the measurement of the intensity and colours, and the human visual perception must necessarily be considered.

The spectral analysis and synthesis of white light are particularly relevant to understand the objects' physical colours. The use of a particular spectral composition may be constrained by the object conservation restrictions and the public aesthetic and visual expectations and therefore alternative choices must be considered to overcome those possible incompatibilities.

Radiometric and colorimetric measurements must be made to characterize the illumination conditions and establish the best set-up. The physical observation conditions must be evaluated through the knowledge of the reflection, transmittance, absorption and scattering phenomena, affecting colours and intensities. Finally, the physiological effects of a particular illumination on the human vision have to be evaluated through the principles of photometry and human vision physiology.

KEYWORDS Lighting; Illumination; Colour; Radiometry; Photometry

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1. Introduction

For the illumination of displayed museum objects, we must take in consideration the requirements and constrains associated to the object and the observer. Lighting with a suitable light spectral composition and correct levels of illuminance must satisfy the object preservation limits and fulfil objective and subjective viewing conditions, such as colour rendering (fidelity) and the observer's comfort.

To preserve the object integrity, the illumination must have a spectral composition not to induce photochemical reactions, photo-degradation, colour fading, degradation, or heating which may cause the expansion, cracking and detachment of the object materials.

The concept of colour temperature (CT) is used to spectrally characterize incandescent lamps, since their spectra throughout the visible region can be very closely approximate to that of a blackbody. Blackbody or Planckian locus is the line path, in the CIE chromaticity diagram, that represents the colour of a blackbody at different temperatures. Therefore, the colour temperature of an incandescent lamp can be read on that line (FIG. 1). For other lamps producing white light that don't have chromaticity coordinates that fall exactly on the Planckian locus but lie near it, the correlated colour temperature (CCT) must be used instead to characterize their temperatures.

The CCT of a light source, expressed in Kelvins (K), is therefore defined as the temperature of a blackbody, which is closest to the chromaticity of that source. It is an essential measuring parameter in the general lighting to specify the perceived colour of an artificial non-incandescent lamp.

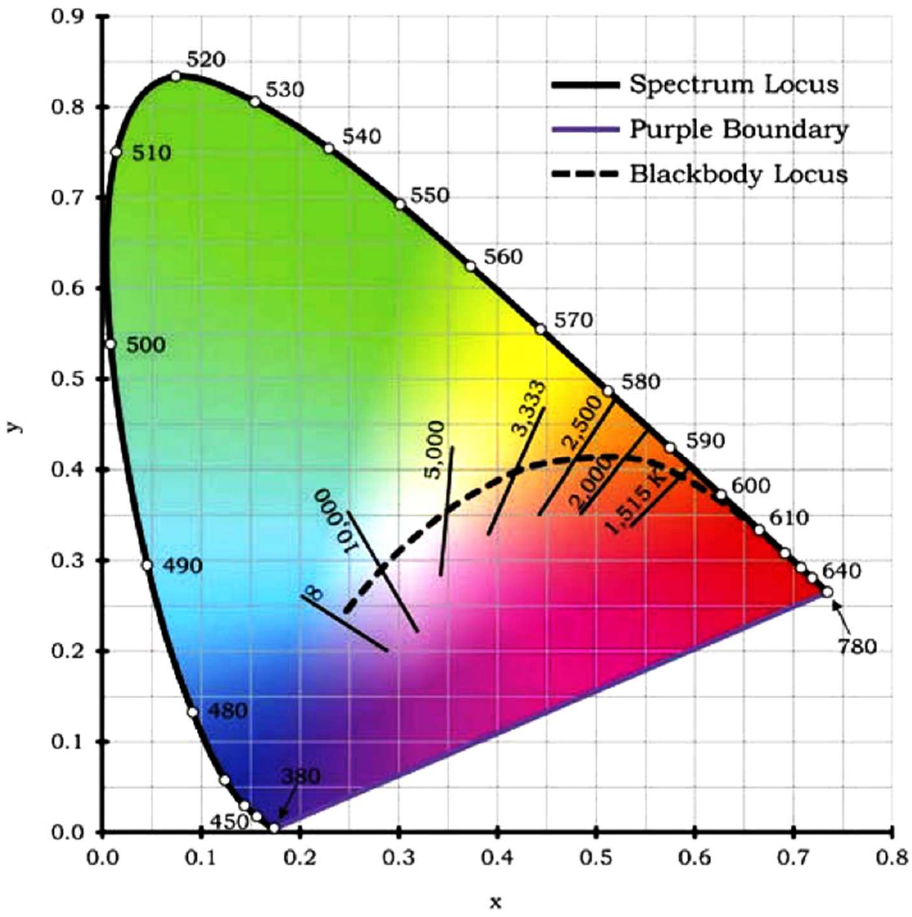

FIG. 1 - Planckian or black body locus: curve in the CIE 1931 diagram covering colour temperatures from 1515K up to infinite. The temperature straight lines are the locus of CCT. Their interceptions with the black body curve are the colour temperatures (Houser et al., 2016).

By international conventions regulated by the CIE (Commission Internationale de l'Éclairage), the illuminants are defined as ideal light sources with specific spectra, providing a basis for comparing images and colours under different lighting. Real light sources try to approach those standards (Malacara, 2011, pp.33-35). By conscious or subconscious comparison, the colour appearance of an object illuminated with a particular lamp may be different of that illuminated with a reference illuminant. The colour-rendering index (CRI) is a quantitative measure of the ability of a light source to reveal faithfully the colours of various objects, in comparison with an ideal or natural light source (Houser et al., 2016). The method of measuring and specifying colour-rendering properties of light sources is established by the CIE norm 13.3-1995, under specific protocol and well-defined parameters (Schanda, 2007). The CIE has specified a series of colour-rendering groups of light sources. In museums and art galleries, it is recommended that all lamps should be within group 1A, which is restricted to CRI values not less than 90 in a scale range from 0 to 100. It must be noted, however, that a high CRI does not imply necessarily a good colour rendition, since the reference source itself may have an imbalance colour. On the other hand, LED systems usually have a CRI rather low, regardless of showing a good colour appearance and a pleasant visual appeal. In face of this, some proposals are being published to establish in future a better colour-rendering criterion (Wendy et. al., 2005; Malacara, 2011, p.38).

The deteriorating effects of light on the material objects depend on the quality and amount of the light energy, measured by the spectral composition and the levels of illumination and exposure. The amount of heating due to light absorption increases with illuminance and exposure and therefore their values should be sufficiently low, without compromising the minimum viewing conditions. As a general approach and reference, the following parameters are used: correlated colour temperature, $3000 \leq CCT \leq 3500K$; wavelength, $420 < \lambda < 750$ nm; illuminance, $50 < E_v < 200$ lux; exposure accumulated during a year $15000 < E_v t < 150000$ lux.h. The use of flash photography by the museum visitors should therefore be restricted according to the responsiveness of the exhibited materials, but it should be noted that its effect is cumulative.

At the observer's point of view, a good illumination must have the potential to show all the visual attributes of the object. Therefore, the illumination must create the conditions for the most accurate viewing, discriminating detail and colour and providing bright and clear impressions of the object. These requirements can be evaluated by a *discrimination factor*. Other observer's subjective conditions, as pleasure, attractiveness, preference and stimulation, can be assessed by a *quality evaluation factor* (Cutte, 2007, p.29).

Some incompatibility may arise from opposing requirements concerning the object and the observer. If this is the case, a decision must be taken to favour the object conservation. For example, the level of illuminance needed for object preservation and the best viewing conditions at vision photopic regime (luminance > 3 cd/m^2, exitance >10 lm/m^2) can be inconsistent. Lower lighting may lead the observer to mesopic (luminance 0.001 to 3 cd/m^2, exitance 0.003 to 10 lm/m^2) or even scotopic (luminance < 0.001 cd/m^2, exitance < 0.003 lm/m^2) viewing regimes. Those regimes correspond to different physiological visual conditions and sensations. The cones are operative in photopic regime allowing suitable colour vision; both rods and cones are operative in mesopic regime; and only the rods, that are nor sensitive to colours, operate in the scotopic regime. The observer´s adaptation from photopic to scotopic regimes may take about ten minutes, which can be very inconvenient if the observer moves between displays illuminated at different lighting levels.

2. The basics of radiometry and photometry

Radiometry deals with the physical quantities associated with light energy. All radiometric quantities are qualified as *radiant*. For example, the radiant flux Φ_e is defined as the time rate of flow of radiant energy of a source.

On the other hand, photometry deals with the visual sensation or brightness caused by the light energy on the eye (Williams et al., 1972, pp.23-47). The respective quantities are qualified as *luminous*. For example, the luminous flux Φ_v is the light power of a source as perceived by the human eye.

The relation between radiant flux and the luminous flux for photopic vision is given by $\Phi_v = V(\lambda)\,\Phi_e$, where $V(\lambda)$ is the luminous efficacy curve for photopic vision. From this relationship, we may easily calculate that the amount of 1 W of radiant flux corresponds to 683 lm of luminous flux, at $\nu_0 = 540 \times 10^{12}\mathrm{Hz}$ or $\lambda_0 = \frac{30}{54}\,\mu\mathrm{m} = 555{,}55\ \mathrm{nm}$ where $V(\lambda)$ has its maximum. In the case of scotopic vision regime, it should be used the luminous efficacy curve $V'(\lambda)$, with its maximum at 505 nm.

Both $V(\lambda)$ and $V'(\lambda)$ are defined in a norm of the CIE. These functions, available in graphical or numerical formats, measure the ability of a light source to produce a visual response from its radiant power in photopic ($V(\lambda)$) and scotopic ($V'(\lambda)$) vision regimes. From those curves, we may conclude that the brightness of a light source depends on its radiant power but also on its spectral composition. For instance, at the wavelength of the helium-neon laser (λ = 632,8 nm) the sensitivity of the eye is only 23.5% of what it is at the peak, leading to 160 lm/W. The green Nd:Yag lasers (λ = 532 nm) present a 88.5% sensitivity, or 604 lm/W. A blackbody at the temperature of the Sun (5800 K) results in a luminous efficacy of 93 lm/W.

TABLE I presents the most important quantities, units and formulas used in radiometry and photometry. While illuminance indicates the level of brightness of light incident at a surface, the exitance indicates the level of brightness leaving a surface. It should be noted that the lux unit is used only for incident light. Exitance is the product of the illuminance and the object reflectance and is expressed in lumens per square meter (lm/m^2); it represents a measure of surface density of reflected light that is available to the observer.

Radiometry		
Quantity name	**Symbol** (unit)	**Formula**
Radiant energy	Q_e (J)	
Radiant energy density	W_e (J/m^3)	$W_e = dQ_e/dV$
Radiant flux/power	Φ_e (W)	$\Phi_e = dQ_e/dt$
Radiant emittance/exitance	M_e (W/m^2)	$M_e = d\Phi_e/dA$
Irradiance	E_e (W/m^2)	$E_e = dQ_e/dA$
Radiant intensity	I_e (W/sr)	$I_e = d\Phi_e/d\omega$
Radiance	L_e (W/sr m^2)	$L_e = dI_e/dA\ cos\theta$

Photometry		
Quantity name	**Symbol** (unit)	**Formula**
Luminous energy	Q_v (lm.s)	
Luminous energy density	W_v (lm.s/m^3)	$W_v = dQ_v/dV$
Luminous flux	Φ_v (lm)	$\Phi_v = dQ_v/dt$
Luminous emittance/exitance	M_v (lm/m^2)	$M_v = d\Phi_v/dA$
Illuminance	E_v (lm/m^2 or lux)	$E_v = dQ_v/dA$
Luminous intensity	I_v (lm/sr or cd)	$I_v = d\Phi_v/d\omega$
Luminance	L_v (cd/m^2)	$L_v = dI_v/dA\ cos\theta$

TABLE I - Most important quantities, units and formulas used in radiometry and photometry.

The basic photometric units are *candela*, *lumen* and *lux*. The *candela*, the unit of luminous intensity, is defined as *the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.* The *lumen*, the unit of luminous flux, is *the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian*. The *lux*, the unit of illuminance, equals one lumen per square meter. The levels of natural illumination vary by several orders of magnitude. Full moon clear sky corresponds to 1 lux; direct sunlight light corresponds to 100 000 lux.

3. Light sources — spectral composition and performance

Since Newton's time, it is known that white light is composed of different colours, the so-called white light spectrum (FIG. 2). A higher resolution image would indicate the presence of black spectral lines that correspond to the absorption of specific wavelengths by chemical elements in the solar and terrestrial atmospheres.

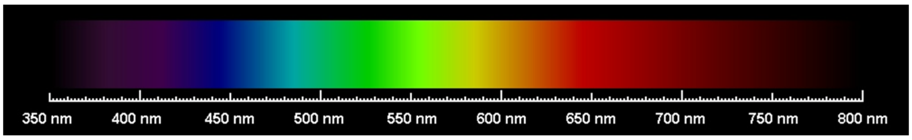

FIG. 2 - Solar spectrum.

The colour perception of a light source depends on its light spectrum and the colour-perception characteristics of the observer (Malacara, 2011). Well-defined colours correspond to a specific spectral bandwidth as indicated in TABLE II.

Colour	**Wavelength interval** (nm)	**Frequency interval** (THz)
Violet	~ 430 to 380	~ 700 to 790
Blue	~ 500 to 430	~ 600 to 700
Cyan	~ 520 to 500	~ 580 to 600
Green	~ 565 to 520	~ 530 to 580
Yellow	~ 590 to 565	~ 510 to 530
Orange	~ 625 to 590	~ 480 to 510
Red	~ 740 to 625	~ 405 to 480

TABLE II - Well-defined colours and its correspondence to specific spectral bandwidth.

Different types of light sources, characterized by different spectra, have been used in museum lighting. Incandescent lamps were the preference but nowadays their use is declining and other types are taken the lead. They have the advantage of excellent colour- rendering and a wide range of colour temperatures. However, they show some disadvantages: lifetime is around 1-2000 hours, efficiency is only around 4-5% and IR spectral content is very high.

White light can be synthesized by light of different colours and therefore can be produced by light sources or lamps of different types including those with discontinuous spectra with well-defined bands, large and narrow, such as those of gas discharge and fluorescence lamps or LEDs (Malacara, 2011, pp.55-157). The colour-rendering index of these lamps is however smaller compared with continuous spectrum lamps. The low-pressure sodium lamp emitting at $\lambda = 589$ nm has CRI=0 and therefore it is not appropriate for colour reproduction.

The colour constancy indicates the human visual system is insensitive to some variation on the whiteness of the light. Somehow the human visual system knows the spectrum of the light source and it takes that into account when determining the chromatic reflectance properties of a surface. Metameric lights have different spectra although they look of same colour. If they illuminate coloured objects, the colours will look different. In these cases, characterized by low CRI, trial and critical observation is the only way to be sure that the colour reproduction is satisfactory.

LED lamps are becoming a reference lamp for many applications including museum lighting. The spectral flexibility and the consequent variability in colour temperature and colour rendering of these lamps are advantages in addition to their high energy-efficiency (85%) and sustainability. Compared with classical tungsten incandescent lamps, the modern LED lamps can be 10-15 times more efficient in energy consumption, and their lifetime can be 30-40 times longer. Nowadays, there are two main processes for generating white light with LEDs: phosphor conversion (PC) and colour mixing with three or more bands. Compared with a tungsten lamp, the LED mixtures are capable of providing not only high efficacies but also very satisfactory colour rendering, as already proved by experience in many museums wide world.

4. Basic phenomena of light interaction with materials

Light interacts with matter at microscopic or macroscopic levels. This interaction is manifested in different macroscopic phenomena: chromatic selective absorption and reflection, chromatic selective transmission, interference and diffraction, between others.

Some incident photons are absorbed by the molecules, but others may undergo multiple reflections before emerging from the surface. Some photons of different energies will be reflected from the first layers before being absorbed and show therefore the wide spectrum of the illumination light (specular reflection); others emerge after reaching deep layers without being absorbed and show their respective colours (diffuse reflection). Selective absorption/reflection explains the colour of common objects such as paintings. Only part of the spectrum of the illuminating white light will be reflected. For example, a red portion of an object absorbs all the spectral components of the incident white light except the red one, which is reflected and then enters the observer's eye.

Selective transmission is a phenomenon observed with colour filters, which are sometimes used to control the incident light spectrum by eliminating or reducing specific bands. Interference is the phenomenon that separates the colours of white light illuminating a soap ball, and diffraction splits the white light incident on colour hologram, for example.

Light interaction with materials may cause the appearance of permanent marks in the objects, such as colour degradation, a well-understood physical phenomenon occurring in organic and inorganic materials, which is caused, particularly, by UV radiation. Structure degradation, deformation, cracking, detachment may also arise in the illuminated objects due mainly to IR light. Degradation of museum objects must be prevented by any means and therefore some limits have to be imposed to the illumination category and lighting level. Choosing the safe illumination and the right levels, according to the exhibition conditions, is essential for the protection of the objects and the viewing quality. TABLE III summarizes the principal factors relating to the ambient and display lighting systems in the exhibition spaces, according to the material responsiveness (Cutte, 2007, p.268).

TABLE III - Principal factors relating to the ambient and display lighting systems in the exhibition spaces, according to the material responsiveness (Cutte, 2007, p.268).

Material responsiveness	Non responsive	Slightly responsive	Moderately responsive	Highly responsive
Lighting category	Uncontrolled daylight	Controlled daylight	Restricted exposure	Minimal exposure
Daylight admission	Yes		No	
Sunlight admission	Yes	No		
Illuminance limit (lux)	No limit	200	50	
Exposure limit (lux h/y)	No limit	600 000	150 000	15 000
Colour rendering Index (CRI)	CRI≥85			
Correlated colour temperature (CCT)	2900K<CCT<4200K			
UV control	No	Yes		
IR control	No		Yes	

The 50 lux limit results from both the minimum required value of exitance for photopic vision (10 lm/m^2) and the reflectance value of a mid-grey surface that is typically equal to 0.2, meaning that 80% of incident light is absorbed. Dividing 10 lm/m^2 by 0.2 we get 50 lux. This is the illuminance value that is widely recommended as the maximum level for displaying moderately and highly light-responsive museum objects. Below this value, visual discrimination ability is likely to suffer if the object surfaces have a mid-grey appearance. The 50 lux standard should really be qualified as being "50 lux of incandescent illumination;" 50 lux of any other light sources can have a completely different potential damage profile. For each case a solution must be studied according to the specific conditions of the object and the illumination. Values of illuminance up to 200 lux increase significantly visual discrimination but above this value that increasing is less significant. For non-responsive or slightly responsive materials, 200 lux is in general an appropriate value for the illuminance of a mid-grey surface.

The ultraviolet control is particularly important for light-responsive materials independently of the level of their response. The radiation of wavelength less than 400 nm should be completely eliminated in a museum. The same should happen to the IR radiation for moderately and highly responsive materials.

Researchers in Berlin have exposed a range of moderately responsive museum materials under controlled conditions, and have monitored resulting colour changes over time. They got the so-called "Berlin function" which represents the relative damage potential as wavelength changes. This function is a monotonic exponential-type decreasing curve with unitary value at 300 nm and negligible values after 750 nm (FIG. 3).

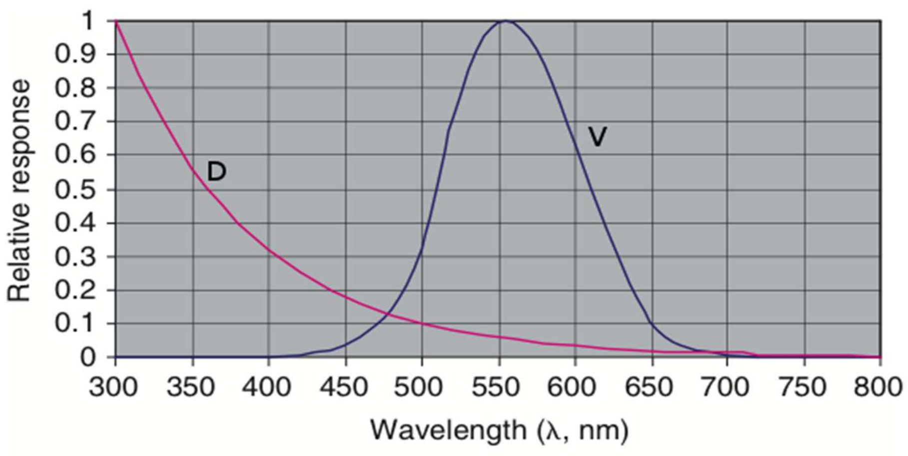

FIG. 3 - The "Berlin function" D compared with the luminous efficacy curve for photopic vision V (Cutte, 2007, p.42).

Comparing it with the luminous efficacy curves we conclude the relative damage response of materials is very different from the human relative visual response. This means that illuminance is not a reliable indicator of exposure rate. The CIE established the international norm CIE 157 2004 for the control of damage to museum objects by optical radiation.

5. Final remarks

For the appropriate lighting of museum objects several aspects must be taken into consideration: the luminous and chromatic characteristics of the light sources; the specific interaction between light and objects; the physical and optical characteristics of the objects; the human visual sensitivity; the limitations imposed by the objects conservation requirements. The chosen solution must not compromise the integrity of the exhibited object even if the appropriate viewing conditions are not completely satisfied. In the most incompatible situations it is always possible to reproduce the objects through photography or 3-D printing, combined with other technologies, and exhibit a model. In the presence of a realistic model, the observer can appreciate the visual characteristics of the original object and thank for the care that is taken to preserve a valuable piece.

Due to degrading effects caused by light in moderately or highly responsive materials of the displayed objects, an especial protection against UV radiation should be taken throughout museum spaces. The readily observed physical effects of light exposure, as the loss of colour and strength will then be minimized. IR radiation, temperature and humidity should also be controlled. Cracking, breaking down of glued joints in wooden objects, and separation of varnishes or painting from substrates will be minimized therefore.

References

Cutte, C. (2007), *Light for Art's Sake: Lighting for Artworks and Museum Displays*, Elsevier, p.29.

Davis, W., Ohno, Y. (2005), Toward an improved colour rendering metric, in *Proceedings of SPIE*, Vol. 5941, ed. Ian T. Ferguson, John C. Carrano, Tsunemasa Taguchi, Ian E. Ashdown, *Fifth International Conference on Solid State Lighting*, pp.59411G-(1-8).

Houser, K., Mossman, M., Smet, K., Whitehead, L. (2016), Tutorial: Color Rendering and Its Applications in Lighting, *LEUKOS*, Vol. 12, pp.7–26.

Malacara, D. (2011), *Color Vision and Colorimetry: Theory and Applications*, 2.nd Ed., Washington: SPIE Press.

Schanda, J. (2007), Color Rendering of Light Sources, in Schanda J. (ed.), *Colorimetry: Understanding the CIE System*, Wiley-Interscience, pp.207-217.

Williams, C.S, Becklund, O.A. (1972), *Optics: A Short Course for Engineers & Scientists*, New York: Wiley-Interscience.

Fiolhais, C. (2016), Physics and biology of colour and vision. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.18-33

PHYSICS AND BIOLOGY OF COLOUR AND VISION

Carlos Fiolhais[1]

ABSTRACT The essential notions of the physics and biology colours are presented, starting with the rainbow, a phenomenon studied by Newton. Colours are properties associated to the larger or smaller deviation of light caused by a glass prism which correspond to different light wavelengths. The white light emitted by the sun includes all colours, while a laser light is monochromatic. There is invisible light of various types, i.e., light which do not correspond to colours: their wavelengths are smaller than that of the violet and larger than that of the red. In view of our evolutionary history in a planet near the Sun, a star which mainly emits visible light, we see only this kind of light. Our identification of colours takes place in the retina in three kinds of receptors called cones, associated with the capture of red, green and blue light. Primates see, in general, in a way similar to humans, but there is a range of animal species whose vision is not trichromatic: This range goes from monochromatic whales to the extreme multichromatism, due to 16 types of cones, of stomatopods, which are marine crustaceans. As the genes encode the cones of each species, one current area of research is the disentanglement of the genetic history which enabled vision enhancement in some animals and not in others. Darwin's theory is at work: the adaptation to the environment was instrumental in the process that led to the development of vision in animals.

KEYWORDS Colour; Light; Vision; Eye; Evolution

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1. Introduction

We see everywhere colours in Nature, whether on Earth or in the sky, not only the seven colours traditionally attributed to the rainbow but also all nuances between them. We also see colours in artificial objects, for example the paintings painted by great artists which we admire in museums. Only an extremely rare defect prevents some people from seeing colours, limiting them to see the world in black and white.

From the point of view of physics, the colour is associated to the wavelength of light (or, equivalently, to the frequency). Since the time of the English physicist Isaac Newton (1642 or 1643 according the calendar, Julian or Gregorian - 1726 or 1727, *idem*), which created, with the help of a glass prism, a rainbow in his room, we know that white light, in particular sunlight, is a mixture of various coloured lights (FIG. 1).

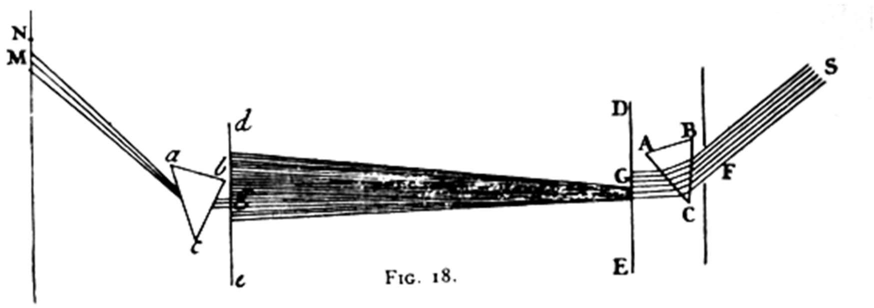

FIG. 1 - Newton's experiment with two prisms as presented by himself in his book *Opticks* (1704).

In an experiment performed by the great sage in 1665 or 1666, the sunlight coming from a window entered a prism and, within the glass, the rainbow colours appeared, while the beam suffered deflection. At the exit of the prism a similar deflection took place, widening the colour splitting. When he focused only red light, conveniently isolated from the light with other colours, in a second prism the red beam entered the new prism and was deflected by it, but remained red. The explanation could only be that the white light was composed of light of all colours, which only emerge isolated within the glass. Newton conceived a corpuscular theory of light, according to which the different colours would correspond to different particles of light, but in the nineteenth century the wave theory of light took the lead since it was able to explain the phenomena of diffraction and interference in contrast with the Newtonian theory. The overlapping of waves of different wavelengths had to obey the general principle of wave superposition. In particular, two waves can completely cancel each other. In 1865, 150 years before the International Year of Light, the Scottish physicist James Clerk Maxwell (1831-1879) realized that light waves were electromagnetic waves, i.e., the propagation in space of a periodic perturbation of the electrical and magnetic fields, the two intimately associated. There was a complete light spectrum to be discovered (FIG. 2).

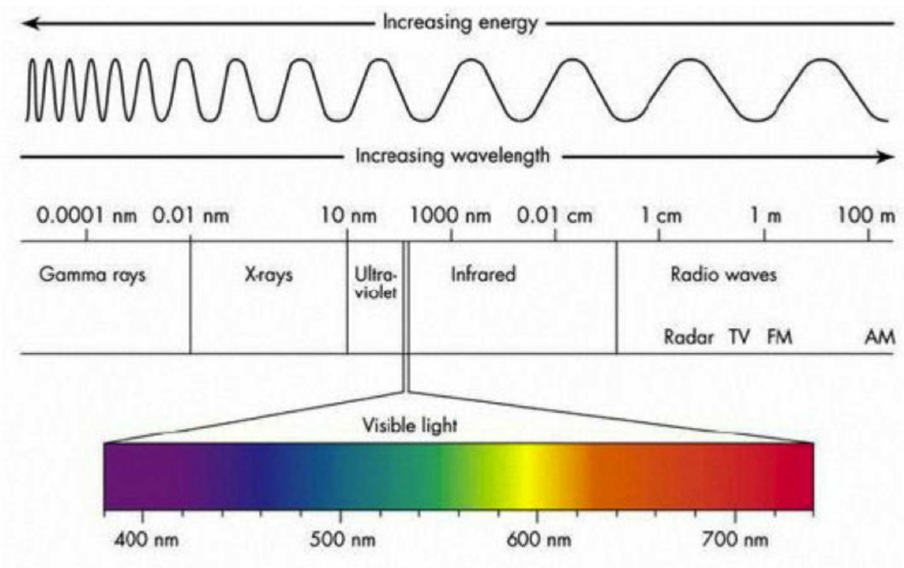

FIG. 2 - Light spectrum, with a zoom of the visible zone.

http://sdhydroponics.com/2012/06/13/par-the-light-spectrum/

Light may be visible or invisible as our eyes see it or not. The visible part corresponds to a range of wavelengths between 3900 and 7000 angströms (between 390 and 700 nanometers, being the nanometer a subunit of the International System, defined as a millionth of a millionth of a millimeter), which is a small part of the total spectrum of light (light with all possible wavelengths). Before Maxwell, infrared waves and ultraviolet waves were already known. Infrared light was the first kind of invisible light to be discovered, and its first observer was the Anglo-German astronomer and physicist William Herschel (1738-1822), who, in 1800, with the aid of a prism and a thermometer, made an experiment similar to that done by Newton in which he detected radiation with wavelengths somewhat greater than those of red light: he called it "calorific rays", since the thermometer showed in the infrared area of the spectrum an higher temperature than in its surroundings (FIG. 3).

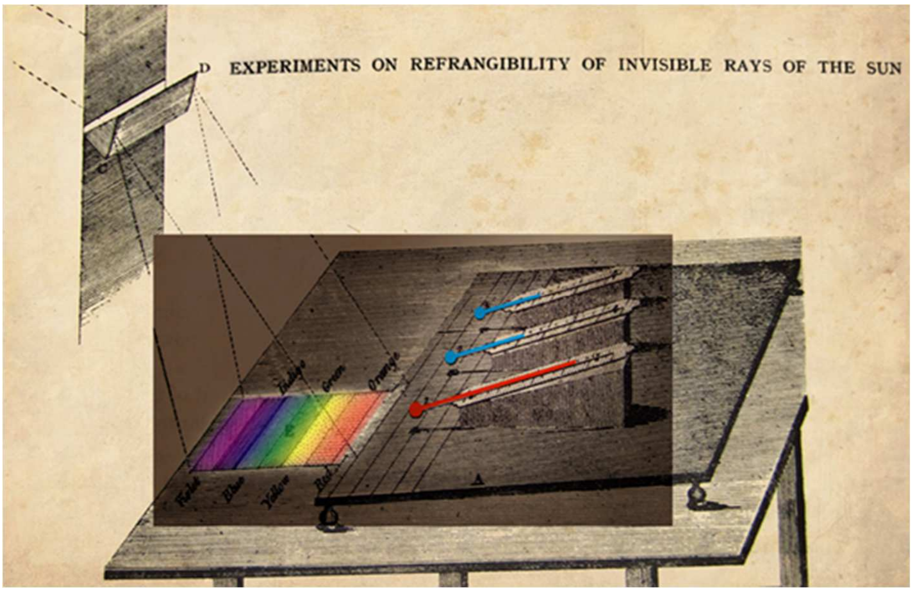

FIG. 3 - Herschel's experiment which led to the detection of infrared light (1800), based on the original Herschel's picture.

http://elte.prompt.hu/sites/default/files/tananyagok/InfraredAstronomy/ch01.html

Ultraviolet radiation was found one year later by the German physicist and chemist Johann Wilhelm Ritter (1776-1810), who noticed the darkening of silver chloride placed in the zone beyond the violet, where the light had wavelengths somewhat smaller than those of violet light: he called it "oxidizing rays" to emphasize its chemical reactivity properties. As the wavelength is a number which varies continuously, we infer that there is light of all wavelengths, that is, of all colours, in between red and violet: an infinite number of wavelengths were possible. After Maxwell, other invisible radiations were discovered such as, on the side of red, radio waves and microwaves (in 1886, by the German physicist Rudolf Heinrich Hertz, 1857-1894), and on the side of the violet, X-rays (in 1895, by the German physicist Wilhelm Conrad Roentgen, 1845-1923) and gamma rays (in 1900, by the French physicist Paul Ulrich Villard, 1860-1934).

We may say that the nineteenth century was the century of invisible radiation: it started with the discovery of infrared and ultraviolet radiations and ended up with the finding of gamma radiation, at the beginning of the nuclear age. We learned in the twentieth century, with the development of atomic and nuclear physics, that most radiations come from electronic transitions in atoms, molecules and solids, but that gamma radiation comes necessarily from atomic nuclei. In the same century, the processes of capturing light emitted by stars was refined: their light had been observed in the range of the visible, using the so-called optical telescopes, but they also came be seen from the Earth also with invisible light, either infrared (infrared telescopes) or microwave or radio waves (radio telescopes). Ultraviolet rays, X-rays and gamma rays' telescopes have to be placed on satellites in Earth's orbit since the atmosphere blocks light with wavelengths lower than those of violet. These types of light, called ionizing radiation, are harmful to life (if the atmosphere did not exist, life would not exist on Earth, at least in the form we know it, based on the genetic code that resides in the DNA).

Our eyes are blind to light with wavelengths which are not in the visible part of the spectrum, from red to violet. There is little variation in the human species in the ability to capture visible light. It is curious that, in a dark environment, we rapidly adapt our eyes to see a little more in the red side. We cannot see ultraviolet light, since the eyeball is made in a way not to allow the passage of this more energetic and therefore more dangerous radiation. Moreover, the Earth's atmosphere protects us from the ultraviolet rays of the sun through the ozone layer while it blocks completely X- and gamma rays. Situations of abnormal vision occur in patients who have undergone cataract surgery. A case which is often mentioned in this context is that of the French impressionist painter Claude Monet (1840-1926), who had a surgery of this type in 1923, and went on to paint with somewhat different colours, especially with more vivid blues. Probably he acquired a limited ultraviolet vision.

The sun emits light of all wavelengths but, having a temperature of 6000 kelvins at its surface, has a sharp peak in the middle of the visible light, but there are stars which emit mainly in the infrared or the ultraviolet (FIG. 4).

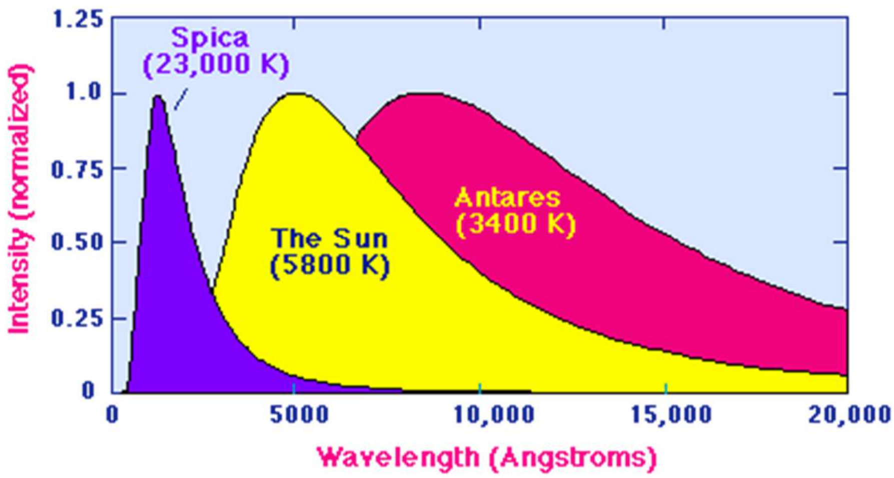

FIG. 4 - Intensity of emitted light (normalized to one for all stars) versus wavelength.

http://csep10.phys.utk.edu/astr162/lect/stars/cindex.html

The sunlight is white due to the mixing of all colours. Clearly we have adapted us along the slow path of biological evolution to better capture the light that our star emits the most. If we would live in the neighbourhood of a star which mainly emitted infrared light, most likely our eyes would be like infrared cameras, which are able to see in complete darkness. From the Earth, we do not see the sun as a white disk, since the atmosphere captures a part of the light falling on it, but the astronauts in orbit in the International Space Station see the sun as a disc with a very intense whiteness.

We prefer white light to work and a white light lamp mimics, although imperfectly, sunlight: filament lamps have already been replaced in lighting by compact fluorescent lamps and these are now being replaced by LED lamps, which are not only more efficient but also more durable. Today we have lasers, with plenty of applications, which emit light, either visible or invisible, with a well-defined wavelength (the first lasers were using microwaves; we have now infrared, ultraviolet and X-ray, but not yet gamma rays lasers).

2. Human vision

In the environment of our planet, our eyes adjusted very slowly along the path of biological evolution, in order to distinguish colours. The eyes are no more than natural cameras (FIG. 5): in the eyeball, there is a lens (just behind the pupil, protected by the cornea) and a photographic film (the retina, the inner membrane of the eye, in which an inverted image is formed).

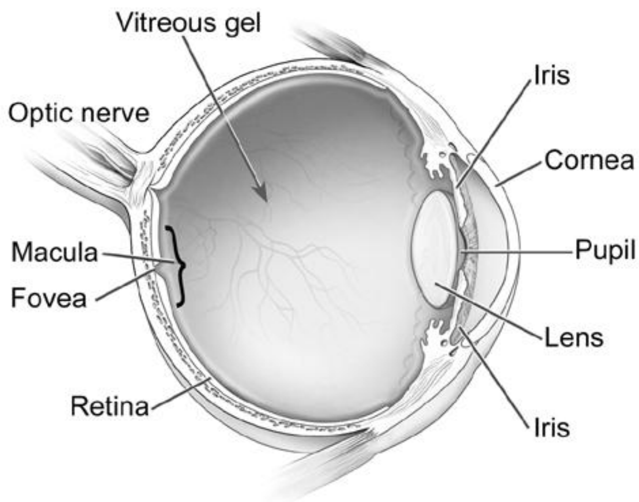

FIG. 5 - Scheme of the human eye.

http://www.familyconnect.org/info/after-the-diagnosis/working-with-medical-professionals/the-human-eye/135

Responsible for our colour perception are cells, located in the retina, of two types: rods and cones. These are photoreceptors or sensors that convert the light that enters the eye into a tiny electrical current, which is conducted by the optic nerve to the brain, which eventually decodes the transmitted signal. The cones, six million in each eye, are of three types. Each type captures better each one of the three basic colours - red (called L. for long, centred in 559 nanometers), green (M, for medium, centred in 531 nanometers), and blue (S, for short, centred in 419 nanometers) - with which all the others can be made (FIG. 6).

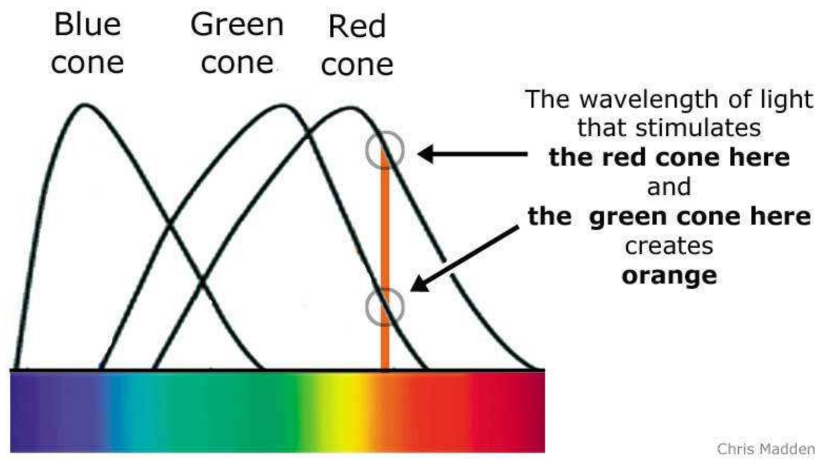

FIG. 6 - Sensibility of the three cones in the human eye to colour.

https://weirderthanyouthink.wordpress.com/2013/02/09/colour-vision-and-the-colours-of-the-rainbow/

Moreover, the rods, centred in the green, are able to capture much less intense light: they are the sensors which provide night vision. As, unlike the cones, rods, in far greater number than the cones (there are about 120 million!), can be located in the retina periphery, they are great aids for peripheral vision. People say that “all cats are grey in the night” since in the dark we can only see with the help of rods, which do not allow a large chromatic discrimination.

In our two eyes, there are therefore about 250 million sensors (the sum of the number of cones with the number of rods in both eyes). This value corresponds to 250 megapixels, a resolution far superior than that of a modern digital camera, which has, if it is of good quality, only about 18 megapixels. To top it off, our view has natural mechanisms to interpolate between pixels, similar to those that some cameras use based on man-made algorithms.

The colour blindness of some people is due to number reduction or operation deficiency of cones. Colour-blind people cannot distinguish some colours, especially green and red. With the blue, there are, as a rule, no problems. Colour blindness affects about eight percent of men (some of them are not aware of their defect although there are simple diagnostic tests, which consist of patterns made up by circles with different colours), but only 0.4 percent of women. It is an incurable genetic defect associated with the X-chromosome, a chromosome which arises alone in males (XY) but matched in females (XX). There are various types of colour blindness, since the cones can be affected in their number or in their operation in different ways. The genetic origin of colour blindness was unknown in the nineteenth century, when the English chemist, physicist and meteorologist John Dalton (1766-1844), a forerunner of atomic theory, studied the abnormality which he detected in himself. In modern times, it was possible to do a genetic test of Dalton's cells which confirmed, beyond any doubt, his colour blindness, even clarifying its precise type.

The extreme vision defect consists of complete blindness to the variety of colours: this disease is called achromatopsia. It happens when the cones do not exist or do not work. People having that defect, who are called monochromats (basically they see greyscale), only see typically with their rods (FIG. 7). They are no more than 0.003 percent of the population (one in 30,000 people). The neuroscientist, medical doctor and English writer Oliver Sacks (1933-2015), in his book *The Island of the Colourblind,* wrote about this type of vision defect, referring to the case of an atoll in Polynesia, where five per cent of the population is affected. Although very uncommon in humans, there are atypical monochromats, who only see with a given kind of cones. Moreover, one of the three types of cones (red, green and blue) may be lacking or failing: people affected by this defect are said dichromats.

FIG. 7 - Simulation of achromatopsia in comparison with normal vision.

http://psych.ucalgary.ca/PACE/VA-Lab/Brian/acquired.htm

The colours, whose perception arises in the brain, result from three factors: the light source, the object which reflects or diffuses some of the received light (the occurrence of reflection or diffusion depends on the regularity of the object surface; usually both phenomena coexist with the prevalence of one of them), and our eyes, which perceive the colours.

A modern visitor of a museum perceives colours of a painting which are different from that which were seen by its author or to its first observers who had other types of lighting. And, as people do not see exactly in the same way, each painting provides a different aesthetic experience to every observer. Not only the perception of colour is different in the retina, but there are also different brain processing mechanisms. When, going through the optic nerve, the electrical signal containing information about the received light reaches the brain, the emergent sensation of colour is necessarily subjective. Very interesting cases of kinesthesia, i.e., sensations junction, are known, for example the appearance of sound sensations driven by visual stimuli. The French poet Arthur Rimbaud (1854-1891) spoke in verse of the colours of vowels: "*A black, E white, I red, green U, Blue, vowels, / I shall tell, one day, of your mysterious origins.*" ("Vowels" sonnet, 1871). Regardless of the pathologies, which are always curious, the fact is that our perception of colour has an eminently cultural side, as we have always associated colours to facts and feelings. That is to say, colours have cultural histories.

3. Animal vision

The other animals see colours like ourselves, as can be easily checked by simple tests, but in a different way: in general, they do not have our three types of cones which allow people without defects to see about a million colours. In fact, only a restricted number of animals have a vision similar to the human one: the most obvious group is formed by some primates, who are like us trichromatic. But not all primates are trichromatic. Evolution led to separate developments: many New World monkeys have only dichromatic vision, because they followed a different evolutionary path. Kangaroos and bees also have trichromatic vision, although the case of bees is very particular, since they do not see red, as we do, but instead ultraviolet, getting to locate the sun, even on a day of thick fog. Ultraviolet vision is not exclusive of bees, belonging to other insects and to other orders (goldfishes, for example, can see ultraviolet).

The overwhelming majority of mammals, which are not primates, have dichromatic vision: they are colourblind, being unable to distinguish between red and green. And there are mammals with monochromatic vision such as some marine mammals: this is the case of whales, living in the open sea and therefore not requiring a good sense of colour. But many animals have more types of cones than humans: several species of reptiles, amphibians, fish, birds and insects possess higher colour recognition ability than humans: their vision is tetrachromatic. Some insects - such as certain species of butterflies - and some birds – such as probably pigeons - are even pentachromatic, having five types of cones. The world is, for them, far more colourful than it is for us: one pentachromatic species may, at least in principle, distinguish ten thousand million colours.

The most extreme case of colour vision ability in the animal world is that of the stomatopods or mantis shrimp (called "lacraias do mar" in Brazil), which are marine crustaceans that capture in a very efficient way their prey (shrimps, crabs, small fishes, etc.) thanks to their very keen sense of sight (FIG. 8). They have 16 types of cones, 12 types sensitive to light and four types that filter light allowing them to detect polarized light (i.e., light with a well-defined plane of vibration of the electromagnetic field). These animals can see ultraviolet, but it is unclear whether they can see infrared (such as some snakes, which have night vision).

FIG. 8 - A stomatopod (or mantis shrimp): *Ontodactylus scyllarus.*

4. Evolutionary history

The evolutionary mechanisms to achieve a better view of some colours have, in general, to the improvement of food capturing. A good view of the red was very helpful to our prehistoric ancestors to catch some fruits that have that colour, whereas, for the bees, which do not see it, it was more useful to see ultraviolet vision in pollinating flowers (there are not many red flowers). As for the bees, ultraviolet vision is also very useful to some birds.

Birds are, among all animals, those who have more visual capacity, both in discerning shapes and colours. One talks of "eagle eye": this is four to eight times more capable than the human eye. The extraordinary sight of eagles has to do not only with the variety of cones (the degree of chromaticism), but also to the number of rods and cones (the number of megapixels) and, of course, with the size and sophistication of the other optical components of the eye, since a good photography results not only from the sensors but also from the lenses and control devices. An eagle or a hawk are birds of prey: they can see a mouse in a meadow when they are flying over a kilometre high, since the size of their eyeballs is huge for the size of their bodies and since they have good systems to focus along the flight. "Lynx eye" is, in some languages, somewhat equivalent to "eagle eye". Indeed, lynxes are animals with highly developed visual ability, although that expression may have more to do with the supernatural vision capability attributed to the lynx in Greek mythology (this mythological aspect explains the name *Accademia dei Lincei*, the very first science academy, of which the Italian physicist Galileo Galilei, 1564-1642, was a member). Both in the air and on land, the vision has evolved in the animal world over millions of years so that each species could more easily find its food and, besides that, see their prey without being seen by their potential predators, thus ensuring their survival. The colour vision in animals, particularly in birds, also plays an important role in sexual selection.

The evolutionary history that led to the colour vision in the animal world is extraordinary, still containing many riddles to be solved (FIG. 9).

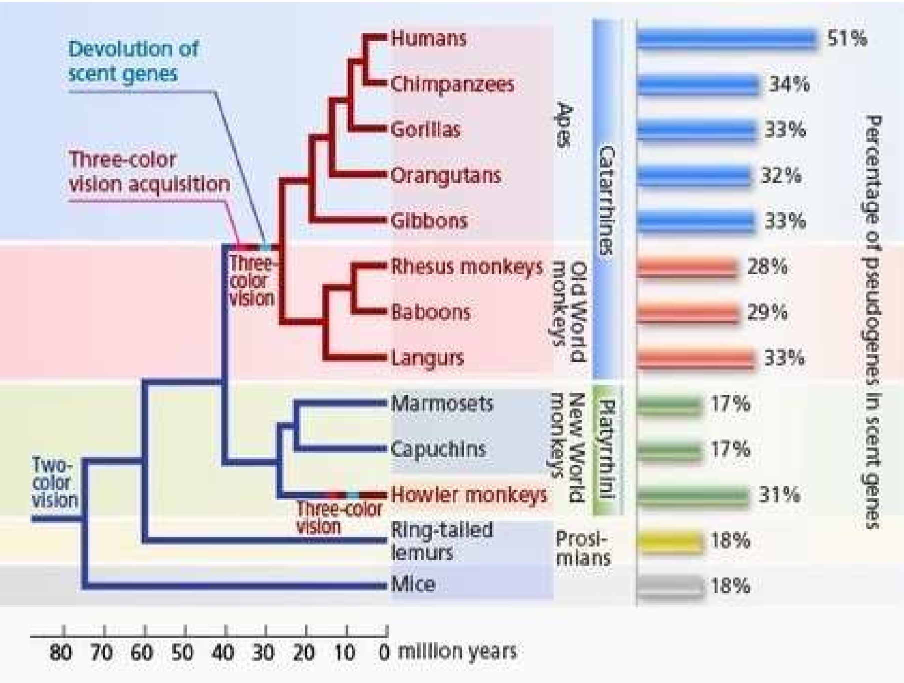

FIG. 9 - Evolutive history of animal vision. It is interesting to note that our branch of the tree started to lose olfactory capacities while getting more visual capacity (scent pseudogenes, i.e. inactive, are indicated on the right).

https://www.quora.com/What-are-the-human-inactive-genes-that-we-inherited-and-are-active-in-other-animals

The variety of situations is huge, because there is quite a variety of genetic histories. A very remote ancestor of primates must have been tetrachromatic, but, at some point at the time of dinosaurs (who lived between the Triassic, 231 million years ago, and the Cretaceous, 66 million years ago), the ancestors of today's mammals lost by a mutation (an occasional modification of DNA in the auto-replication process), a good deal of colour vision, staying with only two of the four existing cones. Primates reacquired in the Lower Tertiary, over twenty million years ago, some of their ability to see colour, by a phenomenon called gene duplication (dubbing mechanism of a DNA region containing a gene). Paleontologists, geneticists, biologists, physicists and chemists work together nowadays to clarify mysteries that remain on the origin of the amazing ability animals have to see the colourful world around them. Although many unclear aspects remain, all advances have confirmed so far the theory of the great English naturalist Charles Darwin (1809-1882), according to which, after species differentiation, adaptation to the environment is crucial.

References

We indicate a couple of references, both scientific and popular science, which allow the reader to deep into the matters which were here only briefly exposed. We follow alphabetical order in each section.

On the physics of colour

Mota, P.G. (coord. (2006), *Museu da Ciência, Luz e Matéria*, Coimbra: Universidade de Coimbra.

Tito de Mendonça, J. (2015), *Uma Biografia da Luz: A triste história do fotão cansado*, Lisboa: Gradiva.

Weiss, R.W. (1996), *A Brief History of Light and Those that Lit the Way,* Singapore: World Scientific.

Wyszecki, G. & Stiles, W.S. (2000), *Color Science: Concepts and Methods, Quantitative Data and Formulae* (2^{nd} ed.). New York: Wiley Series in Pure and Applied Optic.

On human vision

Bucklow, S. (2016), *Red: The Art and Science of a Colour,* London: Reaktion Books.

Eckstut, J. & Eckstut, A. (2013), *Secret Language of Color: Science, Nature, History, Culture, Beauty of Red, Orange, Yellow, Green, Blue, & Violet*, New York: Black Dog & Leventhal.

Ings, S. (2008), *A Natural History of Seeing: The Art and Science of Vision,* New York and London: W. W. Norton & Company.

Kernell, D. (2016), *Color and Color vision, An Introductory Survey,* Cambridge: Cambridge University Press.

Palmer, S.E. (1999), *Vision Science: Photons to Phenomenology,* Cambridge, Mass: The MIT Press.

Rameau, H. (1971), *Os Olhos e a Visão,* Lisboa: Estúdios Cor.

Sacks, O. (2008), *A Ilha sem Cor,* Lisboa: Relógio d'Água.

Vavilov, S.I. (1963), *Os Olhos e o Sol,* Lisboa: Arcádia.

On animal vision and evolutive history

Ali, M.A. & Klyne, M.A. (1985), *Vision in Vertebrates.* New York: Plenum Press.

Bischof, H.-J. & Zeigler, H.P. (eds.) (1993), *Vision, brain, and behavior in birds*. Cambridge, Mass.: MIT Press.

Darwin, C. (2010), *A Origem das Espécies,* Oeiras: Lello Editores.

Hubel, D.H. (1988), *Eye, brain and vision*, New York: Scientific American Library.

Johnsen, S. (2011), *The Optics of Life: A Biologist's Guide to Light in Nature,* Princeton: Princeton University Press.

Land, M.F. & Nilsson, D.-E. (2002), *Animal Eyes*, Oxford: Oxford University Press.

Neiva, M. (2016), ColorADD. Color identification system for colorblind people. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.34-43

COLORADD. COLOR IDENTIFICATION SYSTEM FOR COLORBLIND PEOPLE

Miguel Neiva[1]

ABSTRACT

In most countries, colorblindness affects 10% of the male population. It is estimated that 350 million people in the world are colorblind! This handicap incurs limitations as well as uncomfortable personal and social situations for those afflicted that depend on others to choose products in which color is a predominant factor, such as pieces of apparel, decoration, traffic, recycling, identifying specific rooms in museums and other public spaces when color is the relevant element for choosing. A sample group of colorblind people questioned in a study found relevant the development of a system which would allow them to identify colors. The development of a graphic color identification system was the answer to this need, its concept and structure making it universal, easy to communicate and memorize - a unique, universal, inclusive and non-discriminative language that enables the colorblind to identify colors, with a wide infinite spectrum of usage whenever color is a factor of identification, orientation or choice. This system can be applied to a variety of products and allow the colorblind to reduce or even eliminate their dependence on others.

ColorADD was born for all, allowing full integration whilst keeping the privacy of colorblind - including without discriminating. ColorADD creates added economic and social value to companies or entities that use the code, by offering to their consumers an innovative product with a strong social footprint. Also, Culture is a strategic activity of our mission and consequently it is one of our primary concerns. At several national museums, ColorADD is already adopted not only as part of the museums themselves but also several activities are already developed to allow people/children to become acquainted with this code, thus providing another acquisitive tool of universal and transversal utility. Our target is to take color to all!

KEYWORDS Colorblind; Inclusion; Culture; Museums; Accessibilities

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1. Introduction to the colorblindness problem

Colorblindness is the common denomination to a congenital alteration related to the incapability to distinguish several colors of the spectrum due to a visual deficiency (FIG. 1).

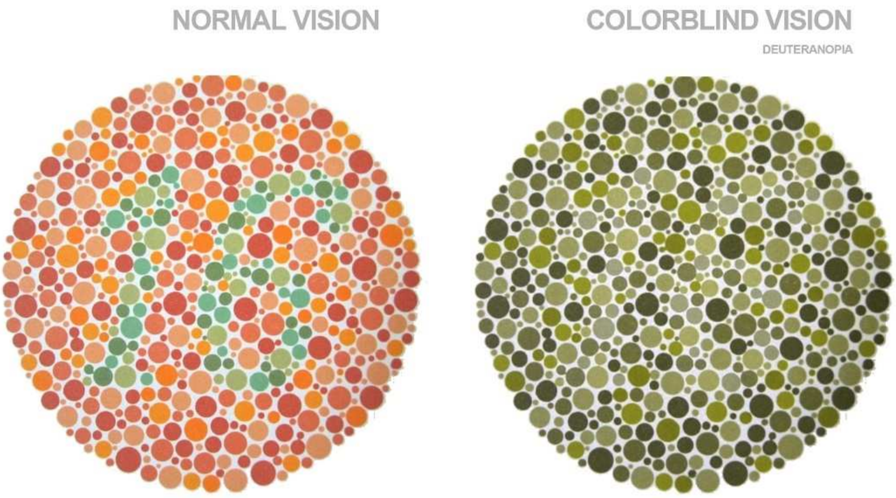

FIG. 1 - Normal and colorblind vision.

This people have a normal vision relatively to the other characteristics which compose it, even though the deficiency hampers, or even makes it impossible for those afflicted to perform certain everyday social and professional tasks. Colorblindness affects approximately 350 million people - 10% of the world's population and it's a handicap usually of genetic origin associated to a flaw in the X chromosome. Because of this, 98% of colorblind people are male.

The first symptoms of colorblindness are detected at school age due to the difficulty in interpreting drawings, maps and identifying colored pencils. Later in life, a colorblind person is prohibited of performing certain jobs, while some professions will bring added difficulties. Similarly, managing daily routine poses problems, as well as, for instance, buying and choosing wardrobe as well as using maps and signs to provide orientation. Even while accessing internet some texts can become illegible due to the use of certain colors. Some companies have started creating web pages which can be seen correctly and easily by all. This has been possible due to the rising awareness that colorblind people represent a high percentage of the world population.

2. Objectives

Once the problem had been identified, its extent and impact on the subjects was evaluated. On a first phase of the study, a sample of color blind people was identified and presented with a questionnaire. Its purpose was to identify the main difficulties of the respondents concerning their color blindness and the processes and methods used by them to lessen and overcome these obstacles.

The collected information was treated and analyzed. Based on these results a conceptual basis was defined, capable of constituting a universal method of graphic color identification, easy to comprehend and memorize.

3. Materials and methods

Using primary colors, represented through simple symbols, the system was constructed through a process of logical association and direct comprehension, allowing its rapid inclusion in the "visual vocabulary" of the user. This concept makes additive color a mental game, which lets the colorblind relate the symbols amongst each other and with the colors they represent, without having to memorize them individually.

The system proposed is based on the search of the pigment color, using as basis the primary colors – blue (cyan), red (magenta) and yellow its additive secondary colors (FIG. 2) and not the light color (RGB), because the colorblind person does not possess the correct vision of the colors, nor a tangible knowledge of how their addition works.

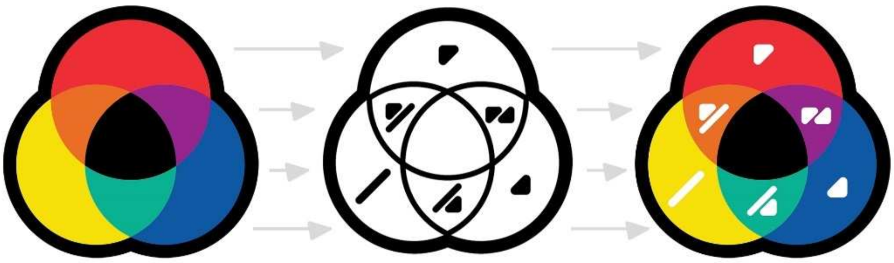

FIG. 2 - Primary color addition – pigment colors.

Each primary color of the code is associated to three forms which represent red, yellow and blue; from these three is the code developed. Two additional forms were added representing black and white; in conjunction with the other elements they represent lighter or darker tons of the colors (FIG. 3).

FIG. 3 - Graphic symbols for 3 primary pigment-colors and white and black.

The secondary colors can be formed using the basic forms as if "mixing" the primary pigments themselves (FIG. 4), making their perception and subsequently the composition of a color pallet easy.

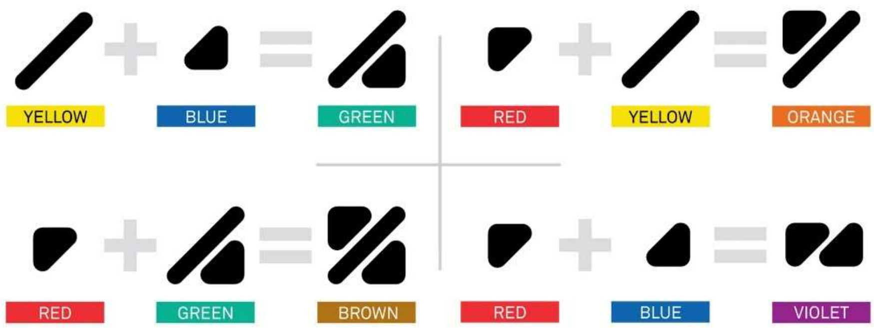

FIG. 4 - Graphic symbols – three primary colors and their addition.

By associating the icons representing white and black to define darker and lighter tones to the three basic forms and their additions, a wide palette is constructed as observed in FIG. 5.

FIG. 5 - Graphic representation of color addition with dark and light.

Conventional color designations were attributed to the additions and other combinations of colors, especially those used in apparel.

Grey, was divided into two tones: light grey and dark grey (FIG. 6). The importance of gold and silver in clothes implies the creation of a specific icon. Considering the logic of the codes' construction, these colors are represented by the combination of the golden-yellow and the element representing shine to define gold; light grey with the same element identifies silver (FIG. 7).

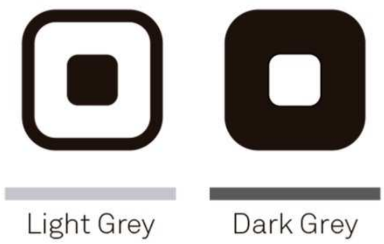

FIG. 6 - Graphic symbols – tons of grey.

FIG. 7 - Graphic symbols – gold and silver.

The totality of the code, represented in FIG. 8, covers a considerable number of colors and can be easily conveyed through information posted at the sales point, on web sites, or the product itself.

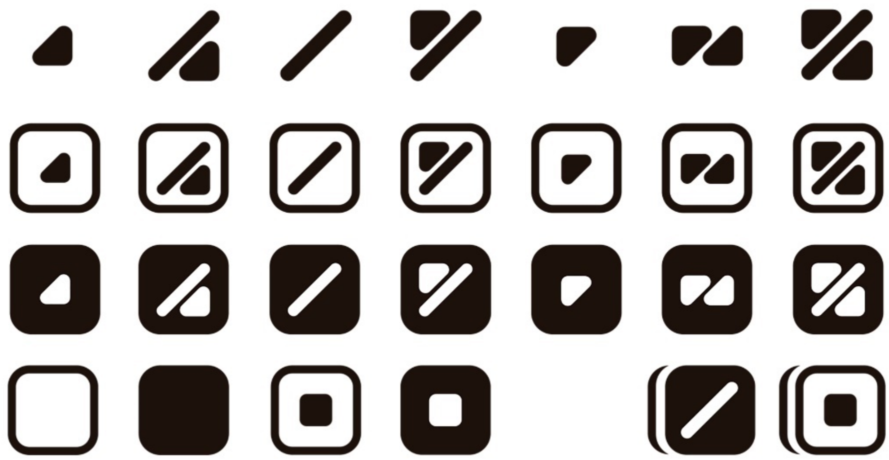

FIG. 8 - Monochromatic graphic code.

4. Results

The application of the system is transversal to all the areas of the global society, regardless of their geographical localisation, culture, language, religion, as well as to all the socio-economical aspects.

School and stationery. It is at school-age that usually appear the first and sometimes traumatic situations and difficulties caused by the wrong color identification. The inclusion of the system in the school and stationery leads to inclusion (FIG. 9), allowing the colorblind kid a perfect integration, with no doubts and shames.

FIG. 9 - School material.

Museums and cultural infrastructures. ColorADD code is already in use in several museums – not only as part of the *spolium* but also as a support of communication and organization of the museum space (Fig. 10).

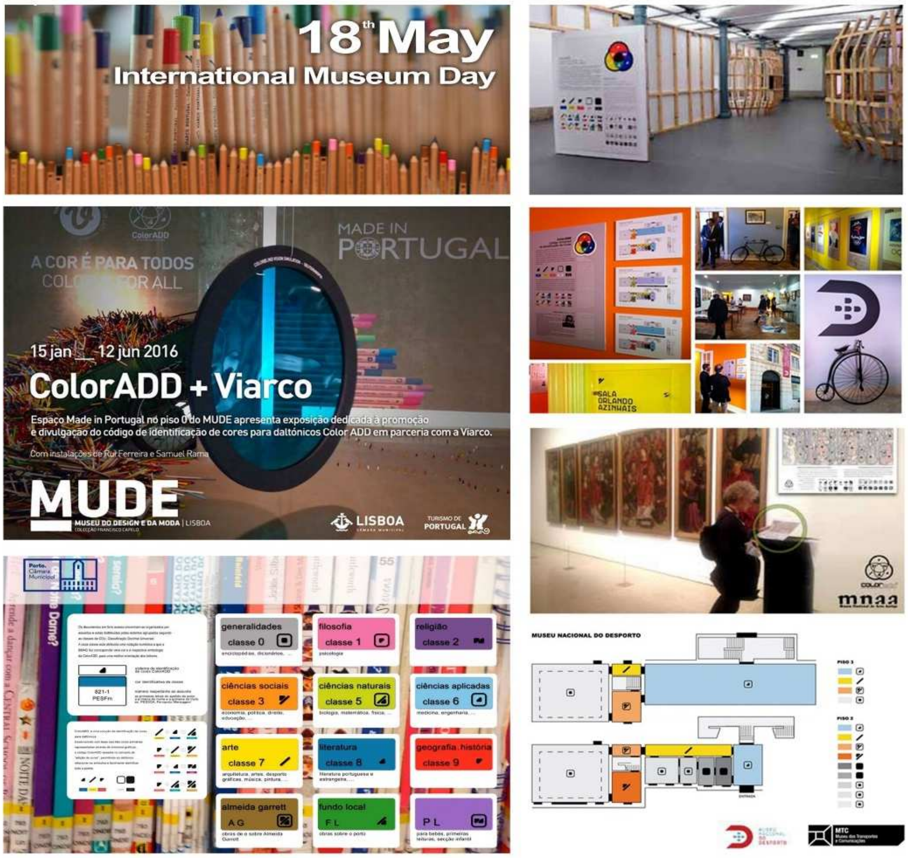

FIG. 10 - Design Museum Budapeste; MUDE, Design and Fashion Museum, Lisbon; National Sport Museum, Lisbon; Museum of Antique Art, Lisbon; Museum of Transports and communication, Porto and Municipal Library, Porto.

Health and services. The selection of patients at hospitals is made through color. At the ER, it is carried out an evaluation of the grade of "gravity" of a patient and a bracelet corresponding to a certain grade of priority is provided. The inclusion of the system in hospital services and spaces where color is an element of identification and guidance makes orientation and easier task to colorblind.

In many places, color is the element of identification of the different services. A colorblind, resulting from its handicap, cannot identify the color and its meaning. Also, many medicines have color as an identifying factor (FIG. 11).

FIG. 11 - Health and hospitals.

Transports. The Metro system maps are a different context but equally valid on what concerns the use of the color identification code, in this case to individualize the different transit lines (FIG. 12).

FIG. 12 - Metro map, Porto, Portugal.

Clothing and textiles. The developed code can be applied in multiple contexts in which color is important. One of the most relevant fields of application is in apparel and the color symbols can be applied to tags or integrated into the clothes themselves, similarly to maintenance and care information. The simple and stylized graphics and its monochromatic nature reduce the production cost of the labels in paper or cardboard, textile or stamp (FIG. 13) and another implementation in cross-sector (FIG. 14).

FIG. 13 - Application to clothing tags.

FIG. 14 - Cross-sector implementation.

5. Conclusions

Each day, society grows more individually centred. The "wrong" interpretation of colors can harbor insecurity in social integration of the individual, whenever the projected personal "image" is a key factor in rendering judgment.

The color identification system, aimed at colorblindness, can be greatly beneficial to a group which represents such a significant percentage of the population. Its use, given the characteristics of the system, means a practically insignificant cost and its adoption by the industry and society may improve the satisfaction and wellbeing of a group of individuals whose vision characteristics deprive them of a fully independent and tranquil everyday experience.

References

Arnhein, R. (1982), Arte e Percepção Visual, Ed. Livraria Pioneira Editora.

Dubois, B. (1993), Compreender o Consumidor, Publicações Dom Quixote.

Frutigier, A. (1981), Signos, Símbolos, Marcas y Señales, Ed. Gustavo Gili.

Goldman, L. & Ausiello, D.C., (2004), Textbook of Medicine, 22nd ed. Philadelphia, Pa: WB Saunders, p.2410.

Hogg, M.A. & Vaughan, G. (1998), Social Psychology**,** 2nd ed, Prentice Hall.

Lanthony, P. (2001), Science et Vie, 216, September.

Learch, E. (1993), Cultura e Comunicação, Lisboa: Edições 70.

Worsley, P. (1993), Introdução à Sociologia, Publicações Dom Quixote.

Yanoff, M.; Duker, J.S.; Augsburger, J.J., et al. (2004), Ophthalmology, 2nd ed. St. Louis, Mo: Mosby, p.34.

Monteiro, M. & Carvalhal, M.J. (2016), Ophthalmic instruments in a Museum of Science. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.44-60

OPHTHALMIC INSTRUMENTS IN A MUSEUM OF SCIENCE

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ABSTRACT Medical studies in Porto began with the creation of the Medical-Surgical School, in 1836; the attendance of a preparatory course taught at the Polytechnic Academy (1837-1911) was required beforehand. On February 1911, it was elevated to a Faculty of Medicine. The creation decree listed subjects such as Physics and Chemistry for Biology, with a one semester duration, which were taught in the Physics and Chemistry Laboratories of the Polytechnic Academy [which, in March, would become the Faculty of Science (FS) of the University of Porto]. These subjects would be replaced on July 1914 by the "FQN" course (from Physics, Chemistry, and Natural Sciences), preparatory to the study of Medicine, also to be taught at the FS, and contemplating an annual chair of Physics. When the FS was established, syllabuses were changed, foreseeing the attendance of free magisterial and demonstration lessons and mandatory practical lessons. Though there were, in the building of the Polytechnic Academy, several rooms assigned to the Cabinet – later Laboratory – of Physics, these were devoid of resources for experimental work, which imposed the purchase of instruments for demonstration and practice. In September 1912, the FS acquired, from the *Maison Charrière Collin*, a set of instruments for Medical Physics. Among others, a Landolt perimeter (for graphical description of the visual field), a Landolt ophthalmoscope (for fundus observation), a Perrin artificial eye (for practice with the ophthalmoscope) and a set of ophthalmologic lenses, all of them now in the Museum of Science of the University of Porto. We will present some of these instruments, as an initial approach to the study of the physics of vision, and understanding of eye defects and diseases.

KEYWORDS Physics of vision; Museum; Ophthalmoscope; Landolt perimeter; Artificial eye

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Introduction

Medical studies in Porto began, in an organized fashion, with the creation of the Medical-Surgical School (FIG. 1), in 1836 (Diário do Governo, 1837, p.9); the attendance of a preparatory course taught at the Polytechnic Academy (1837-1911) was required beforehand, in order to gain access to this school. The discipline of physics was integrated in this course in 1844 (Diário do Governo, 1844, p.326), in obedience to a decree that increased the list of subjects in the preparatory course, known as the «ancillary sciences» (Ferraz, 2013, p.89), following a proposal by some professors of the Medical-Surgical School.

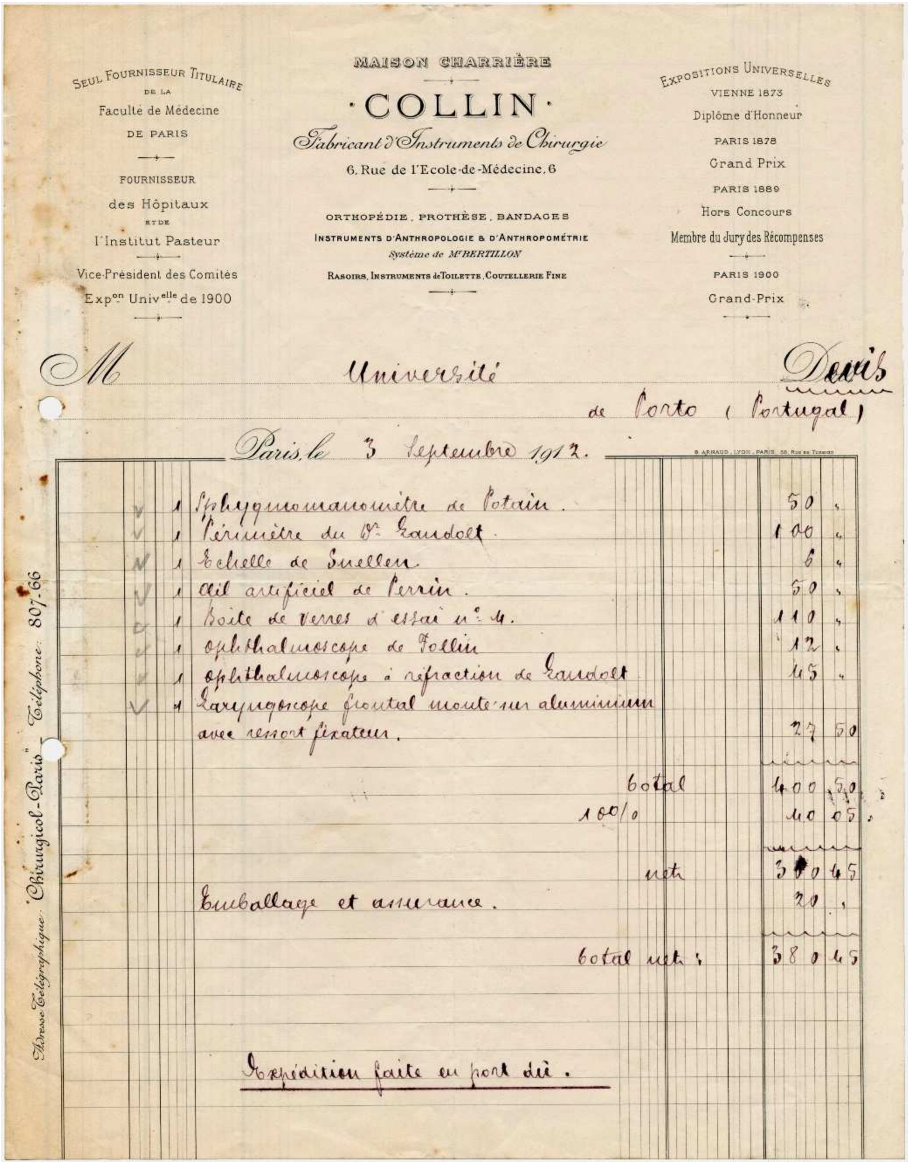
FIG. 1 - Medical-Surgical School (c. 1900) and, after 1911, Faculty of Medicine (Emílio Biel & Cª, Porto, "nº36 – Hospital de Sto Antonio e Escola Medica", stereoscopic pair, c. 1900, detail, Photography Archive of the Museum of Science, Inv. 000482).

On February 1911, within months of the establishment of the Republic in Portugal, the Medical-Surgical School of Porto was elevated to a Faculty of Medicine (Diário do Governo, 1911, p.742). The creation decree listed, among other subjects, Physics for Biology, with duration of one semester, to be taught at the Polytechnic Academy (itself to become the Faculty of Science of the University of Porto shortly after, in March), by the appointed lecturers under guiding lines of the Council of the Faculty of Medicine. The course was first taught by Tomaz Dias da Silva, who would be replaced in 1912/13 by Álvaro R. Machado (Araújo, 2000, p.52); Machado suggested a new program in a report dated June 1913, which he implemented the following academic year. This program introduced some complements of Physics and their connections to Medicine; it included an experimental component, to develop students' skills in this area (Machado, 1913, p.8).

In the same report, that professor proposed the establishment of a group of FQN studies similar to PCN (from Physics, Chemistry, and Natural Sciences) created in French universities in 1893. On July 1914, Physics for Biology, with duration of one semester, would be replaced by an annual chair of Physics – known as Medical Physics – included in the "FQN" course, preparatory to the study of Medicine, also to be taught at the Laboratory of Physics of the Faculty of Science (Diário do Governo, 1914, p.500).

When the Faculty of Science was established, syllabuses were significantly changed, foreseeing the attendance of free magisterial and demonstration lessons, and of mandatory practical lessons. The Laboratory of Physics was by then devoid of resources for experimental work. This would impose the purchase of a variety of instruments for demonstration and practice.

In September 1912, the Faculty of Science acquired from the *Maison Charrière Collin*, based in Paris, a set of instruments for ophthalmology (FIG. 2), intended for practical work in "Radiations", as required by Medical Physics. Some of them are now in the Museum of Science.



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1	Sphygmomanomètre de Potain.	50
1	Périmètre du D[r] Landolt.	100
1	Échelle de Snellen.	6
1	Œil artificiel de Perrin.	50
1	Boîte de verres d'essai n° 4.	110
1	Ophthalmoscope de Follin	12
1	Ophthalmoscope à réfraction de Landolt	45
1	Laryngoscope frontal monté sur aluminium avec ressort fixateur.	27 50
	total	400 50
	10 %	40 05
	net	360 45
	Emballage et assurance.	20
	total net :	380 45

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FIG. 2 - Invoice for purchase of medical instruments from *Maison Charrière Collin*, Paris, including some ophthalmology instruments (Document Archive of the Museum of Science).

1. Landolt ophthalmoscope

Ophthalmoscopy is one of the most commonly used ophthalmological tests; it allows probing inside the fundus of the eye (retina, blind spot and macula) and other eye structures, with the use of an ophthalmoscope (FIG. 3).

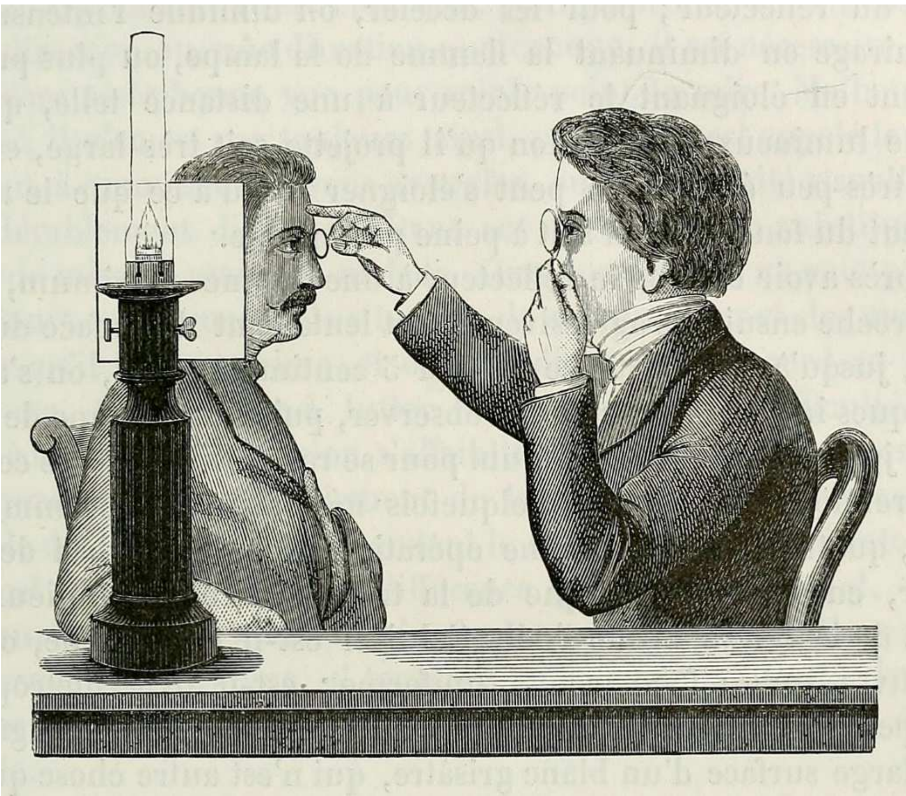

FIG. 3 - Use of an ophthalmoscope (Perrin, 1870, p.57; Duplay et al., 1898, p.17).

The first ophthalmoscope was developed in 1851 by Hermann von Helmholtz (1821-1894). Over the years, it turned out that there was no ophthalmologist who did not have an ophthalmoscope named after him. António Plácido da Costa (1849-1916), professor at the Medical-Surgical School of Porto, seems to have been, among us, the first ophthalmologist to devise an ophthalmoscope (1880); produced in Portugal, this instrument is now on display in the Museum Maximiano Lemos of the University of Porto (Ferraz, 2013, p.516).

Edmund Landolt (1846-1926) was a Swiss ophthalmologist working in Paris, known for his research in the field of ophthalmology. He also developed a new type of ophthalmoscope, based on refraction (FIG. 4), as a result of his pursuit to gather the best characteristics of the different ophthalmoscopes then available (Landolt, 1878, p.86).

FIG. 4 - Landolt ophthalmoscope and accessories in case (Physics collection of the Museum of Science, Inv. 000372).

To look inside the eyeball, light has to be projected through the pupil of the patient, reflecting back on to the eye of the observer, where it must form a clear image. Therefore, this ophthalmoscope is equipped with a concave mirror with a focal distance of twenty centimeters and a diameter of twenty-eight millimeters. It is pierced with a central hole at least three millimeters in diameter; the handle, in ivory and brass, is about twelve centimeters long, making the instrument very handy to use (FIG. 5).

For evaluating the eye refractive condition, the ophthalmoscope contains two discs (FIG. 6): one with six positive lenses and the other with six negative lenses. They are superimposed on the instrument and rotate around the same center, thereby bringing all lenses, subject to all possible combinations, behind the opening of the ophthalmoscopic mirror. Such arrangement allows us to obtain twenty converging systems and twenty-one diverging systems (giving every half diopter from 0 to plus 10 and from 0 to minus 10.5).

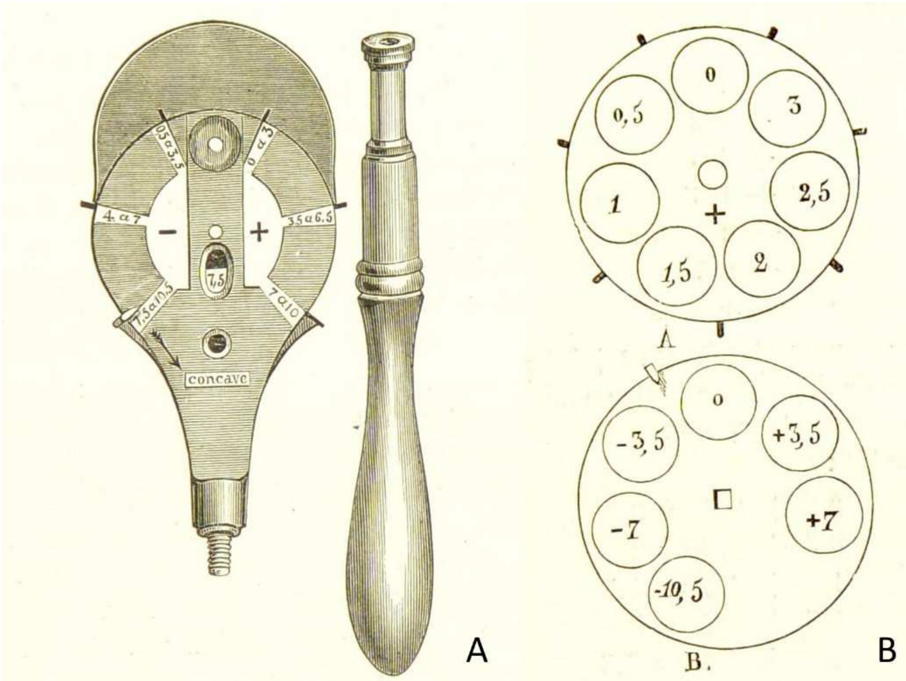

FIG. 5 - Landolt ophthalmoscope, drawing:

A – view of the ophthalmoscope; B – discs with lenses (Landolt, 1878, pp.87-91).

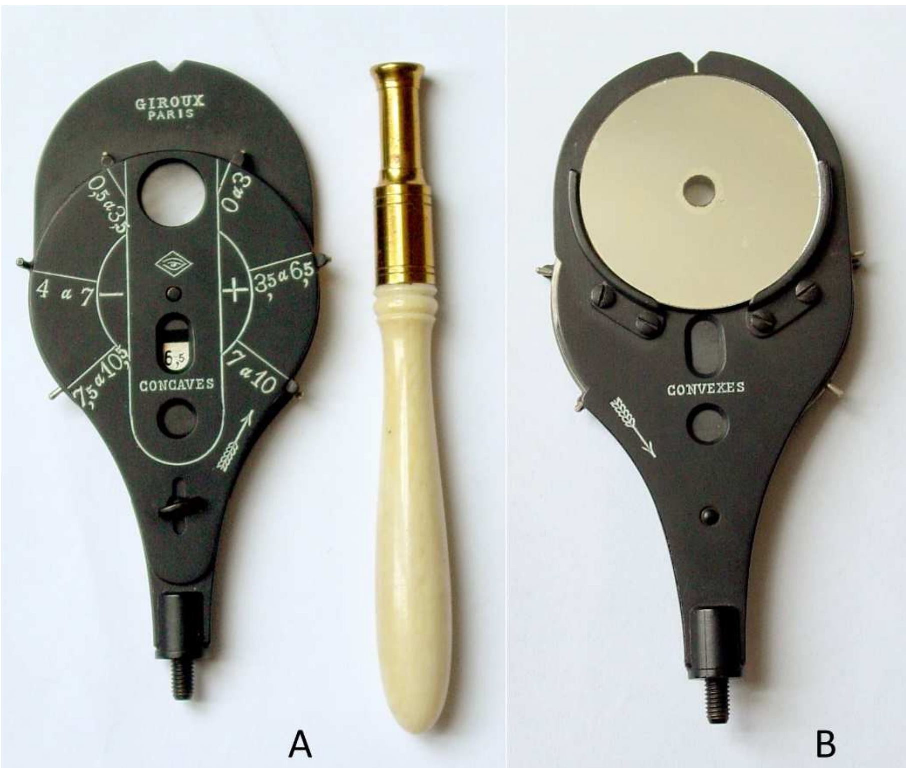

FIG. 6 - Landolt ophthalmoscope: A – view from the observer's side; ivory and brass handle; B – on the other side, the concave mirror with a central hole.

An additional plus 10 diopter lens may be slipped into the groove for the mirror, further extending the working range from plus 20 to minus 20.5 diopters (FIG. 7). There existed probably a second minus 10 diopter lens, to increase the range of powers available. When trying to see the fundus of the eye with different combinations of lenses, the observer will find one that allows him to see clearly; the resulting power should rightly be the one that corrects the eye refractive ailment.

The stenopaeic disk - an opaque disk punctured with a narrow slit – is an accessory for measuring astigmatism (FIG. 8): with edge graduated in degrees, it is placed in the mirror groove, helping determining the power required to correct the refractive error along each major eye meridian.

FIG. 7 - The plus 10 diopter lens.

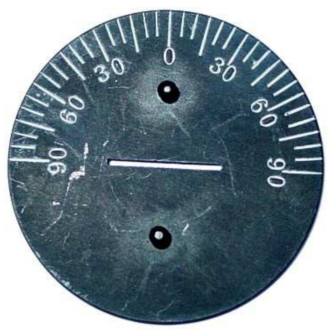

FIG. 8 - The stenopaeic disk.

2. Perrin artificial eye

Handling the ophthalmoscope requires manual skills; however, in order to acquire practice, it is necessary to resort to prolonged exercises, difficult to accomplish with a keen eye, since the strong light source may be dangerous in inexperienced hands. For this reason, trainee physicians used to practice the exam of the retina with an ophthalmoscope by resorting to an artificial eye model.

Artificial eyes with fundus drawings, like this particular model (FIG. 9), were first introduced in 1866 by Maurice Perrin (1826-1889), a French physician and professor of surgery, and first made by *Nachet et Fils*, Paris (Perrin, 1866, p.2). Such models can endure light shining for hours on end, contrary to the real eye.

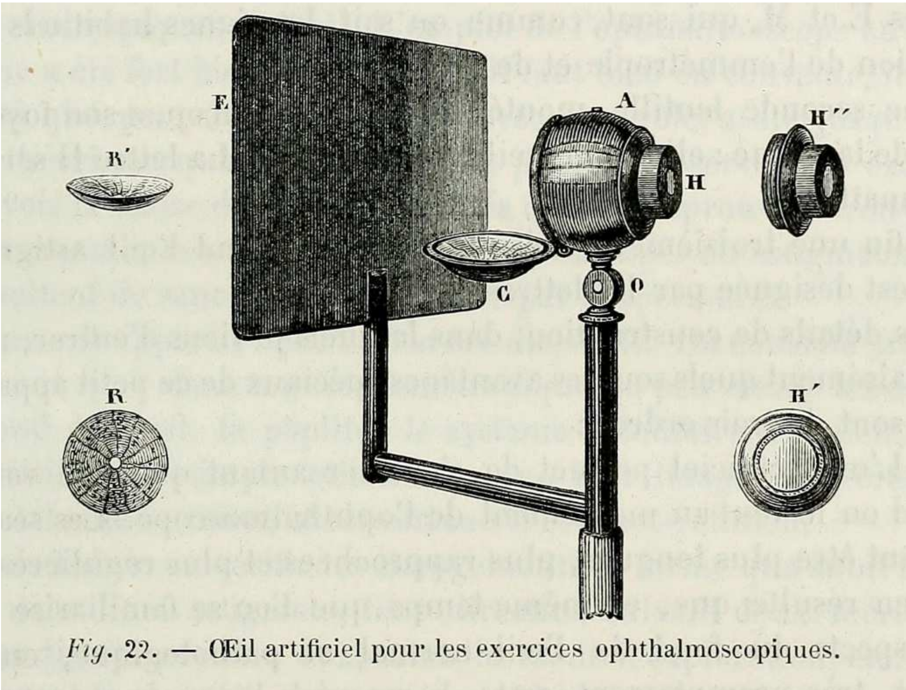

Fig. 22. — Œil artificiel pour les exercices ophthalmoscopiques.

FIG. 9 - The Perrin artificial eye, drawing (Perrin, 1870, p.65).

Opportunity for training would be provided by this model (FIG. 10), in the identification of the blind spot and macula, in the observation of the larger blood vessels entering the eye at the blind spot, or in the analysis of some retina pathologies as illustrated by drawings that lecturers would provide.

It has the optical proportions of the real eye. The central part, representing the intraocular cavity, is a hollow sphere, in copper, blackened internally and with a volume similar to the eyeball's (FIG. 11). It is supported by a variable height stand. A black screen mounted behind helps guiding the light beam.

FIG. 10 - The Perrin artificial eye and accessories, in case (Physics collection of the Museum of Science, Inv. 000373).

FIG. 11 - The central part of the artificial eye, with the black screen.

A lens, which simulates the optical system of the eye, is screwed onto the front. There are three powers available to simulate the normal or emmetropic eye (E), the hyperopic eye (H) and the astigmatic eye (A); the myopic eye is simulated also by the E lens. Different degrees of ametropic eyes are produced by screwing these lenses further or nearer, thus varying the distance from the lens to the cup representing the fundus. Diverse pupillary dilatations may be simulated by caps screwed in front: 7 mm or 3 mm diameters are available (FIG. 12).

FIG. 12 - Lenses and caps.

On a posterior ring mounted on a hinge (FIG. 13 A), different copper cups can be placed, in which different ophthalmoscopic images of the eye fundus have been painted, either normal or pathological.

By 1866, the *Nachet et Fils* house was offering twelve different cups, one representing the normal eye, and the others, different pathologies (FIG. 13 B); they also provided cups prepared with a red background or with no preparation whatsoever. These could be painted with images of different retinal pathologies copied from the *Atlas d'Ophthalmoscopie*, authored by Perrin (FIG. 14).

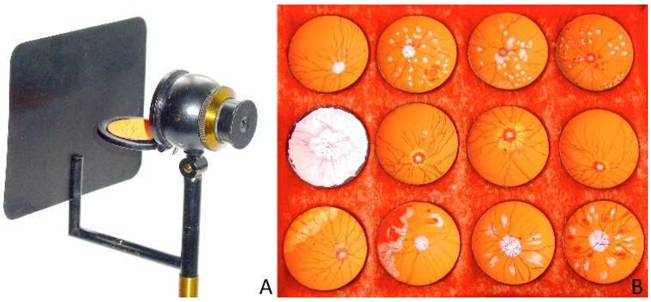

FIG. 13 - A – The artificial eye with the cup simulating the normal fundus fitting the ring; B – Collection of 12 fundi: the top left depicts the normal eye; others reproduce different pathologies listed on a card inside the case.

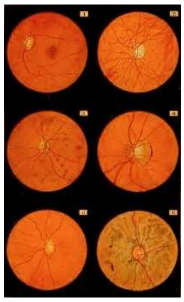

FIG. 14 - Physiological varieties of the fundus of the eye – chromolithograph (Perrin, 1872, plate nº 7).

This eye model also provided the opportunity for studying the dioptrics of the human eye, one of the subjects listed in the program of Physics for Biology.

3. Landolt perimeter

A perimeter, or arc perimeter, is used to determine the visual field, that is, the extent of the outer world which is seen by both eyes. Careful exploration of the visual field can be used to diagnose many ocular or neurological disorders, including glaucoma.

In 1858, Hermann Aubert (1826-1892), a German physiologist, constructed the first dedicated investigational perimeter. Edmund Landolt gave the perimeter the following form (FIG. 15):

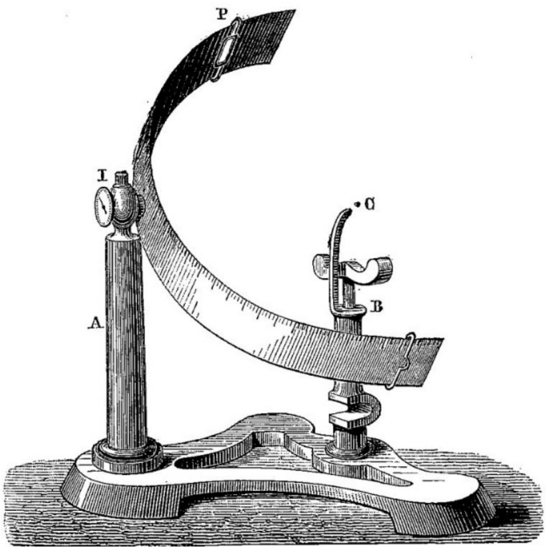

FIG. 15 - Landolt perimeter, drawing (Landolt, 1877, p.175).

To determine the visual field, we must place one eye at a time in the center of a sphere. The most convenient way to obtain such a sphere is given by the perimeter: it consists essentially of a semicircular arc, which, by rotation, describes a hemisphere in the center of which is the eye under examination.

The arc is divided into degrees, on the outer side, from 0° to 90°, starting from the rotation axis, towards the ends. The slope of the arc is read off on a small vertical dial associated to that axis. A piece of wood at variable height works as a chin rest so that the optical center of the eye is placed at the center of the hemisphere described by the arc. The interior of the arc is blackened except for the central fixation point. A grid in the vicinity of the perimeter's center, spaced in half degrees, allows for sensitive measurements around the macula (FIG. 16).

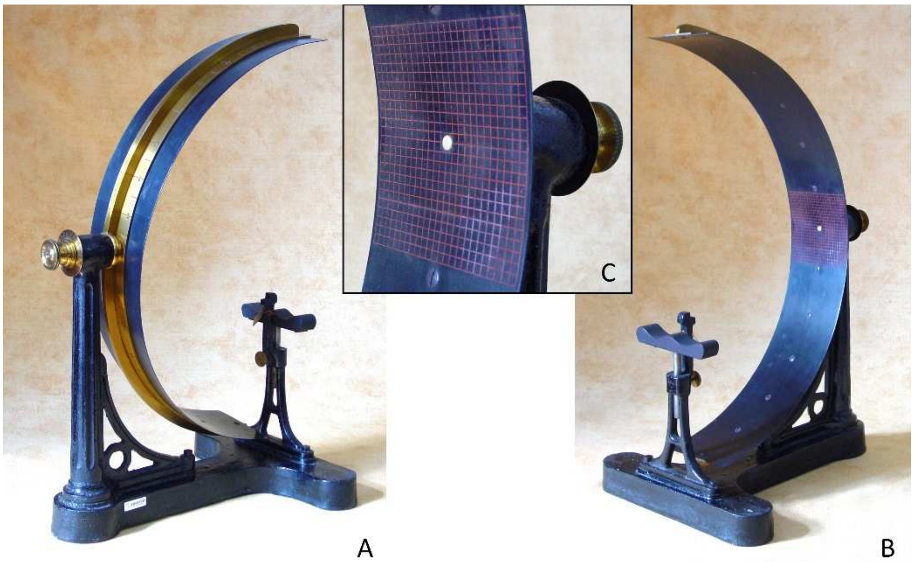

FIG. 16 - Landolt perimeter (Physics collection of the Museum of Science, Inv. 000375): A – The outer side, divided into degrees; B – The blackened inner side of the arc; C – The grid spaced in half degrees.

With the arc of the perimeter maintained at a specific orientation, as the subject stares at the small white dot in the center of the arc, the operator slides a target along the arc and records the angle from which this target is spotted in the subject's visual field. The process is repeated for different orientations of the arc. The results are plotted on a diagram showing a projection of the sphere (polar equidistant projection); the points obtained are joined by segments, thus characterizing the visual field (FIG. 17).

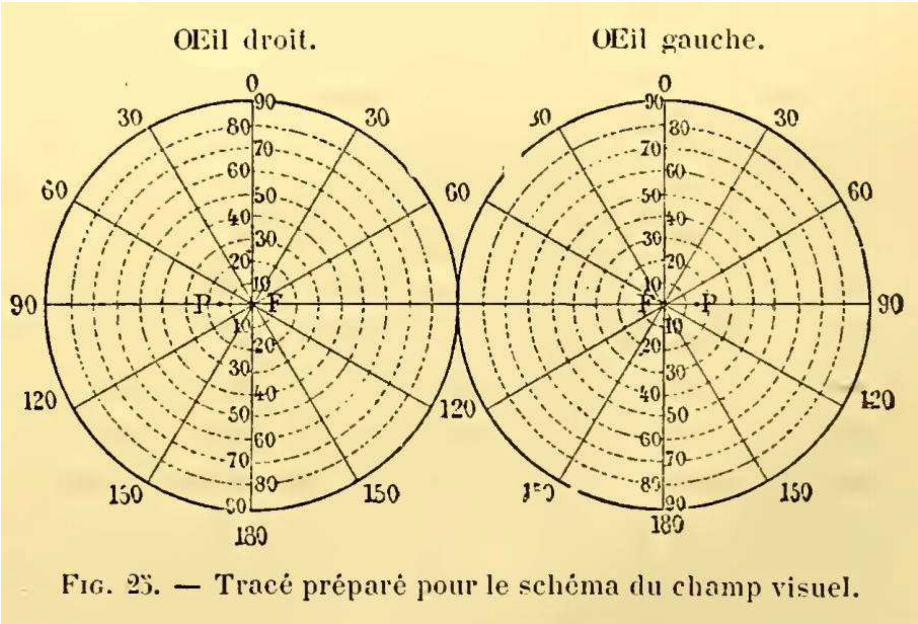

FIG. 17 - Diagram for recording the visual field (Duplay et al., 1898, p.25).

The Landolt perimeter can also be used to determine visual acuity and for the study of the perception of colour. To do this, all it takes is to measure the visual fields associated to red, green and blue colours independently (FIG. 18).

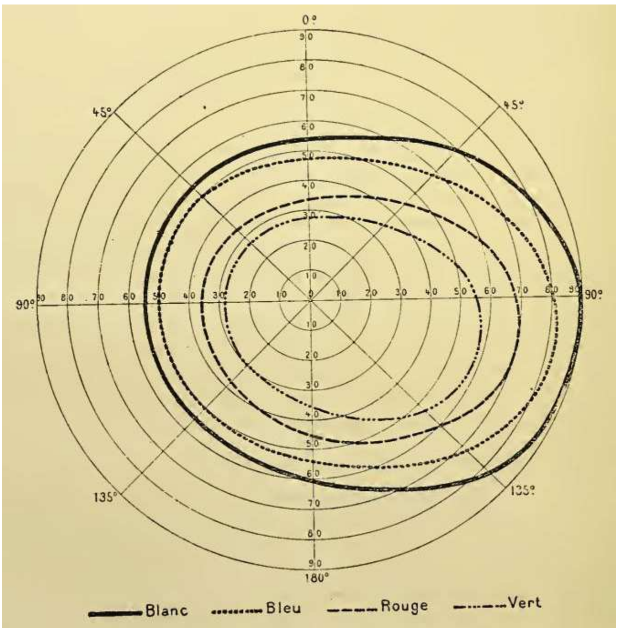

FIG. 18 - Charts which indicate the limits of the medium visual field of different colours: white, blue, red and green (Duplay et al., 1898, p.24).

4. Optician's trial set of lenses

Trial sets of lenses are among the apparatus employed in ophthalmic work. They are used in testing vision for detecting the refractive defects of human eyes and prescription of eyeglasses. It is an array of trial lenses to be mounted on a metal spectacle frame, with different magnifying numbers, expressed in diopters; each one has a flap in which we can read this number (FIG. 19).

FIG. 19 - Optician's trial set of lenses (Physics collection of the Museum of Science, Inv. 000374).

There are pairs of spherical convex and concave lenses, for correction of myopia or hyperopia; pairs of cylindrical concave and convex lenses, for correction of astigmatism; and prismatic lenses, for correction of strabismus. The lenses are stored in a velvet lined case, in grooves, and are classified by their kind of prescription. Flat glasses, colored or opaque, and a stenopaeic hole, are also included. Some lenses and accessories are missing.

Conclusion

With the creation of the Faculty of Science of the University of Porto, in March 1911, the teaching of physics, until then of a markedly theoretical and speculative nature, started demanding practical work and training in the laboratory; such approach asked for laboratories duly equipped for experimental practice (Araújo, 2000, p.51). The acquisition of the instruments we have been describing gave students the opportunity to engage in practical work related to Medicine, though in the context of a Physics course, as a practical assignment was planned for each one (Machado, 1913, pp.20-21).

These instruments are a testimony of the concern for selecting the Physics contents with direct application in Medicine, and for addressing these contents by confronting students with the experimental manipulation of medical instruments.

References

Araújo, J. M. (2000), A Física na Faculdade de Ciências da Universidade do Porto. In: FCUP. *Faculdade de Ciências da Universidade do Porto: os primeiros 75 anos: 1911-1986*. Porto: FCUP, pp. XXX-XXX [1º e última página do artigo].

Direcção Geral da Instrução Secundária, Superior e Especial (1911), *Reforma do Ensino Médico* [online]. Available from: https://dre.pt/application/dir/pdfgratis/1911/02/04500.pdf [Accessed 15th June 2015].

Duplay, S., Reclus, P. (1898), *Traité de Chirurgie*, IV, 2nd ed. Paris: Masson et Cie, Editeurs

Ferraz, A. (2013), *A Real Escola e a Escola Médico-Cirúrgica do Porto – Contributo para a História da Faculdade de Medicina da Universidade do Porto*. Porto: U.Porto Editorial.

Landolt, E. (1877), *Leçons sur le diagnostic des maladies des yeux*. Paris, Ve A. Delahaye et Cie, Librairies Éditeur.

Landolt, E. (1878), *Manuel d'ophthalmoscopie*. Paris: Octave Doin, Éditeur.

Machado, A. R. (1913), Estudo de física médica na actual organização universitária, Separata do *Jornal dos Médicos e Farmacêuticos*. Porto: [s.n.].

Ministério da Instrução Pública (1914), *Lei nº 239* [online]. Available from: https://dre.pt/application/file/478905 [Accessed 15th June 2015].

Ministério do Reino (1836), *Das Escolas Medico-Cirurgicas de Lisboa e Porto* [online]. Available from: http://legislacaoregia.parlamento.pt/V/1/18/15/p30 [Accessed 15th June 2015].

Ministério do Reino (1844), *Decreto acerca da instrução pública*, artºs 147º a 150º [online]. Available from: http://legislacaoregia.parlamento.pt/V/1/22/76/p319 [Accessed 15th June 2015].

Perrin, M. (1866), *Description d'un Oeil Artificiel destiné a faciliter les études ophthalmoscopiques*, Compte Rendu de la Société de Chirurgie [online]. Available from: http://gallica.bnf.fr/ark:/12148/bpt6k54703977.r=Compte%20Rendu

%20de%20la%20Soci%C3%A9t%C3%A9%20de%20Chirurgie

[Accessed 15th June 2015].

Perrin, M. (1870), *Traité Pratique d'Ophthalmoscopie et d'Optométrie.* Paris: Victor Masson et Fils.

Perrin, M. (1872), *Atlas d'Ophthalmoscopie et d'Optométrie*. Paris: Victor Masson et Fils.

BUILT ENVIRONMENT. LIGHTING SYSTEMS. REQUIREMENTS, SOLUTIONS AND TRADITIONS

Pernão, J. (2016), Light and colour in the built environment. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.62-79

LIGHT AND COLOUR IN THE BUILT ENVIRONMENT

João Pernão[1]

ABSTRACT

In the Book of Genesis there is a dramatic change in the world when God says: *Fiat Lux* (Let there be light)! Chaos was ended. In our everyday life when we hear a noise while asleep at night, we are afraid because there is no light, and if there is no light we don't see anything, i.e., we do not know. When we turn on the light, everything around us gets organized: light ends the chaos of darkness. In fact, we rely more than 80% on our sight sense to bring us what is happening around us.

Light is the genesis of visual perception, and colour is its vehicle. We understand the world around us by the organization of colour stimuli received by our eyes, transmitted to our brain and interpreted there. We can say that colour is the form of space because it is through colour that we perceive the limits and the forms of our environment. Therefore, colour should be studied, together with light, its origin, as the main actor in space perception, and therefore in architecture.

With these assumptions in mind, we have to distinguish between Inherent Colour and Perceived Colour. The first is the colour of the surfaces, which could be read by a colorimeter, without the interference of the human perception or the outside lighting conditions. The second is the colour perceived by the human being, always different according to three variables: light, the observer and the surface. If any of these variables change, the perception will be different: if the light changes its position, or its characteristics, if the observer moves to another place or looks in a different direction, if the surface is placed under or above the observer, or with a different angle, etc. Our work as Colour Consultant proves that the knowledge of this continuous variation in colour perception is a tool that we can use to design better spaces for human life and comfort.

KEYWORDS Light; Colour; Perception; Built Environment; Architecture

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1. The importance of a holistic approach to colour and light: the ancient discipline of Optics

Colour is nowadays seen as something that makes part of our daily choices concerning objects, clothes, cars, etc., and we tend to see it as something very personal. Light, on the other hand, is something that we only think about when we do not have it, when it is too dark for us to perform the tasks we need. And usually we do not correlate them as something that in fact constitutes the main origin of what we could call "our reality". If we consider that sight is the main vehicle for conveying sensations from our environment (more than 80%) to one's self, that light is the cause to all visibility, and that colour is the unavoidable interaction between light and matter, we begin to understand their importance, and their fundamental relationship.

This holistic approach, and its importance, was recognized throughout History from the classic world to the XIX century where it becomes divided in various specific fields of knowledge corresponding to the scientific specialisation that exist until today. In ancient Greece, the discipline of Optics had a vast epistemological scope and was seen as the most fundamental way to study and understand Nature, the key that could unlock and reveal its most hidden secrets (Lindberg, 1976, p.ix). Euclid's and Ptolemy's *Optics* were among the first pillars for discussion of the subject, but we find discussions on it from the Atomists, Plato, Aristotle, Galen, the Arabs Al Kindi and Al Hazen, to the "modern" *Optics* of Kepler and Newton, just to cite some. The discussion of processes of visual perception was crucial to the progress of knowledge. This discipline of Optics could encompass subjects such as anatomy and physiology of the eye, the mathematical principles of perspective, psychology linked to visual perception and the nature of light and the laws of its propagation. It has always been a domain of reflection for thinkers and philosophers and currently one can easily recognize the characteristics and controversies of the main currents of thought throughout the various eras. Optics was a holistic field of knowledge for the explanation of the universe and its relationship with the human being.

We should think again of light and colour within this interdisciplinary frame because it is the only way to understand their importance for the perception of our environment and therefore, for architecture and the built environment.

2. Light and colour perception in Architecture

In order to have visual information through our sight sense we must have light; hence, light is considered the first condition for visual perception. Additionally, whenever there is light there is colour. Being the result of light's interaction with matter, colour is responsible for space perception, so we can state that colour is the form of space.

In *De Coloribus,* Aristotle notices this fact when considering that visibility is only possible with light, just as bodies' visibility is only possible through colour (Aristóteles, 2001).

The importance of colour in space perception is well expressed by Goethe in his *Theory of Colours*. He claims that nature seeks to manifest itself to the sense of sight through colours (Goethe, 1988). But more than concurring Aristotle's previous perspective, he innovates when saying that colours are directly related to emotions:

Since colour occupies so important a place in the series of elementary phenomena, (…) we shall not be surprised to find that its effects are at all times decided and significant, and that they are immediately associated with the emotions of the mind (Goethe, 1988, p.304).

The unavoidable relationship between light and colour is also well expressed by Johannes Itten in his book *Art of Color*, where he considers colour as the *daughter of light* (Itten, 1997). He also poetically relates these elements saying that *Light, that first phenomenon of the world, reveals to us the spirit and living soul of the world through colors* (Itten, 1997, p.13).

Colour is an emotional link between the human being and what lies around him. Cézanne used to say that *Colour is the place where our brain and the universe meet* (Merleau-Ponty, 1993). To better understand these concepts, we must empty our mind of any preconceived ideas and establish a new understanding for the role of light and colour in architecture.

Light is a metaphor for knowledge. To see is to know. Accordingly, when we design spaces we must take into account that it is through light that we reveal (or conceal) the architectural spaces, their forms, their proportions, their textures and colours. Light shapes our perception, as stated in Le Corbusier's (Le Corbusier, 1977) definition of Architecture: *the learned, correct and magnificent play of volumes in light* (Le Corbusier, 1977, p.16). And as architectural spaces are revealed through light, we must not simply imagine their outcome during the day, but also during the night under artificial light. Architects should not rely on Electric Engineers for the aesthetical outcome of architectural spaces at night.

Since the spaces are revealed by light, the role of colour is inherent to their formalization: if spaces are defined by their visible limits, these limits have a certain materiality that is brought to us by their colours. It should be made clear that when we talk about colour we are dealing with everything we see in our environment, including raw materials like wood, stone, metal, etc. Jan de Heer (2009) in his *The Architectonic*

Colour states that *Polychromy (…) involves the treatment of the surfaces that are exposed to everyday use. In present-day architecture, this often relates to the choice and ordering of the materials* (De Heer, 2009, p.6).

Colour is intertwined with light. The presence of a colour in space depends on its illumination: a strong colour could have a subtle presence if it is dimly illuminated and a subtle colour could have a strong presence if it is brightly illuminated. Furthermore, there are colours that need more light to accomplish their identity, like some reds, and colours that live well in the shadow, like some Blues (Le Corbusier, 2006). On the other hand, our colour perception also varies with the circumstances of observation (distance, space location, etc.) and with the characteristics of the object's surface (texture, gloss level, etc.).

In order to understand light and colour's relationship with space we have to admit that they play a continuous game of variations. Colour perception is the result of three variables: Light, Object and Observer. If any of these variables change, the colour perception will be different. But the colour measured over the surface, for instance with a colorimeter, will be the same because it has no interference with the human perception or the outside lighting conditions. For this reason, we have to define two kinds of colours: Inherent Colour and Perceived Colour. For each inherent colour, i.e. the colour measured over a surface; there will be thousands of perceived colours, depending on the variation of the light, the object and the observer's point of view.

Josef Albers (1975), a prominent artist and a Bauhaus teacher, based his work upon the variations of colour perception, stating: *In visual perception, a color is almost never seen as it really is - as it physically is. This fact makes color the most relative medium in art* (Albers, 1975, p.1). We can follow this notion back to the work of Aristotle (Aristóteles, 2001), probably the first to isolate the colour phenomenon, when he says:

We do not see any of the colours pure as they really are, but all are mixed with others; or if not mixed with any other colour they are mixed with rays of light and with shadows, and so they appear different and not as they are (Aristóteles, 2001, p.17).

In Architecture, perceived colours are the ones that interest us, which we can model with light, transforming the space perception. But when it comes to formalizing a Colour Study and transmitting our ideas to be applied at the worksite, we have to use colour codes, that is to say, inherent colours.

3. Design using light and colour variation

Variation is the key for perception: if one's perceptive visual field lacks variation, one cannot distinguish forms or volumes (like in a foggy day). Colour and light variation allows us to form coherent associations, detach figures from the background, and in this manner, form a mental space where we can act and move safely.

Colour variation was Leonardo da Vinci's first concern when teaching painting techniques. In his *Trattato della Pittura* he refers that *the first object of a painter is to make a simple flat surface appear like a relievo, and some of its parts detached from the ground* (Da Vinci, 2002). This idea is interdisciplinary: anthropologist Gregory Bateson (1987) stipulates that perception is based on difference: change is the food of perception. Psychologist James Gibson also defines the variation, or change, as the main factor for visual perception (Gibson, 1986).

We can distinguish two kinds of variation: synchronic and diachronic. When you perceive a red square over a black painted background, you are experiencing synchronic variation. The borders of the red figure detach themselves from the black background, and through that colour variation you perceive a figure you have learned to call "square". When you walk through a space, forms and shapes keep on changing and, even when you stop and look around, your perception varies. That is diachronic variation. Another example of this concept could be the changes of colour and light in a room, which are dictated by the movement of the Sun during the day. If we consider that even in the first example of synchrony you detach the square figure from its background by moving your eyes following the difference between red and black, we can say that variation is allays related with movement, and therefore with time.

The human being is naturally related to variation. Our body, and its functions, is regulated by the twenty-four-hour cosmic circadian cycle, alternating light and dark, activity and rest. From our prenatal period, we learn to associate various stimuli with variation: bright hues, intense light, noise (active period) and dark hues, low lighting, silence (period of rest). Variation is a natural element; constancy is not.

Until the end of the XIX century, light variation (and consequently colour variation) was a natural presence for twenty-four hours. Even at night, the illumination resulting from burning materials (like candles or petrol lamps) always produced movement. In our days, artificial light produces a static environment at night, always with the same intensity and direction provoking an immobility that is not natural to us. Jean-Paul Sartre names this fact *the look of Medusa* over things, paralyzing them. The colours caused by artificial lighting will not change over time and the objects will remain motionless in their appearance, as well as their shadows. This unnatural immobility of light and colour perception could cause psycho-physiological disturbances like fatigue, stress, etc. Light and colour variations are indeed a natural and meaningful attribute for space perception and for human comfort.

Knowing all this, how can we use light/colour variation to design better environments?

a) Accentuate different functions within a space

In a classroom, the colour of the wall behind the teacher should be darker than the others, in order to focus students' attention and promote comfort for their eyes. A bright colour in the teacher's background would cause pupil muscle's fatigue in trying to adapt to different luminous fields: the teacher's face and the bright background. In FIG. 1 we can see that, before the colour study, the walls and ceiling were all painted white. The colour study applies a greyish Blue at the teacher's wall and in the ceiling promoting a focus of attention and reducing the excess of glare coming from the large window.

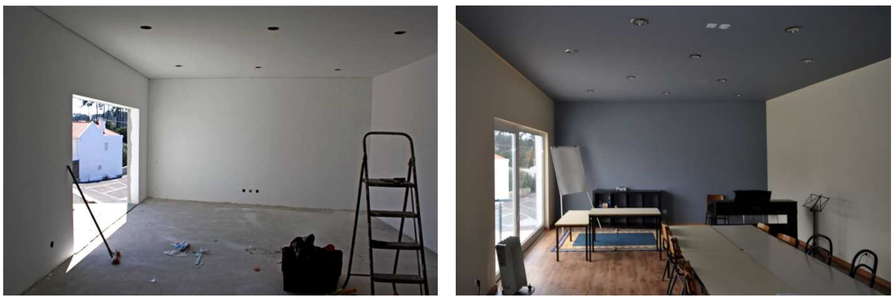

FIG. 1 **-** Before and after: colour could be used to focus attention in a classroom. SAMP School. Colour Study: João Pernão.

Other example of the use of colour variation to accentuate space functions is seen on FIG. 2. A wall dividing two different areas in a classroom could be painted in a strong colour to emphasize its centrality. In this case this wall is covered with a soft material that absorbs sound and allows for papers and drawings to be fixed on it.

FIG. 2 - Colour could emphasize centrality. Cenfic School, Lisbon. Colour Study: João Pernão.

Photo Margarida Dias.

b) Accentuate differences between spaces with different uses

The variation between spaces with different functions could be accentuated by light and colour. In the transition of some environments it is advisable to produce differences in space perception in order to induce different behaviours, for instance from offices and meeting rooms to corridors and lounge areas; from classrooms and study areas to corridors and relaxing areas (FIG.3).

FIG. 3 - Colour and light used to enhance transitions. CENFIC School, Lisbon. Colour Consultant: João Pernão.

In FIG. 4, we clearly state through colour the difference in behaviour inside a classroom, with low saturated colours, and on the stairs, with bright and saturated colours enhancing movement. In this way, we are supporting and directing the psychological environment derived from the functions established by the architectural project.

FIG. 4 **-** Colour used to establish variation in behaviour. CENFIC School, Lisbon. Colour Consultant: João Pernão

Photos: Margarida Dias.

c) Define transitions between exterior and interior

The moments of transition between spaces are one of the most important issues in Architecture. Transition between exterior and interior spaces is perhaps the most dramatic one because it involves many levels of perception and many senses: it's a transition of scale, temperature, sound, smell, and, of course, light and colour. In FIG. 5 the complementary effect of colours (red/green) is used to establish a contrast between the green colour of nature and the interior walls.

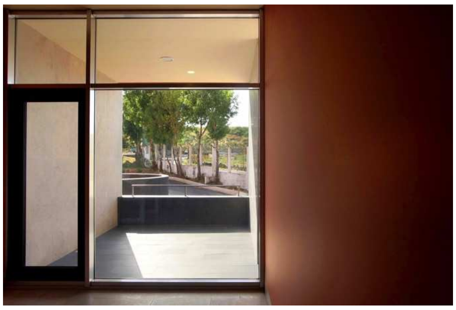

FIG. 5 **-** Using Colour to accentuate exterior/interior transition. CENFIC School, Lisbon. Colour Consultant: João Pernão.

Photo Margarida Dias.

In a social housing rehabilitation, we use different entrance colours to promote identity and distinction between buildings (FIG. 6).

FIG. 6 **-** Entrance differentiation through colours. Bairro das Descobertas, Moita.

Colour Consultants: José Aguiar and João Pernão.

This variation in buildings otherwise all alike, gives inhabitants the sense of recognition of each ones' house as unique.

d) Using colour difference to promote way-finding

Colour is an important tool in recognizing the visual references of our environment; it is through that recognition that we establish a series of key-points or anchors that define our position in space. The *legibility* of our built environment is determinant for a good relationship between the space users and the architecture (Lynch, 1982).

In a colour study for the interior of a hospital facility, we create a correspondence between the access units (stairs and elevators) and a colour (red). The same colour was used to detach the reception spaces on each infirmary. This facilitates orientation of the visitants that used to be lost in the maze of similar galleries and corridors. In FIG. 7 red was used for the infirmary's reception desk, on the right, and to sign the stairs at the end of the corridor. Green and yellow were also used for orientation: the infirmary rooms are on the green side; the yellow side is for medical exams and staff offices.

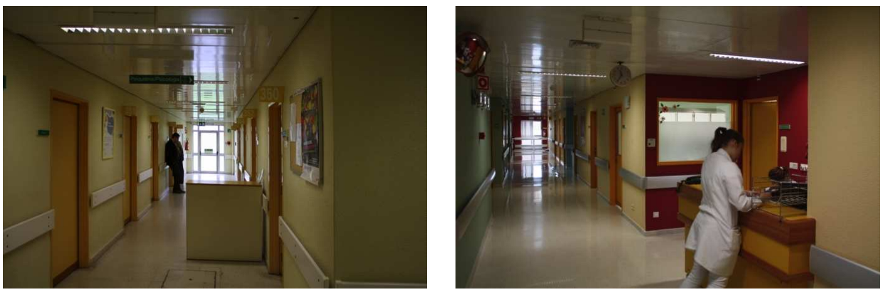

FIG. 7 - Before and after: using colour to promote way-finding. Hospital de Santo André, Leiria.

Colour Study: João Pernão, Luís Bissau, Carla Lobo.

e) Using natural light variation to enrich the architectural experience

We have studied two ways for applying this concept: texture / gloss difference, and colour reflection.

The interplay between light and matter is a key issue in designing good architecture. Peter Zumthor (2006) argues that the materials in architecture should be chosen by the way they reflect light. Stone, wood and other raw materials' finishing, as well as the gloss level of paint, are fundamental decisions for space perception. Glossy finishes have the ability to convey and reflect light and colour variations from the environment in a much stronger manner than matte ones. But it is the difference between them that produces balanced and aesthetically pleasing spaces. In FIG. 8 we can see a simulation of the difference between a choice of matte paint on the walls, on the left, and glossy on the right. The choice of the glossy surface produces a virtual expansion of the space's dimensions through the reflection on the walls.

FIG. 8 - Matte or gloss finish could dramatically change the space perception. Francisco Arruda School, Lisbon.

Colour Consultants: João Pernão and Maria Capelo. Photo Laura Castro .Caldas/Paulo Cintra.

In Portuguese architecture, we commonly use glossy glazed tiles (azulejos), as a wainscot in the lower part of the walls, for aesthetic and protective reasons. This glossy part of the wall plays a perceptual game of ephemeral reflections, always transforming space perception as you walk through a room, or as the sun strikes it at different hours of the day. With this in mind, in a colour study for a secondary school we define a unique colour for the wall, but we choose a paint with a gloss finishing for the lower part a matte paint and for the upper part (FIG. 9).

When light strikes a coloured surface, the result is a reflection of coloured light. That coloured light could tinge the space nearby. We can notice this phenomenon in our everyday life as the sun reflects the blue of a swimming pool, or the green of the grass into a room. This ephemeral variation of the reflected colours could be used as a tool for architectural design, relating space perception with time (Pernão, 2014).

FIG. 9 - Gloss and matte surfaces could bring aesthetical quality to architectural space. Palácio Fronteira, Lisboa / Francisco Arruda School, Lisbon. Colour Consultants: João Pernão and Maria Capelo.

In Braancamp Freire School we tested this concept using yellow to paint the skylights in the atrium, giving that space a continuous variation of warm tones during the day. To balance this accentuation, we paint the auditorium blue, colour which reflects on the white painted walls nearby (FIG. 10).

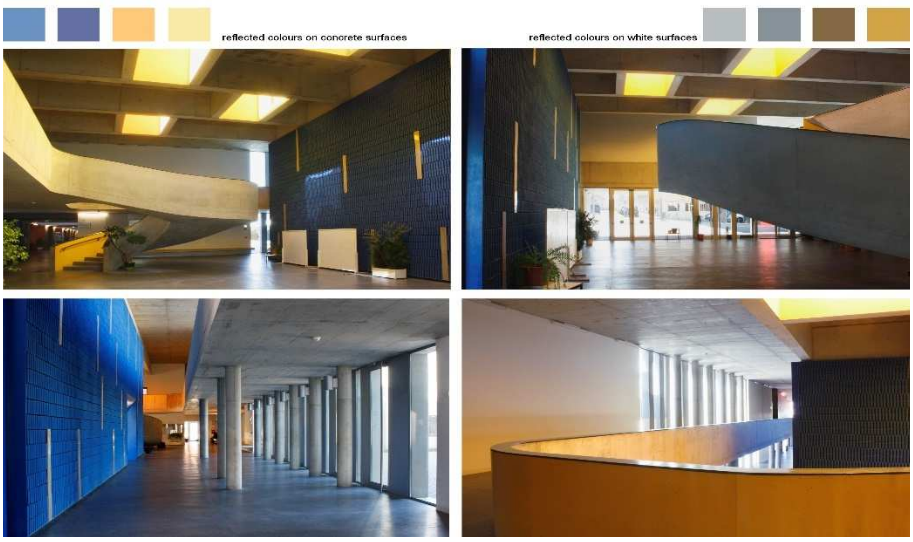

FIG. 10 - Colour and light variation produced by reflected colours transforms space perception during the day.

Braancamp Freire School, Lisbon. Colour Consultant: João Pernão.

In classroom spaces, painted white, light is reflected in the coloured concrete exterior surfaces near the windows. The difference between inherent colour and perceptual colour varies during the day, transforming the classroom space in a rich architectural experience (FIG. 11).

FIG. 11 **-** Reflected colours in the classroom. Braancamp Freire School, Lisbon. Colour Consultant: João Pernão.

4. Two much or too little colour and light

Being so important for the perception of the built environment, light and colour are often wrongly used, most of the times due to lack of knowledge, some of the times due to a blind repetition of an aesthetical stereotype.

One of the most common mistakes is related to the use of pure white in architecture as a dominant colour. White has the highest luminous reflectance factor of all colours, and for that reason should be used with caution, once it can easily produce glare that, when accompanied by high levels of natural or artificial light, could be harmful to our health, causing physical, mental and emotional discomfort (Mahnke, 1996). For this reason, white should not be used as the main colour in an environment where people stay for a long period of time, for instance classrooms, offices, etc. The continuous action of the eye muscles, opening and closing the pupil, trying to focus less illuminated subjects, will result in eye fatigue. It is not a question of aesthetics, it has a physiological one, and that should not be questionable.

Another factor is that the white paint nowadays used as default is the strongest and most reflective white ever available in our entire history. This white was only possible with the manufacturing of Rutile (titanium dioxide) as a pigment and it is used because of its chemical stability and excellent hiding power (twice the opacity of pure lead white). But it is very uncomfortable, and looks false (plastic) in architectural surfaces. It has to be subdued with a small percentage of blackness and colour (yellow + red) for correct use as dominant colour.

Architects, in general, have a serious flaw in their education: schools of architecture are increasingly more technical and less artistic, which leads to the total absence of harmony and aesthetic issues in their curricula, such as the use of colour. The colour white appears as a default, a non-choice, something that is neutral. But it is not.

There is another reason for not using achromatic white, related to its psychological meaning: a sterile and cold environment, only related in nature with snow or ice surfaces. The most stressing environments, unfortunately used for sensory deprivation in some extreme police and military cells, like in Guantanamo, are painted white in all surfaces and use high levels of illumination. These environments are inconceivably similar to others connoted with a “clean” and minimalist architectural aesthetic (Pernão, 2010). But for these ones, people generally pay high amounts in order to live in them!

David Batchelor (2007) names this refusal to use color - *Chromofobia* - stating that the issue is not white but the generalization of white (whiteness) because it makes it abstract.

This *Chromofobic* characteristic was well patent in a recent congress about colour and architecture when we were asked the reason why contemporary architects always dress in black and paint their buildings white.

There are international recommendations for the correct percentage of luminous reflectance factor in classrooms and other public spaces designed for long periods of people's permanence. Those numbers aim at 25% of blackness (NCS system) while the common white has 5% of blackness. The negative effect of excessive light reflection in architectural surfaces could be amplified by the use of gloss or semi-gloss finishes, as well as the incorrect layout of light sources.

Adopting these recommendations and thus removing the glare of walls can correct many situations of lack of concentration and eyestrain complaints in work environments.

Conclusions

With a phenomenological approach to space perception, we state the importance of light and colour to the quality of the built environment. We should always study these two elements together because they are inseparable, being the cause and effect of our image of reality.

Architects should be more aware of this importance in order to apply light and colour considerations right from the first stages of the architectural design process.

Colour should not only be seen as the paint covered surfaces but also as all the materials that assemble the visual field in the built environment.

Colour perception is based on variation, framed in time and always derives from three elements: Light, object, and observer. Variation, the main factor for perception, should be used conscientiously in architectural design as a tool to enhance the quality of architecture and its relationship with the human being.

References

Albers, J. (1975), *Interaction of Color*. New Haven and London: Yale University Press.

Aristóteles (2001), *Da Alma (De Anima).* Lisboa: Edições 70.

Batchelor D. (2007), *Chromophobia*. London: Reaktion Books.

Bateson, G. (1987), *Natureza e Espírito: Uma Unidade Necessária*. Lisboa: Publicações Dom Quixote.

Da Vinci, L. (2002), *A Treatise on Painting*. New York: Prometheus Books.

De Heer, J. (2009), *The Architectonic Colour*. *Polychromy in the Purist Architecture of Le Corbusier*. Roterdam: 010 Publishers

Gibson, J.J. (1986), *The Ecological Approach to Visual Perception*. London: Lawrence Erlbaum Associates, Publishers.

Goethe, J.W. (1988), *Theory of Colours*. London: Frank Cass & Co.

Itten, J. (1997), *Design and Form: The Basic Course at the Bauhaus*. London: Thames and Hudson.

Le Corbusier (1977), *Vers Une Architecture*. Paris: Éditions Arthaud.

Le Corbusier (2006), *Polychromie Architecturale: Les Claviers de Couleurs de 1931 et de 1959*. Arthur Ruegg (Ed.). Basel: Birkhauser.

Lynch, K. (1982), *A Imagem da Cidade*. Lisboa: Edições 70.

Mahnke, F. (1996), *Color, Environment and Human Response*. New York: John Wiley and Sons.

Merleau-Ponty, M. (1993), *Eye and Mind*. Chicago: Northwestern University Press.

Pernão, J. (2010), The *Otherness* of White: Elements for a Better Understanding and Use of the Colour White in Architecture. *Colour* *and Light in Architecture_First International Conference 2010_Proceedings.* pp.154-159*.* Accessible at: http://rice.iuav.it/195/1/07_pernao.pdf

Pernão, J. (2014), *Reflected Colours as a Tool for Architectural Design*. Proceedings: X Conferenza del Colore, Università degli studi di Genova, 10-11 September.

Zumthor, P. (2006), *Atmosferas*. Barcelona: Gustavo Gili.

Silva, G. (2016), Electro-Ceramics Candal, V.N. Gaia; The production of electrical apparatus. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.80-97

ELECTRO-CERAMICS CANDAL, V.N. GAIA; THE PRODUCTION OF ELECTRICAL APPARATUS

Graça Silva[1]

ABSTRACT

The company Electro-Ceramic Candal, founded in 1914 and in operation until the late 1980s, today's business park, Candal Park, SA, was an important ceramic production company of the city of Vila Nova de Gaia (Portugal), either by the diverse number of products it produced, and the electrical apparatus production of high and low voltage, or the role it played nationally, at the height of national electrification, and internationally, with the supply to European cities in the post-World Wars of electric equipment for the reconstruction of their cities.

Around 1948, Electro-Ceramics possessed an important laboratory for testing the production of high voltage electrical apparatus and this is well documented. Not so with the production of small electrical porcelain appliance (lamp holders, various switches, ceiling rosettes, junction boxes, components of electrical panels, etc.), which we try to study, as main goal of this research.

The lack of written documentation led us to look for other sources of information, including oral information, interviews with a former engineer of the company, and access to non-printed documentation from former directors. We will present some results, although it is a work still in progress, and our goal is to continue this study, deepening better knowledge of this company, yet so little explored.

KEYWORDS

Production; Electrical Apparatus; Museology; Industrial Heritage

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Introduction

The Electro-Ceramics Candal factory has labored with the production of ceramic parts made for electric circuit components and many other different products in Vila Nova de Gaia, Portugal, for more than half of the 20th century. It is, nowadays, an important example of conversion of industrial areas, with different purposes and uses: Candal Park - Company and Business Center, a park holding more than a hundred and ten resident enterprises. The study of its history and memory is yet to be expanded, and this is important due to the importance of preservation of technical and industrial heritage in its multiple aspects: communication and availability, benefits and development of the several communities. In a time where international innovation and economy do not sympathize with the existing stagnation, Candal Park may become part of the group of exemplary agents who show us that it is possible to conciliate new functions in converted areas with heritage value, which are not, none the less, not devoid of memory or context regarding its industrial past.

Purpose

The purpose of this contributory for the celebration of the International Year of Light intends to be the one of making it possible to get to know the company Electro-Ceramics Candal, especially its production of small electrical apparatus made of porcelain. This contribution presents itself as the means of initiating a larger study which is intended to be carried out. We intend to contribute towards the preservation of memory and towards the marketing of the industrial and cultural heritage left to us by Electro-Ceramics, towards the study and the collection's characterization, which is composed by the Candal Park's own administrative facilities, by small electrical apparatus, incomplete parts of electric switchboards, telephony appliance, domestic pottery, coins minted out of porcelain and other ceramic objects, as well as by documentation, in the form of record books, guest and dedication books, high and low voltage catalogs, photo albums and graphic catalogs of ordinary pottery.

Notes on the company's history

In 1942, a limited company was founded, with the designation of Mourão & Cª.,Lda. Its deed dated from the 17th of January. Its manager, Joaquim Pereira Ramos had already created, in his own individual name, a small workshop on the street "Rua 24 de Janeiro", in Lisbon, with the purpose of producing electrical apparatus, acquiring the raw porcelain that he required for production from the factory of Porcelain factory of Vista Alegre, in Ílhavo, Portugal. The hardship in the creation of this small workshop and in the acquisition of the porcelain he required, made him purchase, in the name of this already referred company's name, a new land property, in a place called "Lugar da Fonte das Regadas" in Candal, Vila Nova de Gaia. In this place, he based the headquarters of a small facility in Quinta das Regadas, where he assembled his small industrial factory, with only 40 employees. He, then, started to produce electric porcelain in an area of just 1200m^2 (Guimarães, 2009, p.13).

In 1915, the company Mourão & Cª, Lda gives rise to "Empreza Electro-Cerâmica, Limitada". Having a distinct designation, the company Empreza Eletro-Cerâmica, Lda, had the purpose of *"practicing the industrial and business trade of porcelain articles, spare parts, electric devices and any other objects that its partners may deem convenient for the company to produce"* (Guimarães, 2009, p.14).

The First World War imposes its hardships upon Electro-Ceramics, as well as upon the other industries in the country: many financial hardships due to, above all, the national market's protections, to the lack of raw materials and difficulties in importing coal. However, and despite these hardships, the company expands its territory and gives rise to a growing Industry: producing electrical apparatus for low voltage facilities. These were, at the time and due to the difficulty in importing this type of appliance, in great need (Saraiva, 1985)[2].

In 1919, the already referred hardships lead to a new company reorganization and the company "Empreza Electro-Cerâmica", S.A (referred as E.C)", is formed. From this day forward, the company gains new energy and starts to produce, besides the already usual small appliance, the Bergmann tube[3]. A small laboratory is also built with the purpose of designing and producing high voltage isolators, equipped in 1922, for tests of up to 222 000 volts. A laboratory that was already by then acknowledged as the best laboratory in the Iberian Peninsula, and one of Europe's best, under supervision of the engineer Augusto Bastos Ferreira do Amaral. The E.C.'s management also had the ambition of making different products. For this, they acquire, in 1920, some old rustic facilities in Regadas, for the construction of a department containing packaging and new offices. They acquire also new land with the purpose of establishing two new industrial production units for electric lamps and electric conductor wires.

[2] Saraiva, José Nicolau Vilar (1985), *Apontamentos sobre a vida da empresa Electro Cerâmica desde a sua fundação até à sua compra pela fábrica de porcelanas da Vista Alegre*. Non-printed document, lent by the management of Candal Park. José Nicolau Vilar Saraiva was incorporated in the E.C. in the year of 1924 to work in the metallurgical department, which he then began to lead in 1926, among other roles. Around the year of 1926, he starts to work as the company's Technical Manager. Data provided by the author in his own notes.

[3] The Bergmann tube was made of a tube of soaked paper, covered in wrought iron bands or zinc, destined for the protection of electric wires in a distribution system, with a high level of security (Saraiva, 1985).

However, these new projects are not carried out due to financial difficulties (Saraiva, 1985).

In 1926, the company faces a big crisis and is forced to get a loan in the bank Companhia de Crédito Predial Português, in the amount of 9.000.000$00. In 1936, the company establishes an agreement with the porcelain factory "Fábrica de Porcelanas da Vista Alegre", in which each of them acquires 50% of the Porcelain Society's capital and agrees not to carry out sales in certain regions of the country, so that the society is made feasible in those regions (Saraiva, 1985).

The E.C. was, without doubt, one of the most modern enterprises of its time and one of the first companies to produce electricity for its own consumption and for the production of its own porcelain. It had a power station with synthesis gas and two engines, an Otto horizontal model of 100HP, and a vertical one of 4 cylinder with 300HP of the Campbell brand. These would activate an alternator of 65 kVA and another one of 210 kVA. It even provided electric energy for the little public illumination of the municipality, while the negotiations between the Gaia City Council and the hydroelectric station of Varosa were taking place, as a response to the local councilor's request, who was at that time (1920/21) Armindo Ramos, Secretary of the General Assembly of the E.C.. The power station recovered its full strength during the Second World War, when there was an urge to control the usage of electric energy (Saraiva, 1985).

In 1945, the E.C. was once again highly indebted and its creditor, the Companhia Geral de Crédito Português bank executes its last guarantee, which corresponded to 99,98% of the company's stock, to settle the debt. Thus, the Companhia Geral de Crédito Português and the porcelain factory of Vista Alegre make an agreement in which all company debts are settled and a new loan for the economic reorganization in the amount of 5.000.00$00 was requested (debt settled in 2005). This way, the Grupo Vista Alegre became the only domestic and decorative porcelain producer, as well as of electrotechnical porcelain and small electric appliance. The E.C. starts focusing the production on small electrical apparatus, isolators, plastic and Bergmann tubes, as well as of PVC (polyvinyl chloride) pipes, while the table's porcelain is focused on the Porcelain Society. An economic reorganization of the company takes place, now equipped with new and more modern technology, favored by the country's new strength in electrification and by the openness of international markets (Guimarães, 2009).

In 1964, a new company branch is inaugurated in Luanda, Angola, whose production was mostly based on PVC, but also in small electrical apparatus and new products in the growing market, particularly the hard PVC pipes. This product starts being greatly adopted throughout the whole country for water supply and sanitation systems. The following decade is marked once again by strong movements, especially after 1974, due to various factors, such as the loss of the colonial markets, the opening of national borders, the competition from big economies, the process of finalizing national electrification and the strong demanding spirit of the time, with the ongoing salary raises and collective contracts.

With Angola regaining his independence in 1975, the branch in Luanda is lost. This phase is only overcome by the end of the 1980's, with a new reorganization. In 1989, the company's activities are split into different individual companies, thus being born the Ecoplás, Empresa de Plásticos Técnicos, S.A. (PVC pipe production), the EC-Electric Appliance, S.A. (small electric appliance production), and the Cerisol, Ceramic Isolators. This last one is the only company who is still active nowadays. On a second phase, Ecoplás, S.A. is sold to the Finnish group NESTE and the EC- Electrical Apparatus, S.A. is sold to GE Power Controls Portugal (Guimarães, 2009).

From 1989 onwards, the E.C, owner of the facilities and company land, transforms the area in an Industrial Park, whose first residents are the E.C. Electrical Apparatus, S.A. and the Cerisol Ceramic Isolators, S.A., who rented their facilities there. And it is thus that "*located in Vila Nova de Gaia, in an area fit between the highway and an urban yet rural town(...) the built area of Empresa Eletrocerâmica do Candal is going to develop itself throughout time and through transformations of a farm territory into a factory territory, until the actual setting of Industrial Park."* (Oliveira, 1998, p.233).

The Candal Park -Company and Business Center of today as we know it, has transformed itself into a reorganization area, as well as an area of urban industrial memory conservation.

Elements for characterization of production

Throughout the various decades of Electro-Ceramics existence, its production has been very varied. We will not here refer to the production of every article individually, but we shall focus on a few relevant aspects of the company's production and on its most relevant products, important for its characterization.

The company first focused on the production of porcelain for electric components and having, for said purpose and according to the engineer Saraiva (1985), four production systems: pressing process, joules, turning and slip process. We will refer only to the production through pressing process, for it is the one that constitutes the foundation of small apparatus, which is our object of study. We underline the lack of documentation and data about the process, at least until the present day, and the importance of oral sources, such as engineer Vasques de Carvalho's testimonial.

The crushing system was the most used system for the production of compressors, small isolators, ceiling rosettes and small entries, or components used in small electric devices, which after being metallized, were used in switches, commutators, junction boxes, power sockets, extension cords, etc.

The production of these components was of high relevance to Portugal, due to the ongoing phase of electrification of the country. It was also important for exportation. The E.C. was exporting to Spain, Belgium, Italy, Switzerland, the US, Argentina and Brazil, as well as to the Portuguese colonies in Africa (Soeiro, et al., 1995). After the two great wars, most European countries had multiple problems with production insufficiency, for they had to rebuild their cities and provide for their markets.

In 1920, it was necessary to increase the pressing process section, and it began to occupy a building from the old factory (Fábrica de Fitas do Aranha[4]). Here, they installed 120 presses and, in 1942, around 50 male employees were working there. With the expansion, it was necessary to hire more employees due to the needs created by exportation. Until the First World War, the production of small apparatus was focused only on raw apparatus. This increase of exportation led to the need of metal installation and the correspondent component metallization. Then it was built a facility of two floors: the ground floor, meant for metal production, and top floor, with the purpose of its assembling (Saraiva, 1985).

[4] This is the reason why they still refer to the E.C.'s factory as "fábrica do Aranha".

The electric installations, made in the 1920's, were all external and visible because they were being made in already finished facilities. Thus, in 1924, the major consumption was of the following products: switches, lamp supports, mignon supports, power outlets, ceiling rosettes, air fuses and fuses for E.C. distribution boards. The products that were mostly exported to Brazil were the ceiling rosettes, of a different model than those sold in Portugal. The orders were of around 50 000 to 100 000 units. The small apparatus sector kept growing. In 1924, the production was of around 500 pieces, but, by 1944, this number was above 2 000. And, naturally, we refer to the beginning of the national electrification process, adding up to the exportations (Saraiva, 1985).

The metal section was exclusively executed by women. From 1924 onwards, under the engineer Saraiva's command, the metal cutting process started to have two punctures with inverted positions instead of just one, for he thought that, this way, one could save more brass in the production of multiple pieces. The results were so positive that Mr. Saraiva was congratulated for the intervention, in spite of the company's financial difficulties, as he wrote in his own notes (Saraiva, 1985).

Small apparatus was always marketed through resellers, mostly in the cities of Lisbon and Porto. The agreement held between the reselling firms was the following: the company was limited to selling only to firms who would be part of the contract; these sales were done in minimal amounts, fixed for each article, and the reselling firms could not buy any material from the competitors, be it national or foreign. This agreement was in effect at least until 1935. With the purchase of the Porcelain Society's by the Vista Alegre group and by Electro-Ceramics in equal share, a new agreement was signed, more profitable for both companies, or, at least, in benefit of common interest. However, after the Second World War, the agreement was no longer valid due to the hardships in stocking of raw material. For this reason, the small apparatus business is passed on to storekeepers (Saraiva, 1985).

The isolator tube of Bergmann type started being produced in 1919 and had an exclusive period of 10 years, since it consisted in the introduction of a new type of industry. The acceptance of the national pipe took some time until it reached the buyers, but its qualities quickly stood out, and they were not behind the previously used pipes with Spanish origins. Also regarding the production of the Bergmann tube, hardships were felt in acquiring ribbon/tapes of wrought iron, meant for the soaked paper covering, which is part of the pipe (Saraiva, 1985). Thus, it was necessary to resort to the utilization of zinc strips, initially imported, and later obtained through zinc plate lamination (Saraiva, 1985).

Of great importance for the company's production was also the high voltage isolators production, backed up by the existence of a first lab in 1921, equipped for 220 000 volt tests, which was under the leadership of the electrotechnical engineer Augusto Bastos Ferreira do Amaral. The laboratory was equipped with two electrical transformers, one of them with 50KVA at 220 000 volts, a spherical spark gap, devices for artificial rain production and three electric test tables. In this laboratory, many isolator tests were conducted for power lines, mostly for the firm Companhia Hidro-Elétrica do Varosa (Saraiva, 1985).

In a well performed attempt of securing the production of competitive ceramic isolators in the country, a study and test laboratory (GLE) was created in 1948, whose purpose was to research raw material, ceramic clay, and the raw material handling processes, in order to be able to create high and controlled quality products. It is still possible to see the laboratory facilities in Candal, which was under the design and management of the engineer Prof. Manuel Corrêa de Barros. The building englobes two parts: the first one has two floors, and the second one, destined for high voltage lab. When construction of the GLE was finished, it contained a study room, offices, a design room, a library, an electrotechnical lab to perform electric isolator tests, a laboratory for physic and chemical tests, the study of raw material and ceramic clay, and a small ceramic lab, for the study of ceramic production methods (Guedes, 2003). The official inauguration of this laboratory was on the 15th of February in 1952 (Barros, 1952).

Production of ceramic clay in the General Laboratory of Studies

According to Saraiva (1985), the production of pottery in the E.C. was motivated by the competitors that the group Vista Alegre made in the production of electrical apparatus, in 1921. The painting section only turned active in 1922. The raw materials used in the paste for pottery production were china clay, feldspar and clay from Pombal, and, for the glass, feldspar, quartz and calcium carbonate. The pottery business was handled through storekeepers, who would frequently evaluate the decoration of pieces that would need to be replaced after a while, in order to fulfill the market's demands. On the other hand, the pottery color in the E.C. was not as white as of the Vista Alegre group, and was, for that, less successful. This was due to the use of china clay from a place called Senhora da Hora, which did not provide a color as white as the china clay from deposits in Ovar/Vila da Feira, and those were used by the Vista Alegre group. So, the E.C. decided to acquire their china clay from these deposits and their paste began to contain 1/3 of china clay from Ovar and 2/3 of china clay from Senhora da Hora, resulting in an improvement in the pottery coloring. It would not, however, match the whiteness of the Vista Alegre group's pottery.

It is also due to Saraiva (1985) that we know that tests were made for the production of Bakelite (Polyoxybenzylmethylenglycolanhydride)[5] and the E.C. started producing it for small electrical apparatus and for small ceramic electrical apparatus lids. By the end of 1940's decade, the production of PVC is included in the production of electrical conductors, and later, accessories and liquid conductor pipes.

The mintage of porcelain coins is noteworthy of recognition, due to its significance and high relevance. After the First World War, the nation had a generalized lack of coins for change, namely of 1, 2, 4 and 10 cents. For this reason, municipalities were authorized to issue paper notes, who would be rendered useless after a few uses, due to the lack of paper quality. Thus, the Gaia municipality placed an order to the E.C. for ceramic coins. The coins had a crown with King Ramiro's mural in the backside, and at the end, the year. On the front and middle, the amount and the unit: cents (centavos). By the end of 1922, the Tax office, by command of the Portuguese Bank, began collecting the coins once again. The municipality proceeded onto the exchange of the coins which were active in its treasury (Saraiva, 1985).

The production of small electrical apparatus

Much of the paste that exceeds from the production of high voltage isolators was used for the production of small appliance.

The preparation of the ceramic paste for electrical apparatus required multiple phases. Taking Professor Corrêa de Barros' description (1952)

[5] Synthetic resin formed by combination, through polymerization, of phenol (C_6H_5OH) and formaldehyde.

into account, the raw-material grinding process was made through ball mils, also known as “alsings”. Before inserted in the mills, the raw materials were weighted, as well as the used silex pebbles, and the required water was measured. The amounts were previously defined, in order to provide the thinness required for grinding. Then, the paste would follow to the pressing filters, after making it through vibrating screen/sieve, which would separate the particles of excessive diameter, and through magnet splitters, which would eliminate any iron that it could contain. After the paste left the pressing filters, it would go through an aging period and would be sent into a vacuum kneader machine, where it would be mechanically disaggregated and, when in a high state of thinness, forced into a vacuum chamber, in order to remove all the existing air. It would be extracted from the chamber by a screwing system, making it go through a nozzle which would calibrate it in cylinders, adjusting it for the next phase, “balling” (Barros, 1952).

The cylinders that would leave the kneader would be cut by a wire and put over a zinc covered table, where parallel and equidistant wires would lay, in order to cut the paste into sufficiently sized pieces that would fit their respective parts. The pieces of paste would, then, be hand mashed into balls and put in the geometric containers to be sent to the press machines. The press machines were manual, with warmed rotatory cleat (Barros, 1952).

The production of small apparatus in which our study focuses was fundamentally done through pressing, as already referred. In this production, according to engineer Vasques de Carvalho’s testimonial, they used something called dry grinded paste, which would then be mixed with a lubricator (fuel-oil), put in the geometric containers and then pressed. The excess of paste would be expelled from the mold. It would then move on to the deburring phase, where all imperfections would be deburred before moving on to the next phase, consisting of the laying of ceramic glaze. Next, it would be sent into the oven, where it would cook with a temperature of 1 100°C. This process would be called moist pressing/wet integration. There was also dry pressing, but its use was not that common. In this case, the pastes would be rich in talcum (magnesium silicate). The talcum would be put in the molds in the right amount (there is no exact data of this amount) and then the paste would be pressed, and, unlike the moist pressing/wet integration process, nothing would be extracted from the mold, and no excess would exist. In this situation, the paste would come out of the press machine already dry, moving immediately on to the glazing and oven section.

This whole section was set up, in order to save room. The paste would move between processes from one table to the other, where it would be moved by the next employee (Barros, 1952).

In the drying section, the dryers were set according to pressure and humidity levels, to make sure that this process would go on uninterrupted. The heating process was accomplished through steam. The dryers had a psychrometer that allowed verification of temperature and humidity of outside weather. Then the glazing by immersion would follow. The ceramic glaze's main purpose is to provide a hard shell, non-absorbing and easy to clean (besides the aesthetic purposes, of course), thus contributing towards the improvement of mechanical and electrical properties (Barros, 1952).

After the glazing, the pieces would be sent to the ovens, which could be a tunnel-like oven or an intermittent coal furnace, shaped like a bottle. The cooking conditions were inspected with thermoelectric and optic pyrometers and with pyrometric bars called “Holderoft”, put in different spots of the oven.

Right after leaving the oven, the pieces would be sent to the picking section, where each and every one of them would be inspected to minimum detail and a book would be filled, where the approved stock would be listed, as well as the ones that would be considered garbage and their respective flaws. The flawed pieces would be put on a table and reexamined, in order to make sure the flaw they contained would interfere with the piece’s behavior or if it could be excluded from flawed condition. On the other hand, it was necessary to verify if the flaws were a product of bad manufacturing or poor choice of cleaning methods, poor usage of oven, etc. After the selection, the pieces would follow to the assemblage of metallic components’ section. Lastly, they would be packed in boxes of different amounts, according to the buyer’s needs (Saraiva, 1985).

It was not possible to characterize the production of metals and copper alloys (bronze and brass) and iron alloy due to lack of information. However, according to Eng. Vasques de Carvalho’s testimonial, there were lathes, press and cutting machines, as well as screw making machines and those who preceded the bronze plates bending machines, such as in the case of production of cylinder thread of lightbulb supports. The bronze plates would go in a machine and, through multiple bending processes, it would provide the plate its cylindrical aspect. Those processes would have to be highly supervised, since the bronze, as a sensible alloy (copper and tin), could break if pushed or stretched too far. The cutting machines would mostly do the cut in small plates, in order to fit the molds for the necessary parts.

And to be concise, the screwing machines would receive the wires, which would be hit on the top, to form the heads. Then, they were cut more up ahead, with the intended size, originating a head with a lean body. They would go through two iron cylinders, which as they rolled would originate the thread.

Engineer Vasques de Carvalho refers to the existence of nickel in the copper alloys, namely in bronze, and of screws in nickeled iron alloys, as well as silver wires for the fuses in the small electrical metallized apparatus. According to Carvalho (2014), phosphor bronze was also used in small appliance metallization. Because it had more elasticity than tin bronze, it could be used in the places where a bigger elasticity was required, without impairing the resilience. The thinner parts were, in fact, usually made of phosphor bronze. They could also use aluminum, just for its cheap cost, but it was also used in less amount due to low conductivity compared to copper and bronze, and for its bigger oxidation potential. Iron and steel were also used as electric conductors, but as to what the E.C. concerns, these materials were more used in alloy, in production of screws for the parts' assemblage process, although few examples of its usage in small electrical apparatus are found.

Conclusion

The purpose of this research was to make a preliminary contribution towards the appreciation and preservation of technical and industrial heritage, more particularly the heritage connected to circuits and illumination systems, through the study of the company Electro-Ceramics Candal and part of its collection. This way, we tried to share knowledge about the most relevant historical facts and of the main production aspects of small apparatus with porcelain, detailing it as much as possible. Far from being finished, our purpose is to expand it and develop it, identifying, locating and exploring other sources of information, in order to contribute towards the preservation of this city's inhabitants' collective memory and towards a future legacy of the old industry's work spaces.

References

ADP – Po 4 º, 844, 27v – 28v

Barros, M.C. (1952), A Reorganização da Indústria da Porcelana em Portugal. *Boletim da Ordem dos Engenheiros, Vol. 1 nº 17*, pp. 117-140.

Carvalho, V.D. 21-01 2015. *RE: Entrevista.*

Electro-Cerâmica (1944), *Empresa Electro-Cerâmica, Vila Nova de Gaia, Portugal. Catálogo de Baixa tensão nº 22.* Vila Nova de Gaia: s.n.

Guedes, M.V. (2003), *Um Laboratório Eletrotécnico no Candal, in Boletim da associação dos Amigos de Gaia nº57.* [Online] Available at: http://paginas.fe.up.pt/histel/MCB_labAT.pdf [Consulted on the 10th of December 2014].

Guimarães, H. (2009), *Vila Nova de Gaia. Electro-Ceramica 1919-2009.* 1ª Edição ed. Vila Nova de Gaia: Modo de Ler, editores e livreiros, Lda.

Oliveira, J.M. (1998), *Empresa Electro-Cerâmica do Candal - Um caso de Reconversão Funcional. A Indústria Portuense em Prespetiva Histórica: Actas do colóquio.* [Online] Available at: http://ler.letras.up.pt/uploads/ficheiros/5291.pdf [Consulted on the 10th of December 2014].

Saraiva, J.N.V. (1985), *Apontamentos sobre a vida da empresa Electro Cerâmica desde a sua fundação até à sua compra pela fábrica de porcelanas da Vista Alegre.* Vila Nova de Gaia: s.n.

SARL, E.-C. (1967), *Material Eléctrico de Baixa Tensão - Catálogo.* Porto: Of. Gráf "O Comércio do Porto".

Soeiro, T.; Alves, J.F.; Lacerda, S. & Oliveira, J. (1995), A Cerâmica Portuence, Evolução Empresarial e Estruturas Edificadas. *Portugália, Nova Série, Vol. XVI*, pp.203-287.

LIGHTS AND COMMUNICATION AND MEDIATION

Faro, S. (2016), COMMUNICATE. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.99-109

COMMUNICATE

Suzana Faro[1]

ABSTRACT Communicating is one of the most complex, challenging and interesting phenomena of human activity, which involves discovering the Other and the technological inventions that have allowed Man to reach further and faster. This is the theme of the Transport and Communications Museum's long term exhibition: COMMUNICATE, opened in December 2012 - a challenge in constant evolution. This exhibition is based on an anthropological concept of Communication and consists of a path that challenges visitors to experiment and reflect upon the forms of communication that Man established to interact with others and with his surroundings. Light is a central concern not only in the exhibition space but especially in its contents:

.*Senses Alert*: sight is the perception of the physical surroundings through the light they emit or reflect.
.*Step into the light*: interactive project where you use your body, voice and senses as a means of communication, combine them with technology and make it a single living, visual and musical instrument.
.*The Message*: it can take many forms and is omnipresent, especially in today's digitised world. The Message acquires meaning in a relationship and requires a code, a context, a medium. The way it spreads and circulates often receives powerful injunctions of technique, art and creativity. The codes broaden the universe of communication and facilitate human interaction: ColorADD (for people incapable of distinguishing colours); Morse (messages transmitted through sound, light or visual signals); Braille (system of reading and writing through touch for blind people); Sign Language (communication using hand movements, facial expression and body language)...
.*Messengers*: the discovery that the chemical element selenium could transform light energy into electric pulses, meant that images could be transmitted through an electric current: TV became a powerful medium, penetrating homes transmitting information, ideas and ideals.

KEYWORDS Communication; Light; Exhibition; Message; Challenges

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COMMUNICATE exhibition

This contribution aims to focus on a different point of view about something as ancient as humanity itself: communication.

This is the subject of the Transport and Communications Museum's long term exhibition: COMMUNICATE.

The Museum is settled in the former Customs House of Porto: Alfândega Nova do Porto. As any other Customs House, this was a *House of Communication*, both a place of trade and a door open to the world, a meeting place for the exchange of ideas, knowledge and experiences: *This is what Oporto was like: a city of trade, so deeply involved in the phenomenon of exchange, in communication and as a meeting place for different peoples that it chose to call itself the port. As simple as that. That's how it got to be a cultural arena, a place that encapsulated the experiences and lessons lived and learnt during daily life at sea* (Barros / Museu dos Transportes e Comunicações, 2012).

Communicating is one of the most complex and interesting phenomena of human activity. By including this theme in its mission, the Museum accepts challenges that are in constant evolution. This requires a level of permanent creation and renewal of approaches and experiences to surprise and involve the public in moments deeply marked by reflection and interaction. The display attempts to convey *the polysemic wealth of Communication, in its various forms. It also includes the paradoxes of a so-called 'communication' society, which continues to have countless difficulties in integrating differences and in overcoming the barriers facing communication processes, whether their origins are cultural, linguistic or any other* (Museu dos Transportes e Comunicações, 2012).

The paths of Communication have always been open and challenging. They may involve discovering the Other, whether he is on our doorstep or at the far reaches of the galaxy, or technological inventions that have always allowed Man to reach further and faster. The same can be said of this exhibition, which we invite you to visit: our aim is for the visitor to reflect upon a theme that is a key part of the world we live in and of the lives of each and every one of us (Museu dos Transportes e Comunicações, 2012).

This exhibition (FIG. 1) is based on an anthropological concept of Communication and consists of a path that challenges the visitor to experiment and reflect upon the many forms of communication that Man established to interact with others and with his surroundings.

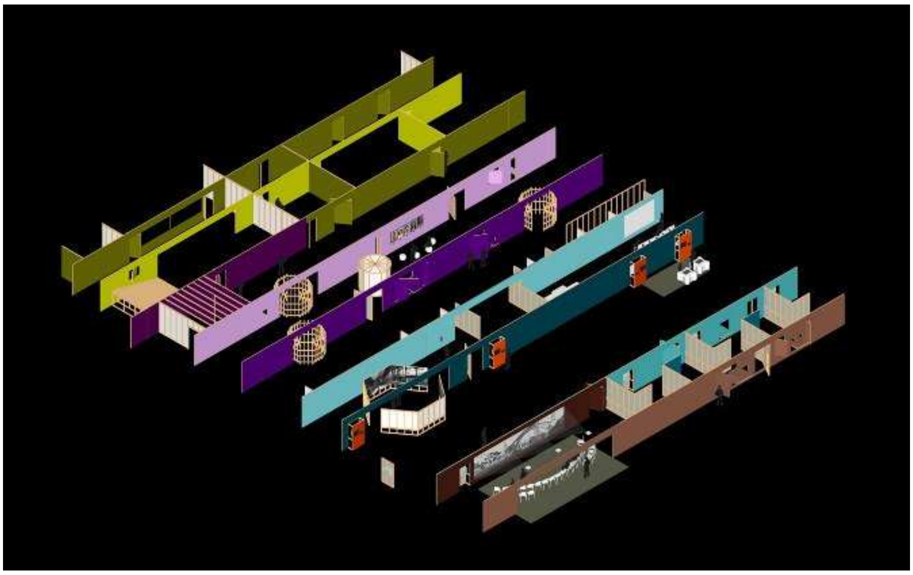

FIG. 1 - Communicate Exhibition plant, 2012, Porto. © Ainda Arquitectura | AMTC Archive.

The project began with the construction of *the idea*, connecting the museum to a small group of volunteers from different scientific backgrounds, meeting regularly for a few months. The approved idea then gave place to *a proposal*, granted by EU founds (QREN-ON2), which allowed the museum to develop the project and construct the exhibition, gathering together all museum professionals and several outer partners. Building the exhibition was a process of research and reflection; but it was, thus, a path of learning and good practice, tightening the ties between the museum and the community. This dialogue was essential for the making of the exhibition as well as for its former evaluation, before opening to the public. The exhibition was built based on partnerships creating a web of links (such as communication does) which enabled the museum to get closer to its visitors – "enlightening" the museum and its public.

Light is a central concern both in the exhibition space and in its discourse, the same way it is in any museum exhibition. But for COMMUNICATE exhibition it is also a main theme for this path interspersed with stations that challenge the visitor:

- *Senses Alert*: Our senses are the first thing we use to communicate with the world around us. With no technological intervention, human perception results from innate anatomical and cognitive mechanisms: structures such as the skin, eyes, nose, ears or mouth that specialise in detecting *stimuli* and are responsible for encoding and sending information to the brain. Whenever we receive a sensory *stimulus*, it is immediately transformed into a nerve impulse and transmitted to the whole organism so that we can respond adequately. Sight is the perception of the physical surroundings through the light they emit or reflect. It is considered the dominant sense, not only because of the large amount of information it receives, but also because it is visual information that prevails when the records of the various senses come into conflict. The visual process starts at the moment the ray of light enters the eye: the pupil receives and determines the amount of light that enters; the cornea protects the eye and enables it to focus on the visual elements (close-up or distant); the retina receives the focused images inverted, converting them into electric impulses – the language of the nervous system (Museu dos Transportes e Comunicações, 2012).

- *Arena of the senses*: a sensory experience that frees the imagination, appealing to all our senses, where light and vision play an important role. It puts the visitor at a non-place, a passing point (S. Bento Train Station), where *everyone is no-one, because no-one knows anyone*. But it is, at the same time, a well-known place of the city, full of identities and people that created the city's soul. The memory of these spaces may well be fleeting, but it holds the moments and stories that form what we are today (Museu dos Transportes e Comunicações, 2012).
- *Step into the light* (FIG. 2): it is an interactive light design project that promotes a new way of communicating, where you use your body, voice and senses as a means of communication, combine them with technology and make it a single living, visual and musical instrument: the machine reacts with light and sound, according to the intensity of noise around it.

FIG. 2 - Communicate Exhibition: "Step into the Light", 2012, Porto. © AMTC Archive.

You can use mobile phones or other communication devices to extend the experience outside the Museum, to any part of the world (Museu dos Transportes e Comunicações, 2012).

- *The Message*: it can take many forms and is omnipresent, especially in today's digitised world. A road sign, a metaphor, a symbol, an email, a tear, a silence, a song, a gesture or a photograph – these are just some of the countless possibilities and forms of the Message. It does not constitute communication in itself. To do so, the Message has to come into contact with somebody capable of giving it meaning - someone who understands the code in which it is constructed and is capable of applying it within a framework of senses and, as a result, is able to take decisions, act or react. The Message acquires meaning in a relationship and requires a code, a context, a medium. The way in which it spreads and circulates often receives powerful injunctions of technique, art and creativity. The codes broaden the universe of communication and facilitate human interaction (Museu dos Transportes e Comunicações, 2012) (FIG. 3).

FIG. 3 - Communicate Exhibition: "7 billions of Others" project, 2012, Porto. © Egídio Santos | AMTC Archive.

Language is the human capacity to acquire and use complex communication systems. But there are other linguistic systems that progress through different stimuli: the language of signs, written language and the construction of artificial codes broaden the universe of communication and facilitate human interaction in the widest of contexts. Light performs an important role in many of these codes:

- *ColorADD* - Colour blindness is a congenital alteration, a disturbance in visual perception which consists of the incapacity to distinguish a specific set of colours. In a world in which colour variety plays a fundamental role, misinterpreting colours may constitute an obstacle, even in everyday tasks, and make social and even professional integration difficult. ColorADD is a code created for people who suffer from this incapacity to distinguish colours. This is an inclusive system based on the principle of attributing basic symbols in the three primary colours. These symbols are combined or undergo variations, allowing them to represent other colours or indicate whether the shade of a certain colour is light or dark (Museu dos Transportes e Comunicações, 2012). This universal code for the colour blind was developed by the communication designer Miguel Neiva.
- *Morse Code* - In 1837, Samuel Morse invented a telegraph that used a device with a single key which, when pressed, sent an electric pulse which was converted into a graphic, sound or light signal (Morse code). These signals can be intercepted directly by

anyone who knows the code, without the need for specific equipment. It was the main system of communication in the 19th century and beginning of the 20th. However, this discovery meant an even greater challenge that would have to be overcome: to transmit voice at the same speed and distance as the telegraph (Museu dos Transportes e Comunicações, 2012).

- *International Flag Code* – Signalling using nautical flags is one common means of communication between ships (which also involves light), normally incorporated into two different systems: the International Flag Code and the Semaphore Code. The former consists of a specific set of flags which represent a letter and a composed message. The latter is based on the movement of two flags, similar to the movement of the hands of a clock, held by a signaller with extended arms. Each position corresponds to a letter, number or punctuation mark, allowing any message to be structured (Museu dos Transportes e Comunicações, 2012).
- *Braille* - This is a system of reading and writing through touch, developed by Louis Braille at the start of the 19th century. Blind from birth, Braille was inspired by a military communication system (night writing) which allowed soldiers to read any message in the dark (without light) through raised markings. The Braille system is based on a six-point grid (Museu dos Transportes e Comunicações, 2012).

  - *Sign Language* - Communication using hand movements but also facial expression and body language. Sign language has its own lexis, grammar, and inherent semantics, which vary according to country, culture and society. There are perhaps as many or even more sign languages in Europe as there are spoken languages. And for all of them light plays an important role to allow communication to happen (Museu dos Transportes e Comunicações, 2012).
  - *Road signs* – They form an essential communication system for keeping traffic in order. The system is therefore fundamental for traffic to circulate safely. There are several types of signs: vertical signs, road markings, traffic lights, temporary signs, traffic regulators' signs and drivers' signals (Museu dos Transportes e Comunicações, 2012).

- *Messengers*: in 1873, Willoughby Smith discovered that the chemical element selenium could transform light energy into electric pulses, which meant that images could be transmitted through an electric current: TV became a powerful medium. Considering all the inventions of the 20th century, few have had such a profound impact as television. The power and fidelity of visual communication had already been proved with photography and heightened with the cinema. But neither of these penetrated homes like television did, making it the most powerful medium ever for transmitting information, ideas and ideals (Museu dos Transportes e Comunicações, 2012) (FIG.4).

FIG. 4 - Communicate Exhibition: “Inside TV”, 2012, Porto. © AMTC Archive.

Despite the technological evolution and the already immense capacities of computers, only Internet came to raise their effectiveness to a completely different level. It enabled the spatial barriers of communication to be eradicated, almost unlimited access to information and the possibility of performing various tasks from home. Much more than just a new medium, the Internet and its development, through social networks, are a new environment, broadening the media eco-system exponentially (Museu dos Transportes e Comunicações, 2012).

What if we could stop being the viewer (FIG. 5) for a while and try the “other side” of a television broadcast? That is one of the many challenges of this exhibition.

FIG. 5 - Communicate Exhibition: “In the first person”, 2012, Porto. © Egídio Santos | AMTC Archive.

3, 2, 1... Lights On...!

References

Barros, A.J.M. (2012,) *Communicate* [Exhibition]. Porto: Museu dos Transportes e Comunicações, 26 Novembro.

Museu dos Transportes e Comunicações (2012), *Communicate* [Exhibition]. Porto: Museu dos Transportes e Comunicações, 26 Novembro.

Silva, P. (2016), Using 3D models in museums: The potential case of "Castro de Romariz 3D" project. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.110-122

USING 3D MODELS IN MUSEUMS: THE POTENTIAL CASE OF "CASTRO DE ROMARIZ 3D" PROJECT

Pedro da Silva[1]

ABSTRACT

Romariz Castro is a proto-historical settlement that was inhabited up until the roman age. Located in Aveiro district, this archaeological site shows superposition of constructions throughout the ages, demonstrating significant reformulations in architecture. Between 2011 and 2013, the "Castro de Romariz 3D" project took its first steps during the Master's degree in FLUP, by studying architecture and urbanism and reconstructing the historical village using 3D computer generated models. This project is part of the interpretation of Romariz Castro and the information can be accessed by the public through its dedicated website. Achieved by means of a computer gaming platform, this technology shows great potential in museums, as it can be used by the public, in a 'learning by entertainment' experiment.

Discussions about the impact of media and technologies in museums tend to take this impact as an opportunity for the museum to reinvent itself and ensure its survival in the XXI century. The reconstruction of archaeological sites in 3D and its exhibition in museums fulfils this paradigm; that visitors should develop knowledge through interactive activities. Likewise, a gaming platform like the one used in the project can maximize the physical and real experience of public by reducing the exceeding amount of quantitative perception of the historical information and by answering the most common questions in a playful way: how was this site in the past and how did its society organized itself? Is it possible to understand the 'Romanization event' by looking at the village's architecture? This gaming technology gives museology a new theoretical light - the impact between the real-world of the present and the virtual-world of the past in museum's visitors.

KEYWORDS Archaeology; Museology; Technologies; 3D Models; Castro de Romariz

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A brief archaeological context of the Romariz Castro

The Romariz Castro is located in the district of Aveiro, more specifically in the surroundings of the Romariz Village, in the municipality of Santa Maria da Feira (Military Letter of Portugal, page n.° 144). This archaeological site, which has height levels between 360 to 375 meters, is implanted in the vicinity of Inha, Ul and Uíma rivers, surrounded by an exquisite landscape: the Casal do Monte and Monte Alto mountains in the north; Monte de Goim in the east; in the west by the peaks bordering lands of Bajouca and Gândara towards south to Gaiate. There is also, toward the south and southeast, a flat land which currently locates the villages of Romariz, Vila Nova and Mouquim.

According to Almeida (1984), it is possible to define the Castro Culture of that time as the first stone civilization or the first petrified villages: for the author, this is more coherent than to call it an iron culture. The plans of these populated settlements were, more or less, circular and delineated by walls or curbs. These were relatively small villages, located at the top of hills with a low or average height, not far from rivers and fields, with peculiar organization of the infrastructures (Almeida, 1984; Silva, 1986). The interior spaces of these villages were composed of buildings also with circular or elliptical shape. As for the urbanization, these sites show two main evidences: a planned manner, wherein there is clearly a major axis, as in the case of Citânia de Sanfins (with older occupancy levels dated to about 500 BC); or a spontaneously manner, in which the Castro would suffer interventions over time in a self-organizing form of the population, as in the case of Romariz Castro (with older occupancy levels dated to about 1 000 BC).

According to Centeno (2011), the archaeological work carried out in the Romariz Castro revealed that the occupation of the site remount the last phase of the Late Bronze Age (around 900-700 BC). For some authors of the historical-culturalism school, the Romariz Castro, as it is patented today, was formed along with new regional planning after the arrival of a peculiar people coming from the south of the Iberian Peninsula designated "Turduli", who settled in the southern bank of the Douro river around the 5th century BC (García and Bellido, 1986; Silva, 1986). However, the only archaeological data that might feature a single or ‘concrete’ fact of this story is just a *tessera* from 7 AD that mentions *Turduli Veteres* as a family or maybe a community name (Silva, 1986). With no sufficient archaeological data to address an issue or a concrete history of the origins of the Romariz Castro, we can keep on with the study of the available age determinations, artefacts and all kinds of records. As it referenced by Centeno (2011, p.11), "to the earliest stage of the settlement's occupation, few data have been revealed by archaeological excavations", since most of these recent excavations have been effectively incident on the last occupation phase of the Castro, that ends around the first century AD.

Despite the few archaeological data for older chronologies of the Romariz Castro in 1843 and 1940-46 excavations, the existence of buildings overlays was observed, demonstrating significant reformulations in the local architecture (Centeno, 2011). These overlays refer to buildings that were destroyed, corresponding to the initial stage of petrification of dwellings which, according to the author, appear to have occurred during the second century BC. Also, in earlier periods most of the housing structures would even be built only by perishable materials (Silva, 1986; Centeno, 2011), demonstrated by the results of excavations carried out in 1980 and the following years.

Another phase of the Romariz Castro coincides with the time of change of the political system in the center of the Roman Empire, particularly during Augustus. It is at this time that we first start to see a 'Romanization' of this village. However, this event does not seem to have influenced the Castro's urban organization, but contributing only to a better definition of some streets and even its flooring (Centeno, 2011). During this time, we also see a new type of housing, which has been adopting a more regular style in terms of shape and introducing plaster and paintings on the walls, as well as the roof, gradually replacing the previous perishable materials permanently. The abandonment of the Romariz Castro will have been given-from the end of the first century.

The 3D technologies in archaeology

The 3D modelling is a technique of representation of something, by developing a model. These models are in turn designed to study and scientifically describe a phenomenon. A mathematical model is the representation of a specific phenomenon through variables and functional relationships between these variables. Thus, Computer Generated Models consists in the development of a mathematical model to represent certain aspects of a phenomenon or real system (Bianchi, 2006). When the computer representation of a real system introduces graphic shapes that mimic how this phenomenon occurs, we then have a computer simulation. To have some guarantees of properly representations of the ambient that these simulations purport to represent, these must be based on a mathematical and computational model correctly designed. So, there are simulation programs specifically designed for most of the scientific and technological academic areas, whether for its didactic nature or of a more technological nature, to study or demonstrate its mechanisms of operation.

Only in the last six years, the 3D modelling has been recognized in archaeology for its potential in terms of studying the archaeological sites and, most importantly, its aptitude and capability when it comes to attract the attention of the public and simultaneously disclose the historic information and knowledge. However, the biggest impasse on archaeologists to adopt this technique is precisely the lack of its acquaintance by most archaeologists. Nevertheless, it has been noticed in recent times an effort from the archaeological community to catch up in the world of new technologies, even if by a transdisciplinary work. Proof of this is, for example, the increasing use of panoramic photography and its treatment with 3D effect.

The most common way to create objects in three dimensions is using pre-defined geometric shapes (spheres, cylinders, cubes or pyramids) in three-dimensional design programs such as Autodesk 3ds Max Studio. The user then applies the necessary manipulations on these objects to give rise to the desired model. Once elaborated the three-dimensional models, a full simulation is applied, giving the necessary coverage on surfaces with textures. These can be based on solid colours, conferring a flat appearance or with simulated reality images. What we could call of 'last phase' of the three-dimensional modelling is the process called rendering: this process is done through the creation of a digital 2D image (or an animation from another virtual model), which it represents the output of the data that constitute the visibility of the details of the created model. The duration of the rendering process can last from a few minutes to several days, depending on the amount of textures that have to be created or the quantity of models that have to be added.

Virtual reality and 3D virtual worlds are usually created to be viewed on screens and may include more or less interactivity with the user. These applications are untaken in numerous areas, such as car and flight simulations, equipment for surgical operations, creation of models in engineering or architecture, games and other forms of entertainment. As already mentioned, within the framework of archaeology in Portugal, this computer technique has recently given its first steps. One example is the compendium of Morais (2012), whose 3D illustrations of the Roman city of Bracara Augusta, serve to support the description of the city elements.

The 3D reconstruction of Romariz Castro

Any reconstruction of an archaeological site (or a portion thereof) in 3D assumes that this site is properly understood. The study of the archaeological record is undoubtedly one of the most important aspects of the archaeological interpretation and investigation. It is this study that identifies the quality and degree of preservation of the archaeological contexts, and the relationship between artefacts, structures and samples for dating and other analyses (Bicho, 2006). That is, the log formation process of the archaeological record is essential, since the archaeological context suffers a number, greater or lesser, of changes from the time of its deposition and decay. So is the archaeologist's primary task to identify changings, register them and then explain them. These tend to become more complex since most archaeological sites not only corresponds to a single use of the same space or to a single placement site, but it is mostly a palimpsest of occupations and uses of the same space (Bicho, 2006).

To make a correct 3D modulation, it is strictly necessary that the requirements of a good archaeological practice are met. Above all, the archaeological site is the place where archaeology exercises its methodologies: it is the environment in which are preserved the remains, the set of artefacts and environmental and spatial records which the archaeologist must endure to register during its excavation campaign. For the Romariz Castro, two distinct realities are exposed: the results of the excavations carried out between 1843 and 1946 and the scientific research elapsed from 1980 to the present day under the direction of Professor Doctor Rui M. S. Centeno and Professor Doctor Armando Coelho da Silva from the Faculty of Arts and Humanities, University of Porto. Naturally due to the lack of registration methods, which are used today and the lack of scientific accuracy in general, the results of the first excavations in Romariz Castro require a critical analysis on the ground, since the current location (presumably *in situ*) of the foregoing structures and their contemporaneity may be put in question. It is important to mention that the 3D reconstruction provides an important aid in this type of research, since there may be doubts between a structure that is being rebuild and its surroundings with the already rebuilt structures.

Rebuilding in archaeology means to assign an image to the past that will qualify its look and functionality. Moreover, by 3D modelling the architecture of what might have existed in the Castro Romariz (and other archaeological sites) is to retrieve an architectural memory, with its urban spaces and paths that no longer exist today. Simultaneously, archaeology contributes not only to the study of the relationship between materiality and memory, but also has an active role in the formation of these same memories (Hodder and Hutson, 2003). For example, the experimental archaeology has yielded valuable information about techniques performed by the people of the past with the material world around them. Written up by empirical and quantitative issues, this area corresponds to the line of a good scientific practice which states that any experience must be based on repeatable and reproducible data (Dunn and Woolford, 2012). Nevertheless, it is clear that the reconstruction by digital technologies has a significant role in experimental archaeology and this will certainly tend to grow in the coming years.

This 3D reconstruction project was theorized throughout 2013, during the 2nd year of the Masters in Archaeology in the Faculty of Arts and Humanities, University of Porto, with the supervision of Professor Doctor Rui Manuel Sobral Centeno. The project, that has a dedicated website[2], was divided in five main stages: (1) The analysis of the geo-archaeo-spatial registration by surveying the site; (2) The vectorization of the structures or 2D drawing and the later 3D reconstruction; (3) The modulation of the Romariz Castro's terrain and its involvement in the gaming platform; (4) Inclusion of the simple models of all the infrastructures in their proper location and position; and (5) Total reconstruction of both indigenous and typically Roman infrastructures based on the intensive study of a vast bibliographic list (Silva, 2013).

A virtual tour in a museological context?

Contemporary discussions concerning the use of multimedia and

[2] http://pedro.dirtycoding.com/Romariz3D

technologies in museums tend to take radical differences between the impact of both virtual and material world, a difference that is conceived through a series of oppositions (Witcomb, 2007). In general, the introduction of multimedia items is seen as a threat to the traditional concept of culture and established museum practices but, on the other hand, is seen as an opportunity for the museums to reinvent themselves and ensure its survival in the XXI century. Those who argue that technology in museums is a threat, usually indicate that the ability to distinguish between the real and the copy will be reduced, which will inevitable end with the death of the material object and the reduction of knowledge through the imposition of information (Witcomb, 2007). Theorists that argue in favour of technology constantly point to the favourable reduction of institutional authority, which will, in turn, end with an increase of knowledge in popular culture, as also with the recognition of multiple meanings and lore, and, finally, the extent of the media sphere to the museum's space. This would mean that the scope of culture would significantly grow and expand. More importantly, the use of technologies in museums automatically results in adapting the information and knowledge resources to the new generations which consequently, and contrary to what the critics point, would keep the material world quite present and even more reachable by the masses.

According to Geary (2006), there are affordable technologies that can be used in the reconstruction of possible appearances of original artefacts (either movable or immovable) for 3D visualizations in full-realistic colour in the field of conservation or cultural heritage. To Bahn (1997), the ultimate goal of archaeology is the communication of its findings to the public. This is also stressed by Renfrew and Bahn (2008), when the authors defend that archaeologists have a duty to both colleagues and the general public, to explain what they are doing and why. Fundamentally, this means publish and disseminate findings of their results to be available to other academic members and, simultaneously, to be appreciated and understood by the general public. The reconstruction of monuments and other archaeological sites fulfils this paradigm that visitors should develop scientific skills through interactive experimental activities (Semedo, 2005).

The question that arises is, how do these scientific technological approaches create impact in a musealization context? As it was mentioned before, the ultimate aim of archaeology is the communication of its findings and historical productions to the public as well as the scientific community itself. In recent decades, archaeologists have realized through the theoretical discussion that, by its choice of artefacts, themes and approaches in museums constantly reflects and projects either consciously or unconsciously image of their own prejudices and beliefs. And indeed, all the multiple factors included there give the colour of their own version of the past. Through the idea that a visitor is an individual who seeks to impose sense and meaning of the materials exposed in a museum, the development of a 3D modelling project and its application in a gaming platform gives some answer to this question. That is, to help the public understand some of the scientific explanations by the visual sense of a particular site, a window would be open to support people understand better about their world and, in this context, about their history (MacDonald, 2002).

According to Bahn (1997), it is necessary to achieve a delicate balance between education and fun, and museum studies over the last twenty-five years has been important in this aspect by the complexity of the issues involved in the selection and arrangement of the material for the public. Leask and Fyall (2006) point that it will also be inevitably to think about the relationship that museums have with the tourism industry to consolidate archaeology and, thereby, realize economic gains that should serve to enrich this scientific area and even the very regions where the museums are inserted. In fact, the use of a gaming platform with a reconstructed archaeological site, like this one of the Romariz Castro 3D, reflects the idea of the Interactive XXI Century Museums. Above all, it has been inevitable that these new museums have recourse to new technologies to transmit their contents that have a participatory manner to thus attract the attention of their audience.

Conclusion

The history of museology considers the constant theorizing about the studied exhibits, always with the purpose of revamping them and, thus, to cause and provide an appropriately pleasant visual impact to visitors. Likewise, a gaming platform can maximize the physical and actual experience in museums. That is, the experience gained from this computing device enriches the knowledge of a proto-historic settlement and Romanised, like Romariz Castro, by a playful way through experience and which will reduce the quantitative perception of information. Nevertheless, its applicability also gives museology a new theoretical discussion: the impact between the real world of the present and the virtual world of the past.

References

Almeida, C.A.F. (1984), A Casa Castreja. *Memórias de Historia Antigua*, (6), pp.35-41. Universidade de Oviedo.

Bahn, P. (1997), *Arqueologia - Uma breve introdução*. Lisboa: Gradiva.

Bianchi, C. (2006), Making Online Monuments more Accessible through Interface Design. *Applying Digital Imaging to Cultural Heritage*. Oxford: Elsevier.

Bicho, N. (2006), *Manual de Arqueologia Pré-Histórica*. Lisboa: Edições 70.

Centeno, R. M. S. (2011), *O Castro de Romariz*. Aveiro: C. M. de Santa Maria da Feira.

Dunn, S.; Woolford, K. (2012), Reconfiguring Experimental Archaeology using 3D Reconstruction. *Electronic Visualisation and the Arts*, pp.172-178. London: Computer Arts Society and BCS.

Geary, A. (2006), 3D Virtual Restoration of Polychrome Sculpture. *Applying Digital Imaging to Cultural Heritage*. Oxford: Elsevier.

Hodder, I.; Hutson, S. (2003), *Reading the past - Current approaches to interpretation in archaeology*. Cambridge: Cambridge University Press.

Leask, A. & Fyall, A. (2006), *Managing world heritage sites*. Oxford: Elsevier Ltd.

MacDonald, S. (2002), *Exhibitions and the Public Understanding of Science Paradox*. Berlim: Universidade de Humboldt.

Morais, R. (2012), *Bracara Augusta: a opulenta*. Braga: Câmara Municipal de Braga.

Renfrew, C. & Bahn, P. (2008), *Archaeology: Theories, Methods and Practice*. London: Thames & Hudson Ltd.

Semedo, A. (2005), Que museus universitários de ciências físicas e tecnológicas?, pp.265-281. *Colecções de Ciências Físicas e Tecnológicas em Museus Universitários: Homenagem a Fernando Bragança Gil*. Porto: Universidade do Porto.

Silva, A.C.F. (1986), *A Cultura Castreja no Noroeste de Portugal*. Porto: C. M. de Paços de Ferreira.

Silva, P. (2013), *A Informática e Multimédia Aplicadas à Investigação Arqueológica - A modelação 3D do Castro de Romariz e a sua aplicação numa plataforma de jogo*. MPhil. Faculdade de Letras da Universidade do Porto

Witcomb, A. (2007), The Materiality of Virtual Technologies: A New Approach to Thinking about the Impact of Multimedia in Museums. *Theorizing Digital Culture Heritage: a critical discourse*. Cambridge: The MIT Press.

Maniello, D. (2016), Michelangelo's David: An augmented reality application on real scale, using the technique of video mapping. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.123-138

MICHELANGELO'S DAVID: AN AUGMENTED REALITY APPLICATION ON REAL SCALE, USING THE TECHNIQUE OF VIDEO MAPPING

Donato Maniello[1]

ABSTRACT The present work is the result of a research started with Studio gloWArp (www.glowarp.com) in partnership with Academy of fine arts in Naples. To achieve and prove such result, in this project it was used a particular technique of augmented reality called video mapping with the aim of reevaluating the replica in scale of the world famous "David" by Michelangelo, sculpture present in the same building. The installation (projected the 27th February 2015), entitled "Michelangelo's David", is the demonstration of how new technologies can play a fine role for the enhancement of cultural heritage of a nation it got the patronage of UNESCO that has entitled the 2015, International Year of Light (IYL) and of the technologies based on light. Thanks to the art of video mapping the rediscovery of this sculpture has achieved a great result, success based not only on the reevaluation of the work of art but also because such performance touched the soul of the audience leaving them in an ecstatic state. Thanks to the live event, a large number of the audience for the first time came to know the existence of this replica work, present in the building of the Academy, of which they totally ignored the presence. Another aim of the project is that of showing the artistic potentiality of the mix among analogical and digital media and how video mapping could be also considered as an extension of the painting. A reevaluation of cultural heritage through video mapping that is perfect for the standards expected by the law in matter of cultural properties in Italy. The action of reevaluation is not to be considered as an attempt to substitute the peculiar value of the work itself. Part of this project will be show in a website.

KEYWORDS Augmented reality; Cultural heritage; Video mapping; Michelangelo's David

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1. Introduction

"[...] We are the digital artisans. We celebrate the heroic energy of our work and of our imagination to give shape to the virtual world. Hackering, coding, mixing and designing, we build our interconnected future thanks to our commitment and to our inventive [...]". The quote here above is a fundamental passage to best describe the basic approach of the present research work but also, the quote addresses us towards the aim of the project in description, putting in constant conversation digital and analogical fields in which the handmade work is in tight connection with the technological process. The quote is from "The Digital Artisans Manifesto" written in 1997 by Richard Barbook and Pit Schultz. The manifesto is an independence declaration of the digital artisans who evoke through electronic manufacture the experience of the manual creative labour. Technological innovation, if well interpreted and with the right poetic, can assume more interesting shapes and dimensions. Thanks to technology it becomes possible to totally revolutionize the way we understand and project whatever kind of cultural experience and create innovative contests for the fruition of it. Nowadays, in fact, it is possible to notice how the majority of museums, of exhibition spaces, of architectonic realizations and restorations, of the studies of ancient construction industries and urbanization make a good use of the potentiality of augmented reality. *The definition of the concept of "cultural heritage"* spurred a broad debate with the enforcement on May 1st 2004 of the Code of the Cultural Heritage (entirely transposed in the Italian legislation by the legislative decree 42/2004 as amended). To this regard we would like to focus on one specific aspect, that is the legislator's precise intention of strengthening the idea of identity in cultural heritage, so much that the traditional definition of cultural

heritage intended as "things … testifying the values of civilization" was modified as follows: "the founding and representative element of national identity". This definition expresses the intent to include the vast category of "immaterial things" and broadens the framework in which the measures of protection and safeguard of cultural heritage are set. Specifically, *Art 6 of the Code of the Cultural and Landscape Heritage states the fundamental principles for the development of cultural heritage, defined as follows:* "[…] the exercise of the functions and in the regulation of the activities aimed at promoting knowledge of the cultural heritage and at ensuring the best conditions for the utilization and public enjoyment of the same heritage, with the aim to promote the develop culture […]". This function sets the framework for the present study. Doing so, the intrinsic cultural value of a due subject of study becomes evaluated thanks to the use of advanced new technologies.

This research continues the one started by the Studio gloWArp (is a multimedia studio that focuses on applied new technologies in the sphere of art and is specialized in applications in museum contexts for the promotion of cultural heritage) in technology implementation on cultural heritage. One example is the use made of this technology in previous work and some being as the application of augmented reality utilizing the A.R.I.M. system (Augmented Reality In the Museum) (FIG. 1) devised in 2013 by Studio gloWArp in the reproduction of axisymmetric vases of Greco-Roman era for multimedia totem (Maniello, 2015) (FIG. 2)*;* on Block NXLVI Parthenon Nord Frieze (Cirafici et al., 2015) (FIG. 3); on the scale reproduction of the Dinos, coming from the hypogeum Varrese in Canosa di Puglia, Italy (FIG. 4).

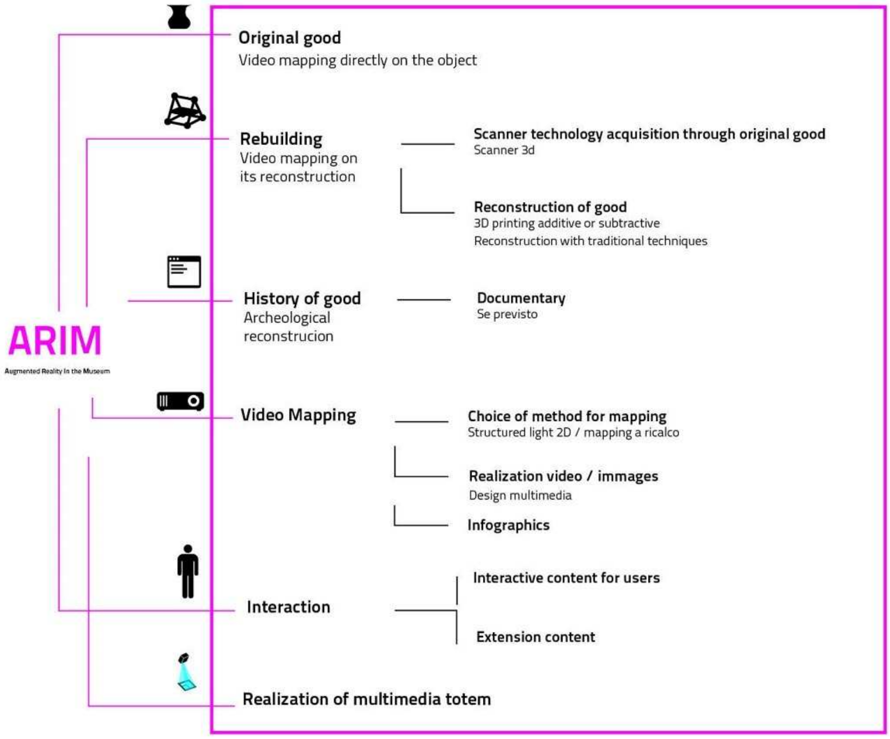

FIG. 1 - A.R.I.M. system_2013.

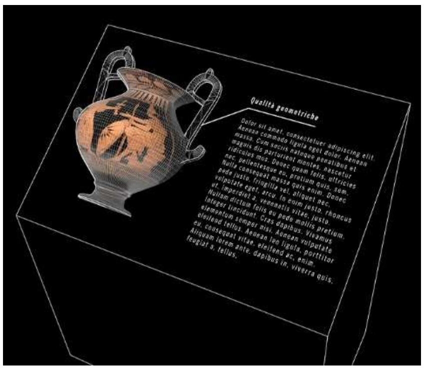

FIG. 2 - Proposal for a multimedia totem_2013.

FIG. 3 - Picture of documentary screened_2015.

FIG. 4 - Video mapping on Dinos from hypogeum Varrese_2015_Canosa di Puglia (Italy).

In Italy, there are few examples, of other author, of such operation to consider and are firstly, the one which took place in Rome for the rediscovery of the "Altare della Pace" (FIG. 5; Ara Pacis, 2014, Alberto Pizzoli) for the remembrance of the Emperor Augustus.

FIG. 5 - Ara Pacis_2014_Rome.

Thanks to the projection technique of video mapping, the marble facades of the monument were rendered in colours to recreate its original polychromy to give a realistic effect without risking to damage its structure. The choice of each single coloration of the "Ara Pacis" was operated on the base of precise laboratory analysis compared to roman time paintings, especially from Pompeii, and further chromatic researches on ancient architectures and sculptures. Those analyses were carried out during many years by a team of researchers. With a similar approach and aim, in the south of Italy, it was established an event named GLOWFestival (Maniello, 2014) (www.glowfestival.it), that reaches its third edition in 2015. The festival was conceived and created to reevaluate the cultural heritage of Ostuni, thanks to this particular technique of augmented reality that is the video mapping. The founders of the festival (Studio glowarp.com) saw in the video mapping the right qualities to be implemented in reevaluating various places of the city of Ostuni such as the inside of: "Chiostro di San Francesco" (FIG. 6; video mapping performance, Palazzo di Città, Ostuni, Ist Edition of GLOWFestival 2013, Studio gloWArp); the Saint Vito Church, which is also the location of the "Museo della Civiltà preclassiche della Murgia Meridionale" (FIG. 7; video mapping performance, Ostuni, IInd Edizione of GLOWFestival 2014, Studio gloWArp), and "L'Arco Scoppa" (FIG. 8; IIIrd Edition of GLOWFestival 2015, Studio gloWArp). The festival was based on various performances selected via open call, modality that gave to many artists the possibilities to participate with their own projects and visions. This was a fundamental experience that gave the chance to investigate a different kind of fruition in the cultural-artistic field. Augmented reality lets add more information to a subject consenting to discover and to see a work of art with new sights. The aim is also that of reaching a larger audience tickling their curiosity and fascination, establishing a

FIG. 6 - GLOWFestival, I edition_2013_Ostuni, Italy.

FIG. 7 - GLOWFestival, II edition_2014_Ostuni, Italy.

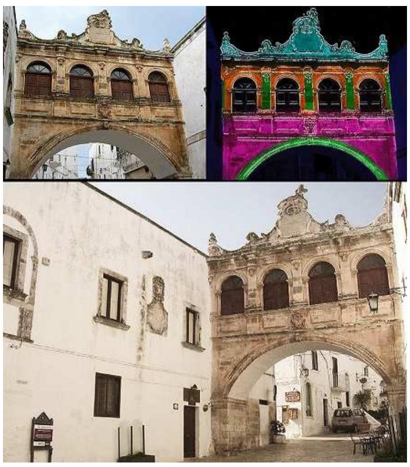

FIG. 8 - GLOWFestival, III edition_2015_Ostuni, Italy.

bridge between the people and the cultural heritage of a city, composing a new narrative based on local history and traditions using contemporary innovative techniques.

This type of project involves the interaction among different arts, where sculptures, painting, architecture and technologies meet to create a unique interactive experience for the audience to enjoy. The spectacular nature of the fruition through the technique of video mapping is in the situation where the public participate directly with their own bodies in the interaction without any use of other devices. Nowadays, one of the disadvantages present in the majority of the systems based on augmented reality is that they imply the use of devices designed to appreciate its potentialities. In cases like this, the audience should have a knowledge about the functionality of the technology to really appreciate its innovation and acquire information. This type of situation requires a longer time and a practice not always available which makes it more difficult for everyone to enjoy it.

Cultural heritage is the proof that allows us to glimpse and to explore with our imagination what it was and why it was built. To be in front of a work of art gives us the opportunity of flying on the wings of fantasy and totally immersing ourselves in a kind of mystery, a discovery that can be enriched thanks to innovative tools but also thanks to the use of a classic method that always works fine and succeed in its aim; the research based on hard-copy manuals. Augmented reality increases our sensory perception but too often is just limited to the momentary spectacular effect offered by a digital object. The risk is that augmented reality becomes only an ephemeral technological experience that could substitute the real value of a work of art. This is why the project "Michelagelo's David" is focused on a sculptural reproduction that not everybody knows, a reevaluation that is not available in any manual of history of art and that calls out for imagination. This type of fruition of cultural heritage, where the analogical gets mixed with the digital, gives the possibility to explore a work of art under different point of views, highlighting the true importance of the sculpture itself.

2. The acquisition technique

The first step to produce a video mapping project is the mapping, which is essential to match the virtual model with the real one. The mapping is obtained starting with the marking of the structure we wish to work on and it is achieved using various tools such as a computer, a reflex photo camera, a video projector and a wide-angle. Those tools allow us to collect all the information we need to rebuild the sculpture and the structure around it. Because of the difficulty in the acquisition of the scene, two techniques were used: 2D scansion (structured light) and a photographic mapping (Maniello, 2014). With structured light mapping once the position and distance of the video projector are set, this method allows the creation of an image that appears as if it were being "seen" by the video projector (FIG. 9).

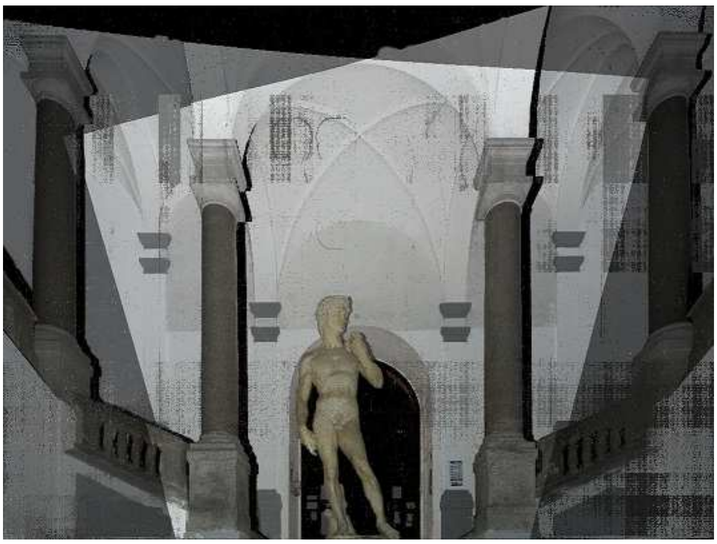

FIG. 9 - Image that appears as if it were being seen by the video projector_2013_Academy of Fine Arts_Naples

This is the first image from which the mapping process starts. A file generated this way can encounter two kinds of problems: whites off range and the loss of levels of detail (a fundamental aspect of indoor mapping and on a small scale), and noise due to the generation of the file with structured light. The levels of detail, if significant, can be recovered using the other two mapping methods while an attempt to clear noise effect can be made with Photoshop. In fact, the surface being white and the projector's light frontal but the source low, levels of detail are lost that only split lighting can provide. For this reason, the following mapping methods are useful. With trace mapping, once the image to be traced has been obtained, this technique allows real-time tracing of the detail lost with the previous method with the use of Photoshop. Once the image has been corrected with the previous techniques, photographic mapping allows us to use a photograph shot in the appropriate scale and then modified (with warping techniques) to make it perfectly coincide with the mapping file previously created. This procedure provides a perfect texturizing, where all the details rest perfectly on the tridimensional original model, the colours enhanced by the model's whiteness. With the above-mentioned methods and the real-time correction of imperfections here and there we have obtained the definition of the final image (FIG. 10), a stage followed by the creation of the layer masks with Illustrator (FIG. 11).

FIG. 10 - Final image_2013_Studio GLOWArp.

FIG. 11 - Layer masks with Illustrator_2013_ Studio GLOWArp.

The creation of these masks was carried out in conjunction with the archaeological study of the exhibit, as this provided useful means for understanding the shapes and details and their spatial configuration and depth. This is a very delicate step because the layer masks represent a synthesis of the shapes from which all the files necessary for the creation of the documentary are derived.

In fact, once we have obtained the image, which was taken from a near point of the projector, this was adjusted according to the real proportions of the subject and the rest of the chromatic aberration were eliminated with the use of Adobe Photoshop.

The masking layers are the materials needed to create 2D and 3D animations and will be useful during the warping phase of the creation process.

The warping is used to create the illusionistic effect and it is based on three geometrical transformations (FIG. 12). Those are the homothety, the homography and the anamorphosis. Those are needed to match the virtual model with the real one. Homothety is a geometrical transformation of the space and of the plane, that either expands or compresses the objects, leaving unaltered the corners and so the structure. Homography is the relation between the points of two spaces in which at each point of Space A correspond one and only one point of Space B. Anamorphosis is when an image is distorted and it is made visible only from one perspective point of view, creating the optical illusion that is the fundamental and spectacular characteristic of video mapping. In summary, the procedure was adopted: the real model, to scan with structured light and finally the projection with video mapping technique. (FIG. 13).

FIG. 12 – Warping phase _2015_ Studio GLOWArp.

FIG. 13 - Real model. Scan with structured light. Video mapping_2015_ Studio GLOWArp.

3. The creation of performance

The accurate study of the architecture is a fundamental step for the making of a performance because it allows the constructing of the contents based on the design of the planes on which we will go to work on, aiming to a conversation among the surrounding and the video and not vice versa. Once the reconstruction of the masking layers was completed and the acquisition of the painted boards was finished, the next step was the importing of the files to Adobe After Effects and Cinema 4D. This software allows the creation of the majority of the animation effects. An important factor for the success of a video mapping performance is not just the visual contents but also its soundtrack. In "Michelangelo's David" the fundamental characteristic is the fusion between two moments: the transition from winter to spring. The music chosen for this project was "The winter and the spring" of Italian compositor Antonio Vivaldi. Some sound effects were used to put emphasis on some particular parts of the video performance. The video and sound editing was done with Adobe Premier (FIG. 14), which resulted in the creation of a final piece of the length of 5 minutes. The performance was presented to the public on the evening of the 27th February 2015 (FIG. 15) at the Academy of Fine Arts of the city of Naples after obtaining the authorization for the performance by the directorate upon presentation of a formal request.

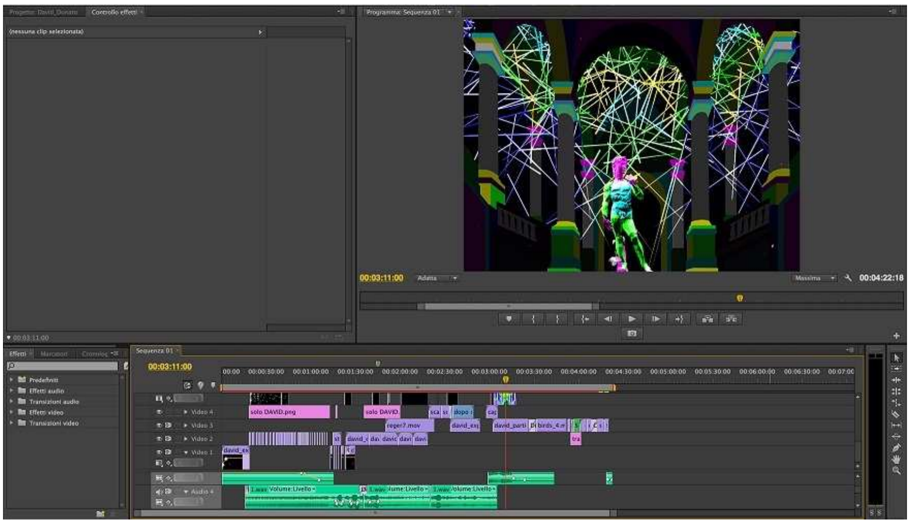

FIG. 14 – Adobe Premier project_2015_ Studio GLOWArp.

FIG. 15 – Frame performance_2015_ Academy of Fine Arts.

4. Communication and website

A multimedia event was created. To keep track of the flux of visits on the website Google Analytics code was used to monitor the access. Social networks were employed to spread the communication online with a positive feedback from the target audience.

This art project was finalized towards the creation of a multimedia event. To achieve so, the project was curated in its total, from the video mapping performance production to the communication plan. Flyers and leaflets were designed and printed. The graphic design included a QR Code (FIG. 16). A web site was designed (www.3david.it), which was built making sure that it would be available and fully working on computers but also on mobile devices such as smart-phones, tablets (FIG. 17).

FIG. 16 – Graphic project, flyer ad invitation card_2015_ Naples.

FIG. 17 – Website sample view on mobile devices_2015_ Naples.

The graphic design was kept simple and essential in its lines and contents to allows its users an easy and intuitive utilization, information was put together to be available to be enjoyed either analogically or digitally. The choice of the colours is based on the idea of having a chiaroscuro contrast so, a dark background and light text perfectly aligned in the page to make it easy to read and consult thanks also to a very clear font (Gill Sans Regular). The rendering of the reproduction of the David in 3D was placed centrally, reducing the polygonal effect to give the subject a more contemporary design style and fading its colour composition and making it just visible in a way that the whole figure could not disturb the viewing of the readers. On the web site is available the video recording of the live performance, photos of the event and a pdf with the dissertation. To publicize the event a press kit was put together and sent to a large number of magazines and newspapers, two weeks in advance and also it was available for download from the website. Also, social networks as Facebook and Twitter were employed to spread the communication online with a positive feedback from the target audience. To keep track of the flux of visits on the website it was used Google Analytics code, which was placed in the index and helped the monitoring of the numerous access to the website. This was useful to have data available about the work done for the communication giving positive numbers as result of a communication well planned and professionally carried on. It was essential the value of feedback obtained by the online monitoring because the high virality and virtual expectation was then matched by presence of people at the night of the event. This was a great result which went well beyond the expectation considering that those mentioned above were the only communication channels used without receiving any further support. The web site is also well indexed on Google using the keywords: video mapping napoli and video mapping david.

5. Projection

The project was carried out with the XGA projection resolution (1024x768 px), 4:3 format, luminosity of 4000 AL and wide angle. This resulted in a perfect illumination of the subject and the surrounding space once the area was totally dark. For the warping phase, Mad Mapper software was used. This software allows to edit the video in real time. The final result is visible at this link: https://vimeo.com/122750458.

6. Conclusions

Among the many aspects of this project, the use of light as artistic medium is the one of major importance. In fact, this is the year entitled as UNESCO International Year of Light and of the technologies based on light (IYL). Video mapping is based on light and it is the art form that promotes sustainable developments through culture. Another aim of the project "Art Remixed on Michelangelo's David" is that of showing the artistic potentiality of the mix among analogical and digital media and how video mapping could be also considered as an extension of the painting. An artistic language and a new creative method that allows a total immersion and an augmentation of the sensory perception through the use of digital media in an analogical field. The projection of paintings lets us experience the brush strokes and the colours tonalities under a new light towards a total different perception of the unique works of the artists of the past century. The video mapping puts a new pictorial skin on the hero of Renaissance totally transforming its white marble surface. The spectators experience the subject as never seen before, a very original vision of it. A reevaluation of cultural heritage through video mapping that is perfect for the standards expected by the law in matter of cultural properties in Italy. In fact, the regulations for Cultural Heritage and the Territory state, in the article number 6, the fundamental principles for the activity of reevaluation of the national cultural property, defying such activity as *"[…] all of those activities directly involved in the promotion of knowledge of the cultural heritage and assuring the best conditions for the public utilization and fruition of such patrimony with the aim of promoting the progression of national culture […]".* This aim was fully achieved during the performance "Michelangelo's David", because thanks to the live event a large number of the audience for the first time came to know the existence of this replica work present in the building of the Academy of Fine Arts of Napoli of which they totally ignored the presence. Thanks to the art of video mapping the rediscovery of this sculpture has achieved a great result, success based not only on the reevaluation of the work of art but also because such performance touched the soul of the audience leaving them in an ecstatic state.

References

Cirafici, A.; Maniello, D.; Amoretti, V. (2015), Block NXLVI_Parthenon_Nord Frieze_In Augmented Reality the magnificent adventure of a "fragment". *Scires* [online]. 5(2). Available from: http://caspur-ciberpublishing.it/index.php/scires-it/issue/archive [Accessed 25th November 2015].

Maniello, D. (2014), Augmented reality in public space: basic techinque for video mapping. Brienza: Le Penseur.

Maniello, D. (2015), The video mapping projection indoor for promotion of cultural heritage: the glowfestival case. *Screencity Journal* [online]. 6. Available from: http://screencitylab.net/publications/ [Accessed 25th November 2015].

Maniello, D. (2015), Realtà geometrica e aumentata in ambito museale: tecniche base di video mapping su vasi assialsimmetrici con proiezione mono video proiettore. *In: Idee per la rappresentazione, Aversa, 2014. Napoli.*

HERITAGE AND LIGHTS. INTERACTIONS FOR CHARACTERIZATION AND PERCEPTION

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PORTABLE XRF: A (VERY) BRIEF INTRODUCTION

Lee Drake[1]

ABSTRACT

The growth of portable x-ray fluorescence instruments (pXRF) have challenged traditional analytical protocols, primarily in its use in non-destructive contexts.

The present manuscript evaluates the ways that pXRF differs from traditional laboratory XRF, and the limitations and opportunities which emerge from this difference. Both qualitative and quantitative uses are illustrated with a focus on applications for cultural heritage management.

KEYWORDS

Portable X-Ray Fluorescence; Methodology; Qualitative; Quantitative

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Perception of visible light

The perception of colors, from the reds of the thin, subtle smile in Da Vinci's Mona Lisa to the blue sky of Picasso's Starry Night, owe a debt to the evolution of our primate ancestors. While most mammals can clearly see blue and red, the ability to differentiate lower-energy/longer wavelength colors is rare. In the deep past, the primate ancestors of humans were dependent on differentiating red from green to find fruit in dense jungle stands - this created a powerful selective force which gave primates a broader spectrum than most other mammals (Regan et al. 1998). As can be seen in FIG. 1, the long and medium cone cells, responsible for red and green, have very subtle differences in sensitivity to different photon energies, as can be seen in FIG. 1. Our ability to see green may be due to a gene duplication event with some mutation that formed the M-cone from the L-cone (Nathans and Thomas, 1986).

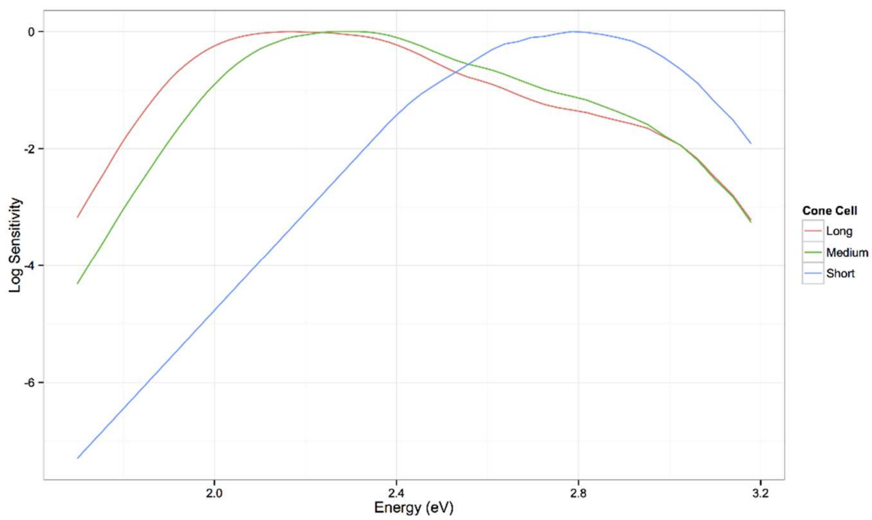

FIG. 1 - Cone cell energy sensitivity (Stockman et al., 1993).

Despite the closeness of energy sensitive, the eyes of modern humans are generally capable of differentiating between multiple hues between red and green, giving the world, and art, its richness of experience. It is important to underline here that the color range of humans, which extends from 1.7 to 3.1 electron volts (eV) of energy

(700 - 300 nanometers), is a product of our unique evolutionary history. Our perception of the world is confined to these limits. Other organisms have colors which exceed the unusually broad and detailed spectrum humans enjoy; some species of honeybees can see into the ultraviolet (UV) range, while others such as snakes perceive in the infrared (IR) range.

Outside the visible spectrum

The developments in instrumental science over the past several decades have used increasingly sophisticated light generators and detectors to make the known entirety of light's spectrum available to humans for study, from radio waves with 100 km wavelengths (1.2398e-11 eV) to the gamma rays of supernova of 300 keV (0.0004 nm wavelength). As such, the concept of color expands dramatically when we consider these higher and lower energy photons.

Miniaturization of components have taken formerly large laboratory-confined instruments into smaller, handheld devices (Bostco, 2013). This displacement from the lab has led to the use of handheld instrumentation in contexts which present unique challenges and opportunities. This paper concerns itself primarily with handheld x-ray fluorescence (pXRF) spectrometers, however the principles of matrix effects and attenuation will affect other types of instrumentation as well.

XRF instruments (FIG. 2) attain their portability by using geometry to fit key components in small spaces. An X-ray tube is configured at a 52° angle relative to the nose of the instrument. This is not the best geometry of an XRF instrument, an angle of 90° is preferable for maximum limits of detection (Klockenkaemper, 1997). However, the geometry is key for portable instrumentation to work, and this is one sacrifice to a smaller system. Photons edited from this angle will strike the sample and excite atoms within it. Emitted photons from the sample will then strike the detector which is set at a glancing angle. The detector functions in the same way as cone cells do in the human eye; they identify the energy of a photon.

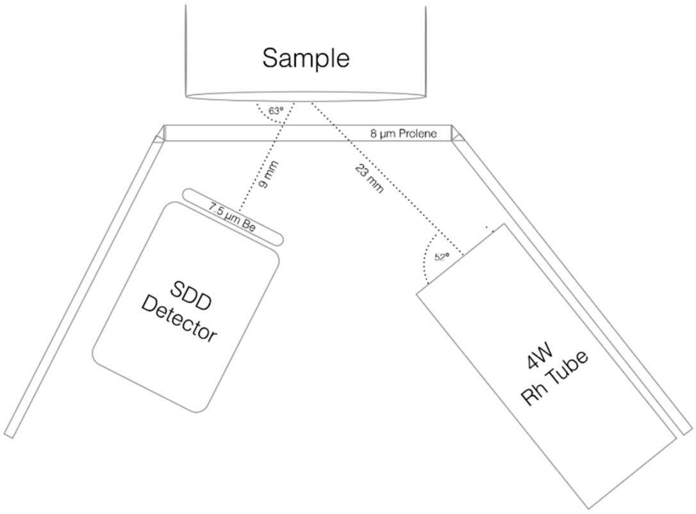

FIG. 2 - Configuration of typical handheld XRF instrument (Bruker Tracer IIISD).

X-ray fluorescence (XRF) as a process concerns itself with the fluorescence of elements. These energies range between 0.3 and 100 keV, though most XRF or similar instruments analyze only a portion of that range. Physically, they operate based on the same principles as visible color, an incoming photon excites an electron, and causes disorder in the electron shells. As the electrons re-align, they emit new photons which represent the energy residuals of their transitions within the atom. For color fluorescence, this typically takes place in the shared outer electron shells of molecules; with XRF this occurs internally to the atom, in the M, L, and K shells closest to the nucleus. The typical spectrum includes characteristic lines (FIG. 3):

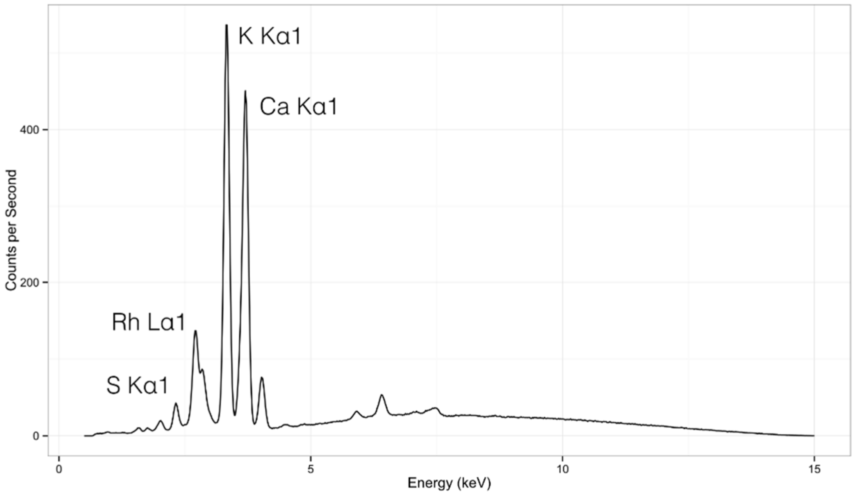

FIG. 3 - XRF spectrum of NIST 1547, Apple Mango Leaves.

In this case, each element fluoresces with unique peaks - Potassium (K) has a K-alpha line at 3.55 keV, and a K-beta peak at 3.60 keV. These can be thought of as the colors of Potassium, if red is 1.7 eV and blue 3.0 eV, then Potassium's K-alpha line is a color at 3,550 eV.

Again, the XRF spectrum is an extension of our color vision, something which enables us to see more than the colors our primate ancestors left us with. The big difference is what we see - with visible color fluorescence it is the molecules which fluoresce. For example, reduced iron (Fe^{2+}) looks black to us, because all visible photons are absorbed. If it is oxidized to hematite (Fe_2O_3) then we would see an orange-red color. This is because photons of an energy of 1.7 - 1.9 eV are emitted from the shared outer electron shells of the molecule following light's absorption.

To an XRF unit, the Fe K-alpha and K-beta lines (6.4 and 6.9 keV, respectively) would fluoresce just the same - the arrangement in the outer electron shells does not affect the absorption or emission energies of those orbitals closest to the nucleus. As such, XRF is primarily a method to detect elements.

The XRF spectrum

The XRF spectrum is most typically used in the identification and/or quantification of elemental fluorescence peaks. However, there are multiple other types of photon interaction present than simple fluorescence.

In FIG. 4, numerous other peaks manifest in the spectrum. These include the Rayleigh peak, which is formed by elastic scatter of photons from the XRF tube. These will have an energy that matches the K-alpha (or L-alpha) line of the x-ray target.

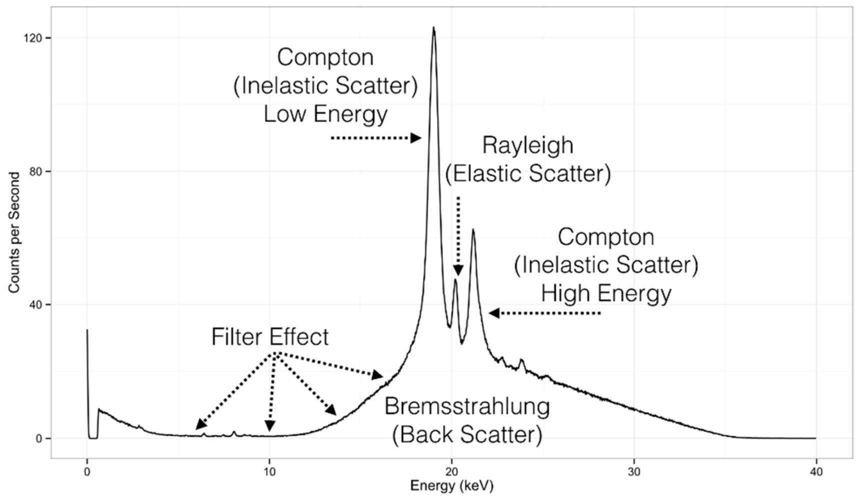

FIG. 4 - Spectrum of a diamond taken with a 25 µm Ti/300 µm Al filter and a rhodium (Rh) tube.

They are formed when photons leave the tube and are reflected by the sample without losing any energy - they are the parallel for white light in this portion of the spectrum. The Rayleigh peak is situated between two Compton peaks, one at a lower energy at another at a higher energy. These are the inelastic scatter that results from photons with the energy of the XRF target (e.g. same as Rayleigh) but they loose (or gain) energy on their way back to the detector. The ratio of the lower-energy Compton peak to Rayleigh will correspond to the density of the electron cloud (e.g. higher ratio with lighter elements). These three peaks overlay a broader set of photon counts, collectively known as Bremsstrahlung radiation. These are the x-ray photons which simply bounce around in the matrix of the material and loose energy - they are informally known as the backscatter. To the left, the backscatter does not mirror its counterpart to the right, it has a bowl-curve descending to 0 counts per second. This is the consequence of adding a filter, which eliminates a portion of the spectrum. This is typically done to increase the signal-to-noise ratio of elements with fluoresce in a given region.

Peaks fluoresce in the spectrum based on the quantity of atoms present and the luminescence settings of the instrument used. Just as with color fluorescence, more energy must be sent than is returned. Each element has a range of photons which can excite electrons in its K, L, and M orbitals. There is a terminal point at which a certain photon can no longer excite these orbitals for a given element, this is known as the absorption edge. This point is also the point of maximum excitation potential, the effectiveness of a photon to excite the element in question declines with higher energies. The overall potential of excitation looks something like a Gaussian distribution which was cut in half (FIG. 5).

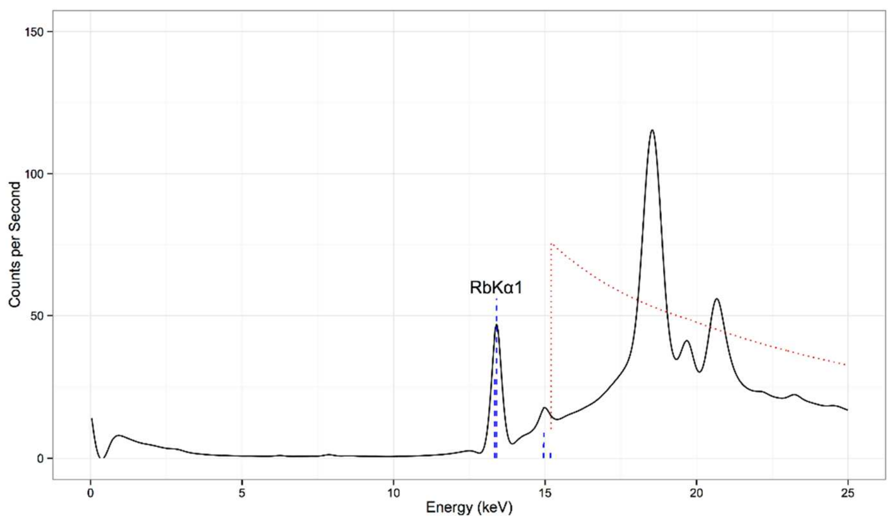

FIG. 5 - Absorption Edge of Rubidium (Rb).

The fewer photons there are to the right of the absorption edge, the smaller the chance of fluorescence there is. The converse is also true, the more photons on the absorption edge, the higher the chance of fluorescence. Filters can be used to increase or decrease the chance of an element fluorescing, but ultimately the ability to seen an element rests with the sample.

What makes pXRF different?

For decades, laboratory XRF units have been highly reliable systems with straightforward quantification. However, portable XRF instruments are much more difficult to use quantitatively (Frahm, 2013). The components between the two are the same, why would portable XRF underperform? The reason has less to do with the configuration of the XRF and more to do with the sample. Laboratory XRF units typically analyze prepared samples, usually fused glass beads. This means samples have been homogenized and prepared for analysis - this also means the matrix (in this case SiO_2) matches that of the reference standards of the equipment. Portable XRF, in contrast, is used in situations where samples are not prepared. In fact, the use of pXRF is frequently on heterogenous samples. As such, the limitations stem not from the physical components but rather the use of the system to analyze paintings, ceramics, and other heterogenous objects in a non-destructive manner (Kaiser and Shugar, 2012). That said, when samples are prepared the same way, portable instrumentation can have equal performance to laboratory equipment (Guerra et al., 2014).

This means, in short, that matrix effects are essential considerations in the use of portable XRF. Some elaboration may be needed on the term matrix; this simply refers to the majority material by composition. The matrix of soil would be SiO_2, the matrix of stainless steel would be a crystalline mixture of Fe, Cr, and Ni. The matrix affects the spectrum in two primary ways, the first is by affecting the depth of analysis.

The depth of analysis is the product of the mass attenuation of photons as they enter any matrix, be it gas, liquid, or solid. The atoms of the matrix gradually absorb photons. The denser the matrix, the more rapid this loss of photons is. Photons with higher energies will be able to make it further into the matrix. The relationship can be expressed as follows:

$$I/I_0 = e^{[-(\mu/\rho)\rho]}$$

where I is the quantity of photons returning from the sample, I_0 is the quantity of photons entering the sample, μ/ρ represents the mass attenuation coefficient of a given element for a particular matrix, and ρ represents the density of the object. Assuming only 1% of photons return from a sample, the equation can be reduced to:

$$\text{depth (cm)} = 4.61/(-\mu/\rho*\rho)$$

In this case, the depth of analysis for a silicate can be calculated (FIG. 6):

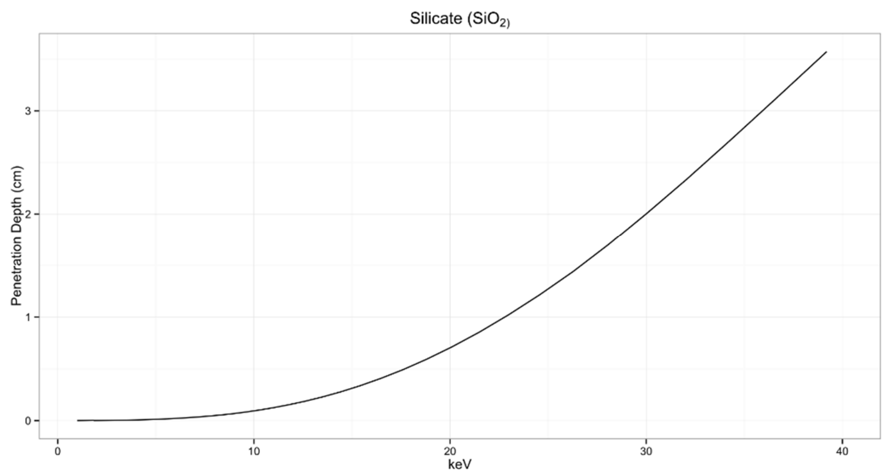

FIG. 6 - Depth of analysis for a silicate by photon energy.

For light elements, such as Si, the analytical depth is only 27 µm for the K-alpha peak. For heavier elements, such as the K-alpha emission for

Fe, it can be 300 µm deep. The L-line for Pb would be 1,130 µm, and Ag's K-alpha peak can be seen at a depth of over 200,000 µm, or 2 cm, deep. As such, the spectrum will produce a biased view of different elements depending on their energy.

Second, the presence of new elements can influence the fluorescence of others as they can overly each other's absorption edges.

In FIG. 7, Fe sits on the absorption edge of Ti, which in turn sits on the absorption edge of S.

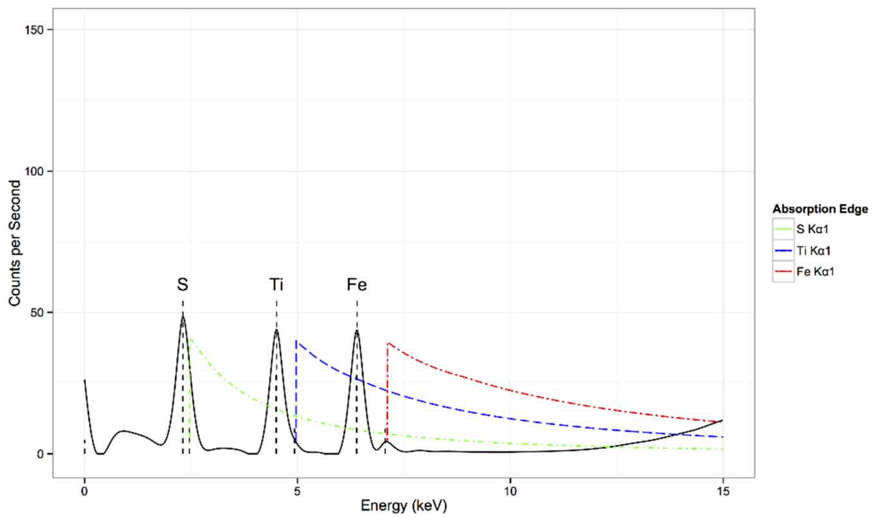

FIG. 7 - Absorption edges for S, Ti, and Fe.

In this case, each element heightens the fluorescence of an element of lower energy. And in turn, each element of lower energy reduced the height of the higher energy peak lying in its absorption edge. An Fe K-alpha photon can be emitted, then strike a Ti atom, which in turn emits a Ti K-alpha photon, which is absorbed by S. This highlights the resonance effect which takes place in elemental spectra. As an analogy, the spectrum can be thought of as a symphony, and each element an instrument. As the violins swell, the clarinet deepens. The user of portable XRF equipment can conduct analysis more effectively by shaping the energy, current, filter, and even atmosphere that the analysis is taken in to accentuate the fluorescence of elements.

As mentioned before, laboratory instruments also deal with these physical phenomenon, but in a controlled setting. They standardize the matrix, and can be calibrated to a higher degree. Portable instrumentation is much more vulnerable to matrix effects because the sample analyzed are typically heterogenous and unprepared. While this is a sacrifice from the point of view of spectrum quality, it is an advantage in that it is non-destructive. A painting can be painlessly analyzed using XRF, while in most cases the homogenization of the pigments into a fused glass bead are unpalatable. It is important to note, in non-destructive uses of the equipment, that matrix effects not be taken for granted. It is important for spectra to be assessed qualitatively given these conditions.

Qualitative analysis

The utility in art conservation for XRF consists in expanding our spectrum to see those elements which are compositionally important to a piece of art or a heritage object. For conservation, XRF can be used to identify elements or materials which may not be consistent with the point of origin of an object, identifying potentially reactive elements, or to analyze variation in the composition, among other tasks. In general, any analysis first needs context. For example, analysis of a historical painting means that a certain set of pigments are expected for its point of composition. A Rembrandt painting will include historical pigments such as lead white ($PbCO_3$), vermillion (HgS) and bone black ($CaPO_4$) based on their availability during the time in which he was alive. If a synthetic pigment base such as titanium dioxide (TiO_2) or zinc oxide (ZnO) is present, then the painting is either retouched, or is not secure in its provenance. Likewise, the identification of calcite ($CaCO_3$) or gypsum ($CaSO_4$) could indicate the presence of the recent, reversible restoration. In either case, the context of the object is inseparable from the interpretation of XRF spectra - neither exists in isolation.

A similar example can exist with heritage objects. In North America, pre-Colombian cultures rarely used anything other than pure copper or gold as metals. An XRF spectrum of these objects should produce pure K lines for Cu or L lines for gold, with the potential for small impurities like Ag and Pb. The presence of a substantial amount of Zn or Sn would indicate a brass or bronze alloy, technology with had no president prior to the arrival of the Spanish in 1492.

Note that in these two examples XRF does not need to be used quantitatively to answer a straightforward question: do we understand the object's place in time? Qualitative analysis is sufficient to answer this question. The qualitative analysis of XRF spectra is, in essence, the same as qualitative analysis performed with human eyes - no further elaboration is always needed when describing a color such as red. In the same sense, no further elaboration is needed when a brass object shows up in a prehistoric collection - it is impossible for it to be both brass and prehistoric.

Complications to qualitative analysis

The intensity of the K-, L-, and M- peaks in an XRF spectrum corresponds to the relative abundance of that element give the fluorescence parameters (energy, filter, atmosphere, etc.). The spectral peaks can be thought of as proxies for atoms themselves, though there are some basic factors that complicate this picture (FIG. 8).

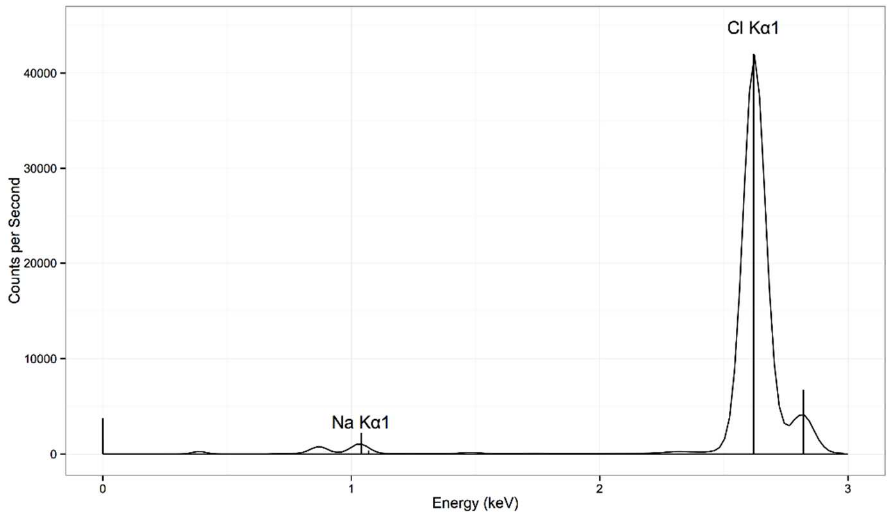

FIG. 8 - Spectrum of sodium chloride taken using a helium flush. The small peak to the left of the Na K-alpha peak is the escape peak for Cl.

By atomic abundance, sodium chloride is 50% Na and 50% Cl. So, why is the Cl K-alpha peak magnitudes of order higher than the Na peak? There are three reasons why:

1. The depth of analysis of Cl is 38 µm, while Na is 5µm;
2. Cl is closer to the medium of the Brehmsstralung radiation, while Na at the tail;
3. Cl has a fluorescence efficiency of 9%, while Na has a fluorescence efficiency of 2%.

As such, there are few photons to fluoresce Na, which in turn fluoresces less efficiently, and at a shallower depth than Cl. These factors combine to dramatically reduce the Na K-alpha peak. The first two factors have been covered earlier in this manuscript, the latter is in need of further elaboration. Fluorescence efficiency refers to how many atoms out of 100 will fluoresce in a given electron orbital if a photon has the necessary energy. This efficiency is determined by the number of electrons in the outer orbitals and the repulsive charges they have on each other. A lower number means less atoms will light up; a higher number means more. Typically, the more electrons in the outer orbitals, the more likely a K-alpha or L-alpha emission will occur.

Because Na is a lighter element than Cl, there are less candidates for the transfer.

For these reasons, the spectral peaks cannot be considered perfect proxies for atomic counts - there are many biases at work that affect the fluorescence of elements, not all of which can be controlled by the user. That said, if fluorescence parameters, or illumination, is kept constant from sample to sample (e.g. same energy, current, filter, time, and atmosphere) then peaks of the same element in different samples will vary based on their concentrations/atomic abundances.

Quantitative analysis

Typically, we tend to think about the presence of elements in material in terms of concentrations, e.g. 7% Fe, 325 ppm Rb. These percentages refer to either volume or, more commonly, weight. However, the use of weight percent to characterize material can sometimes obscure its composition somewhat. Take our earlier example of salt. It is 50% Na and 50% Cl by atomic abundance, captured by its chemical formula NaCl. However, Na has 11 protons while Cl has 17. This means that Na has an atomic weight (with common isotopes included) of 22.99 while Cl has one of 35.45. Cl thus weights 54% more than Na. As such, NaCl is by weight 39% and Cl 61%. Think about the contradiction there for just a moment - while there are just as many atoms of Na and Cl in salt the latter is a greater weight percent than the former. Phrasing composition in the context of weight conflates two different points of variation - the atomic abundance of an element and its atomic weight. A more dramatic example can be seen with water, H_2O. H has an atomic weight of 1 while O has an atomic weight of 16. There are twice as many H atoms as there are of O, yet those H atoms compose roughly 11% of water’s weight.

The prominence of weight % in chemical composition analysis owes to the history of chemistry. In the classical and medieval eras, there were two major branches of chemistry, the first being alchemy (the attempts to transform elements into gold) and the second being metallurgy (the process of creating tools, weapons, and structures). Both carefully weighed out ingredients prior to incorporation into materials and experiments. For example, a metallurgist would add 1 kg Sn for every 9 kg Cu to create a bronze sword. This tradition carried over into modern material science in most cases, remaining the standard by which we analyze objects today.

From the perspective of XRF, a major complication is added - the traditional units of composition are not directly reflected in the atomic spectrum. To perform quantitative analysis - specifically in terms of weight percent - some kind of calibration is needed. There are two primary mathematical approaches to doing this. The first is to use fundamental parameters of the instrumentation to create estimates of an item's composition. This includes the angle of the x-ray tube, the glancing angle of the detector, the space from the sample to the detector, and assumptions about composition. If dealing with a sample in which 100% of the atoms fluoresce in range of the tube and detector's capabilities, this approach can work quite well because all points of variation can be included. If, however, not all elements can be seen, then the situation becomes much more complicated. For example, a piece of glass is, by both weight and volume, mostly O. EDXRF cannot detect this element - even if it could it would only be at a depth of 10 nm in the sample. FP algorithms must from this point make a guess about the elements it cannot see to estimate the weight percent of Fe, Cu, Zn, and other metals. The inability to see Na without atmospheric changes further complicates the task. Though glass represents a partially synthetic material, SiO_2 and Al_2O_3 are dominant and oxygen can be extrapolated from there. Soils and ceramics are much more challenging. There are multiple forms for Ca, including $CaSO_4$, $CaPO_4$, CaO, $CaCO_3$, etc. There are two common oxidization states for Iron, Fe_2O_3, FeO, etc. FP algorithms work best with highly synthetic substances such as metals in which all elements present can be excited by the instrument. An example is the Rosseau (2009) FP algorithm:

$$C_i = R_i\left((1 + \Sigma_j A_{ij} C_j)/(1+\Sigma_j \varepsilon_{ij} C_j)\right)$$

where C_i represents the concentration of an element, R_i is the relative intensity of an element, a_{ij} are the absorption coefficients, C_j represents the element at concentration, and ε_{ij} represents the enhancement coefficients. Determination of a_{ij} and ε_{ij} require information on total matrix composition - thus the algorithm only functions if a prior is given to it (e.g. information about the sample). For proper FP calculation, additional information about the tube and detector geometry/distance is needed, such as those details documented in FIG. 2.

The second major method to quantify XRF spectra is to use reference standards, these are known as empirical calibrations. The approach of an Empirical calibration is most commonly a variant of the common linear model developed by Lukas-Tooth and Price (1961):

$$C_i = r_0 + I_i(r_i + \Sigma r_{in} + I_n)$$

Where C_i represents the concentration of element, r_0 is the intercept/empirical constant for element i, r_i - slope/empirical coefficient for intensity of element i, r_n is the slope/empirical constant for effect of element n on element i, I_i is the net intensity of element I, and I_n is the net intensity of element n. This equation descends from a simple linear model,

$$y = mx + b$$

In which y is C_i, b is r_0, m is r_i, and I_i is x (eg. $C_i = r_i I_i + r_0$). The additional variables present in the Lukas-Tooth equation indicate a slope correction for an element which influences the fluorescence of the element to be analyzed (subscript i represents the element being analyzed, subscript n represents the influencing element). An illustration of how this effect occurs can be seen in FIG. 7. Here, the K-alpha peak of Fe overlays the absorption edge for the K-alpha emission of Ti. In this circumstance, the quantification of Ti may use Fe as a slope correction. While the Lukas-Tooth method of quantification has been criticized for being a brute-force statistical quantification approach, physical principles can be used to guide the application of corrections. It is important, however, to strive for minimalism in these quantifications. Too many corrections can artificially increase the r^2 value of a linear/non-linear model. Unrelated corrections will inflate the perceived accuracy of the model; real world application will increase the chance of a violation to its generalizability. The fewer corrections, the more generalizable the model. An additional benefit is that violations to a simple Empirical Calibration can result in systematic error as opposed to random error (Nazaroff et al., 2010).

By using matrix-specific calibrations, almost any material can be quantified using EDXRF data (Speakman and Shackley, 2013). FIG. 8 shows a simple empirical calibration built for ppm-levels of Pb in water in this case, 10,000 ppm of a reference standard (Lead, 10,000 ppm, ICP Standard Solution) was titrated down to 1ppm using repeat half-dilutions with distilled water (FIG. 9).

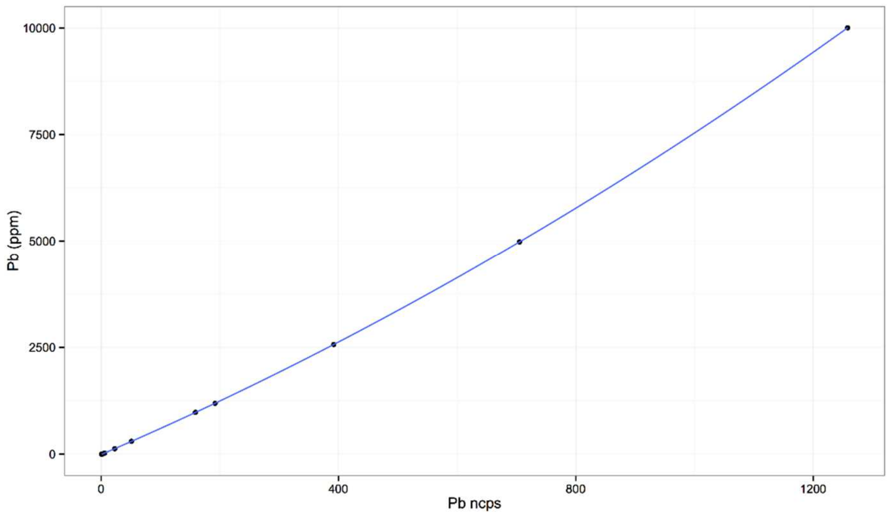

FIG. 9 - Pb in water empirical calibration.

This calibration represents the simplistic possible implementation of a calibration, in which there are no overlapping peaks. Note that even in this case the effect is beyond a simple linear model; a quadratic formula was used due to the effects of depth on the analysis. Calibration curves become more complicated as different overlapping elemental lines influence the curve. The Lukas-Tooth and Price equation will turn these into multilinear models - thus creating multi-dimensional calibration curves that cannot easily be displayed in a bivariate plot. Nonetheless, the principles are simple and straightforward.

Layer thickness and position

XRF has one highly unique application in which non-destructive analysis provides more detailed information than simple concentrations. In the right circumstances, it can be used to predict the thickness of an object with micron-level accuracy. This is a consequence of two factors in XRF; the first is that there are multiple peaks for each element at different energies, the second is that higher energy photons penetrate greater depths of a material. To return to the example of Pb, it has two primary L peaks, an L-alpha at 10.5 keV and an L-beta at 12.5 keV. The attenuation of the L-alpha peak will be greater in every matrix than the L-beta since it has 20% less energy. This means that as the L-beta peak rises relative to the L-alpha peak, the depth of the surface covering must also increase. FIG. 10 illustrated this effect with different thicknesses of pure Al foil, ranging from 0 to 775 µm Al overlaying pure Pb.

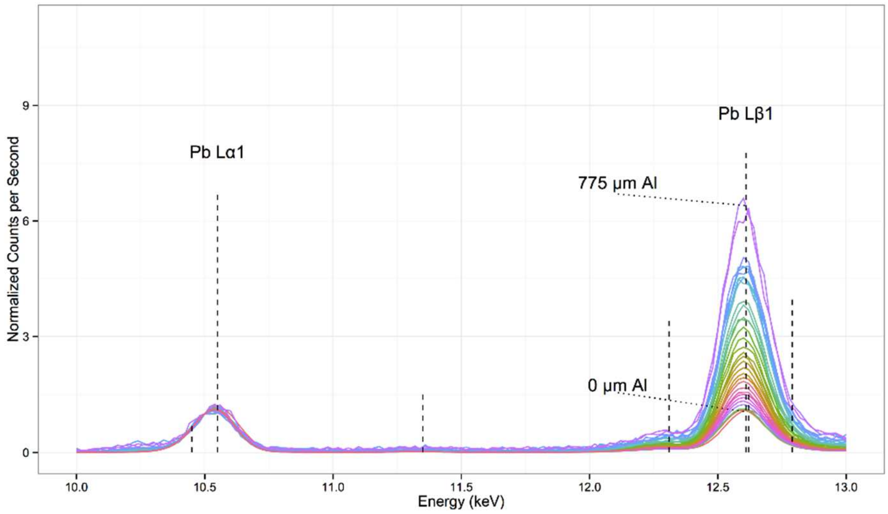

FIG. 10 - Pure Pb covered with increments of 25 µm of Al; as the Al layer gets thicker, the Pb L-beta/Pb L-alpha ratio gets larger.

This principle can be used to identify surface coverings - indeed an entire industry of coating thickness analyzers exists based on this principle. The same principle holds true for any conceivable layering; varnishes on a painting, pigments on top of other pigments, metal plating on other metal. The analysis can be done spectrally, provided that a surface-level reading of the low layer is available. An example of this is the spectrum of Pb in Figure 9: The smallest L-beta represents the surface-level measurement of Pb; the L-beta/L-alpha ratio here is about 0.85. By contrast, the L-beta/L-alpha ratio for Pb beneath 775 µm of Al is 4.92; in other words, the L-beta peak went from being 85% the size of the L-alpha peak to being 492% larger. It is important to note that it is not the case that the L-beta peak is getting bigger - rather it is simply shrinking less quickly. 775 µm Al shrunk the L-alpha peak by

96.5%, while only striking the L-beta peak by 80%. It is resistance to attenuation that creates this effect.

One important word of caution, the above application assumes that there are no independent influences on the fluorescence of Pb. As noted earlier in this manuscript, absorption edges are an important secondary influence on the fluorescence of an emission line. A spectrum should be screened qualitatively for overlapping elements on the absorption edge of the target element.

Summary

XRF is most commonly used as a laboratory technique for determining concentrations, this has been the primary interaction with the technology for decades. The rise of portable, non-destructive instrumentation has challenged many researchers - how to make this technology work in circumstances in which samples are heterogenous? But with every challenge comes an opportunity if one can interpret the spectrum properly.

The present manuscript focuses on a few important spectral effects and guidelines for interpretation. There are many more ways to use XRF as either a qualitative or quantitative tool, but the first step is in the spectrum. Further analysis, qualitative, quantitative, or otherwise, follows from it.

References

Bosco, G.L. (2012), Development and application of portable, hand-held X-ray fluorescence spectrometers. *Trends in Analytical Chemistry*, 45: pp.121-134.

Frahm, E. (2013), Validity of "Off-the-Shelf" handheld portable XRF for sourcing near eastern Obsidian chip debris. *Journal of Archaeological Science*, 40(2).

Guerra, M.B.B.; de Almeida, E.; Carvalho, G.G.A.; Souza, P.F.; Nunes, L.C.; Santos, D., Krug, F.J. (2014), Comparison of analytical performance of benchtop and handheld energy dispersive X-ray fluorescence systems for the direct analysis of plant materials. *Journal of Analytical Atomic Spectroscopy*, 29, pp.1667-1674.

Kaiser, B.; Shugar, A. (2012), Glass analysis utilizing handheld X-ray fluorescence. In Shugar, A. & Mass, J.L. (eds), Handheld XRF for Art and Archaeology. Leuven, BE: Leuven Press, pp.449-470.

Klockenkaemper, R. (1997), Total-Reflection X-ray Fluorescence Analysis, New York: Wiley.

Lucas-Tooth, H.J. & Price, B.J. (1961), A Mathematical Method for the Investigation of Interelement Effects in X-Ray Fluorescence Analysis *Metallurgia,* 64, pp.149–152.

Nathans, J. & Thomas, D. (1986), Molecular genetics of human color vision: the genes encoding blue, green and red pigments. *Science*, 232 (4747): pp.193–203.

Nazaroff, A.J.; Prufer, K.M.; Drake, B.L. (2010), Assessing the applicability of portable X-ray fluorescence spectrometry for obsidian provenance research in the Maya lowlands. *Journal of Archaeological Science,* 37: pp.885-895

Regan, B.C.; Julliot, C.; Simmen, B.; Viénot, F.; Charles-Dominique, P., Mollon, J.D. (1998), Frugivory and colour vision in Alouatta seniculus, a trichromatic platyrrhine monkey. *Vision Research,* 38(21): pp.3321-3327

Rosseau, R.M. (2009), The quest for a fundamental algorithm in X-ray fluorescence analysis and calibration. *The Open Spectroscopy Journal*, 3: pp.31-42.

Speakman, R.J.; Shackley, M.S. (2013), Silo science and portable XRF in archaeology: a response to Frahm. *Journal of Archaeological Science,* 40: pp.1435-1443.

Stockman, A.; MacLeod, D.I.A.; Johnson, N.E. (1993) Spectral sensitivities of the human cones. *Journal of the Optical Society of America A,* 10(12): pp.2491-2521.

HERITAGE AND LIGHTS. INTERACTIONS FOR DOCUMENTATION AND PERCEPTION

Van der Perre, A.; Hameeuw, H.; Boschloos, V.; Delvaux, L.; Proesmans, M. et al. (2016), Towards a combined use of IR, UV and 3D-Imaging for the study of small inscribed and illuminated artefacts. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.163-192

TOWARDS A COMBINED USE OF IR, UV AND 3D-IMAGING FOR THE STUDY OF SMALL INSCRIBED AND ILLUMINATED ARTEFACTS

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ABSTRACT

When heritage objects are being transformed into digital representations, the loss of information is inevitable. The challenge lies in developing integrated systems able to minimize this loss and bring together as many different kinds of recordable characteristics as possible of one and the same object.

This contribution presents an approach that combines the detection of colour, surface shape and the reflective characteristics of surfaces by using a selection of IR, Red, Green, Blue and UV light spectra and applying them on 3D models. A multispectral, multi-directional, portable and dome-shaped recording tool has been developed to this end. With the associated software, virtual relighting and enhancements can be applied in an interactive manner based on the principles of photometric stereo: this allows alternating in real time between computations with IR, R, G, B and UV light spectra. Throughout the testing phases, this non-invasive registration and documentation technique has been applied to monitor and study a vast number of heritage objects, varying from 19th c. BCE Egyptian inscribed clay figurines to medieval illuminations.

KEYWORDS

Multispectral imaging; Photometric stereo; Conservation; Documentation; Ancient inscriptions

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1. Introduction

"(…) *where our predecessors wanted to reproduce the original, if they could not have the original itself, we now try to improve the original*"

(Bülow-Jacobsen, 2011, p.2)

Multispectral imaging has proven its value and usefulness in particular for remote sensing, including earth observations, astronomy and planetary science, and was further applied in other fields, such as biology, medicine, chemistry, etc. In the early 1990s, it also entered the field of cultural heritage studies, especially as one of the main advantages lies in the non-invasive / non-destructive character of this technique. Hence it can be applied to all sorts of objects and materials, ranging from intact to extremely fragile and deteriorated surfaces, since sampling physical material is not required (Liang, 2012). Therefore, it is also used in the fields of art technical research, conservation science and archaeology, where the focus lies mainly on paintings, manuscripts and to a lesser extent on papyri and inscribed pottery sherds (ostraca). Applying the different spectra enables a precise examination and identification of colours and pigments, the visualisation of underlying features, and the identification of varying materials or surface conditions. A shortcoming of these approaches, however, is the absence of geometrical data.

The aim and challenge of the proposed hardware-software solution is the development of a method that can capture, register, and visualize the physical three-dimensionality of objects together with the visible and concealed / faded pigments on their surface. Information is inevitably lost when heritage objects are being transformed into digital representations. Integrated systems, able to minimize this loss and bring together as many different kinds of recordable characteristics as possible of an object, are therefore desired. This paper presents an approach that combines the detection of colour, surface shape and the reflective characteristics of surfaces by overlaying the geometrical datasets with a selection of IR, Red, Green, Blue and UV light spectra. This leads to a user-friendly and cost-effective methodology, applicable to a wide variety of heritage objects.

Within the framework of the research projects RICH (University of Leuven)[4] and EES (Royal Museums of Art and History, Brussels)[5], a multispectral, multi-directional, portable and dome-shaped acquisition system has been developed in collaboration with the ESAT-VISICS research group of the University of Leuven. With the associated software solution, virtual relighting and enhancements can be applied in a real-time, interactive manner. The dome extracts genuine 3D and shading information based on the principles of photometric stereo. This innovative approach allows for instantaneous alternations between the computations in the IR, R, G, B and UV light spectra.

RICH

The RICH (Reflectance Imaging for Cultural Heritage) project has developed two imaging devices for research, study, and exploration of the physical characteristics of graphic materials produced in medieval and early modern times. The first tool – labelled 'Microdome' –

[4] Reflectance Imaging for Cultural Heritage (RICH) is a project from Illuminare (Centre for the Study of Medieval Art, KU Leuven), financed by the Hercules Foundation 2012-2015 (Flemish government) – Project AKUL/11/03, site: http://www.illuminare.be/rich_project.

[5] The Egyptian Execration Statuettes project (EES) is financed by the Brain-be Pioneer programme of the Belgian Science Policy Office-BELSPO (project BR/121/PI/EES): http://www.kmkg-mrah.be/conservation-ir-uv-and-3d-imaging-egyptian-execration-statuettes, and supported by the BELSPO Interuniversitary Attraction Poles Programme Greater Mesopotamia – Reconstruction of its Environment and History (GMREH) (Project IAP 7/14): www.greatermesopotamia.be.

consists of a hemispherical structure, with an overhead camera and white light LEDs regularly covering the dome's inside surface. Similarly, the second Microdome structure exhibits LEDs emitting in five different parts of the electromagnetic spectrum, ranging from ultraviolet over visible to infrared light. The development of this Multispectral (MS) Microdome enables multispectral imaging, expanding such non-destructive art-technical research into the realm of 3D modelling. The two Microdomes have shown their potential as instruments to analyse extremely small art technical features and monitor conservation treatments (Watteeuw et al., 2013; & 2014).

The main focus of the RICH research is on medieval manuscript illuminations, as these are unique artefacts drawn, written and illuminated with mineral and organic materials. Rarity and fragile conditions render manuscript illuminations difficult to access as they are mostly kept in secured library vaults. Imaging the characteristics of the undulating parchment, the pictorial layers and the laid gold reveals to scholars and conservators the 'hand', the techniques and the materials of the medieval book artists. The documentation of these characteristics with the white light and MS Microdomes is extremely useful as it can document and measure 1) the 3D surface structure of the parchment, 2) the sequence of the writing, 3) the underdrawing, 4) the preparation of the gilded layers, 5) the brushstrokes applying the different mineral and organic materials, and 6) the finishing of the pictorial touch with glazes and pen work. Besides supporting questions of attribution, changes and decay of the material characteristics can be monitored, supporting decision-making in the conservation protocol.

The high-quality, accurate results of both Microdomes can be visualized in a most versatile manner. All visualization modes are based on a single recording procedure, taking only a few minutes. For the synthesis of the virtual images a large number of filters and relighting options can be applied. They enable the detection of object surfaces even when difficult to access, the generation of 2D+ models, and the life-like or visually enhanced interaction with the recorded artefact.

EES

The Egyptian Execration Statuettes (EES) project aims to create multispectral 3D images of a series of fragile Egyptian objects of the RMAH collection in order to 1) ensure their sustainability by reducing future handling, and 2) facilitate their study by developing an efficient course of action to record details on their surface. The selected case study includes, more specifically, 104 "Execration figurines", roughly modelled clay figures representing prisoners, dating back to the Middle Kingdom (c. 1900 BCE) (Posener, 1940). Their surface is covered with inscriptions in hieratic, an ancient Egyptian cursive writing system, enumerating enemies of the flourishing Egyptian empire. By listing foreign countries, tribes, rulers, and places, these objects are invaluable primary sources for our knowledge of the ancient political geography of the Near East. They are internationally recognised as Prime Cultural Heritage Artefacts. Unfortunately, the study of this type of collection is hindered by their poor state of conservation (being made of unbaked rough clay), as handling and any intervention carried out on them can result in considerable material losses. The second major obstacle for researchers is the partial preservation of the ink traces and their poor visibility in white light.

The aim of the EES project is to enhance the readability of the hieratic inscriptions on the execration figurines with UV and IR photography, all the while producing reliable 3D models and allowing scholars to examine the results in combination with the actual relief characteristics and properties of the physical object. As our Portable Light Dome systems – the white Microdome as well as the preceding Minidome (Willems et al., 2005) – have proven to be particularly suitable for the registration and visualisation of clay surfaces (Hameeuw and Willems, 2011; Boschloos et al., 2014; Hameeuw and Van Overmeire, 2014), the same approach was selected for this challenge. The newly developed interactive multispectral module offers the ability to search for the most optimal visualisation conditions while shifting between calculations based on the recordings with the different spectra. Subsequently, these tools will also be used to ensure the multispectral 3D digitalization of other fragile objects bearing inscriptions or pigments, such as ostraca, tablets, papyri, bowls, etc. (for a first result, see Van der Perre and Hameeuw, 2015).

2. Related works

Multispectral imaging is frequently used in (and shows excellent results for) the study of manuscripts and palimpsests (cfr. The Dead Sea Scrolls (Caine and Magen, 2011); The Archimedes Palimpsest (Easton et al., 2011); Medieval Palimpsest Manuscripts Project Göttingen (Albrecht, 2014); The Magna Carta Project (Dufy, 2015; Giacometti et al., 2012).

When it comes to using multispectral imaging for the documentation of archaeological objects, the focus lies mainly on papyri and ostraca, i.e. relatively flat objects containing inscriptions and/or drawings (Booras and Seely, 1999; Fisher and Kakoulli, 2006; Macfarlane et al*.,* 2011; Faigenbaum et al*.,* 2012; Sober et al*.,* 2014). In Egyptology, multispectral imaging has also been used for the documentation of wall paintings (Kotoula, 2012), inscriptions on mummy shrouds (Corcoran and Svoboda, 2012, pp.57-58) and mummy masks and portraits (Making the Mummies Talk (Mazza, 2015); the APPEAR Project (Anandan, 2015; Ganio et al., 2015; Shah, 2015). Apart from merely documenting objects, multispectral imaging has also been used for the identification of historical pigments (Dyer and Simpson, 2012; Cosentino, 2014). Whether there is an actual added value in using multispectral recordings, when simple infrared photography might offer equal results, has been the subject of scholarly discussion as well [The value of MS imaging is questioned by Bülow-Jacobsen (2008), while his statements are countered by Bay et al., 2010].

On the other hand, 3D imaging has been intensively used in the past years. Most satisfying results were reached for reconstructions of large architectural features, objects, paper and canvas documents (e.g. Remondino, 2011; Abate et al., 2014) and for the documentation of very small objects or for surfaces on which the smallest details matter, such as archaeological artefacts with cuneiform signs and seal impressions (Hameeuw and Willems, 2011). For art conservation, high magnification 3D in-focus microscopy with the HIROX 3D binocular has been explored for examining the surface layers in paintings by Van Eyck, Vermeer, Hals and Van Gogh (Boon, 2015).

Recently, photogrammetry and infrared techniques have been successfully combined (i.e. partly integrated) in the study of art and archaeological objects (Bennett, 2015; Keats Webb, 2015). Furthermore, in isolated test recordings, Reflectance Transformation Imaging (RTI) techniques were used in combination with the use of IR and UV spectra (Kotoula, 2012; 2015). Unfortunately, these cases cover only one aspect of the documentation process we are aiming at; the outcome is either a method providing information on the geometry of the recorded surface with a texture map based on visible light, IR or UV separately; or it consists of 2D representations based on a recording process with varying spectral wavelengths, whether or not moulded into an integrated interface.

The RICH and EES projects propose an innovative combination of these methods by adding a multispectral aspect to the previously developed Portable Light Dome system (PLD). This comprehensive approach interactively integrates computations based on recordings with visible white light, IR and UV, i.e. detecting texture maps and normal maps. It provides curators, conservators, researchers and other stakeholders with virtual artefacts for a broad range of historical and technical studies and will facilitate the management of the recorded objects.

3. General setup

The starting point was the initial hard- and software infrastructure of the Portable Light Dome system (Willems et al., 2005), which is continually evolving into an effective tool for studying, monitoring and understanding the materials and surface characteristics of a wide variety of heritage objects (Hameeuw and Willems, 2011; Watteeuw et al., 2013)[6]. The initial outcome of the PLD system was the `Minidome' with 260 white light (VIS) LED emitters (Ø80x80mm); transformed within the RICH project into a smaller Microdome with 228 white LEDs (Ø30x30mm). The joint multispectral efforts of RICH and EES resulted in a MS Microdome (finished) and a larger MS Minidome (under development).

[6] The PLD itself was a follow-up result of an initially fixed photometric stereo setup that came with several degrees of freedom in camera motion and was used for the study of textured surfaces.

Based on the experiences gained throughout the development stages and thanks to the joint input by heritage specialists, archaeologists, art historians, epigraphists, photography experts and electrical engineers, the multispectral component could be incorporated into the existing PLD system. Within the RICH project, the white light Minidome was specifically adapted towards documentary heritage objects such as manuscripts and books. To allow for the imaging of the interior, fragile bookbinding of manuscripts, a segment of the Microdome can be taken off. A rigid structure on top of the dome hosts the high-resolution sensor (28.8 million pixels) and lens combination (FIG. 1). It also allows the Microdome to fit onto a Conservation Copy Stand (developed by Manfred Mayer, Graz) as well as a standard tripod or studio stand. Therefore, the Microdome can be used in many desired positions or angles.

4. Choices

4.1 Sensor

The sensor of choice is the Allied Vision Prosilica GX 6600 (Allied Vision, 2015). It is a high-resolution 35mm machine vision CCD sensor (6576 × 4384 pixels) enabling vibration free capture through the digital shutter, the latter as opposed to a manual shutter. The resolution of the sensor allows for the capture of small details at high magnification factors. The sensor can be delivered in both a colour and black and white version. The black and white sensor is sensitive in the UV, visible and IR spectra. The colour version has been fitted into the white light Microdome, the black and white version into the multispectral Microdome.

FIG. 1 - The construction of the Microdome with the rigid superstructure to fit the camera and lens combination. The structure can be mounted on standard photographic equipment such as a tripod or studio stand, allowing the user to position the Microdome in the desired angle. The MS Microdome has the exact same setup. (©RICH project, KU Leuven).

4.2 Lens

Ultraviolet and infrared light have a different plane of focus than visible light, an effect also known as 'focus shift'. The Portable Light Dome uses all the LEDs, with their different light spectra, within one and the same recording sequence. When one wants to ensure stability throughout the image capturing sequence, it is virtually impossible to refocus the lens for optimal sharpness without disturbing it. The option of decreasing lens aperture (Nikon AF-D 60mm F/2.8 macro) to increase the depth of field proved, after testing, unsatisfactory with close-up imaging. The depth of field was also limited due to the use of the large 35mm sensor, compared to smaller sensor imagers that have a much bigger depth of field.

To counter the focus shift the CoastalOpt UV-VIS-IR 60mm Apo Macro lens (Jenoptik inc, 2015) was selected and acquired. Five of its 10 lens elements are made of calcium fluoride, enabling true apochromatic performance between 315 and 1100 nm.

4.3 Light sources

LEDs were selected as light source. A total of 228 LEDs were evenly distributed across the inside of the Microdome. The white light Microdome was fitted with a high-powered neutral white LED, with a colour temperature of 4000° K. The MS Microdome was fitted with five different spectra. The selection of the bands was partly based on the spectra used within the Archimedes Palimpsest project (Archimedes Palimpsest, 2010) and adopted towards the particularities of the PLD set-up. Since the colour and the multispectral PLD versions were planned in a way that most of their structure could be shared, the white light and multispectral LEDs required to have the same specifications such as size, construction, drive current, etc. They also had to be available in sufficient quantities. The choice fell on the LED Engin LZ1 product family (LED Engin, 2015). The five spectra selected are: UV 365 nm, Blue 465 nm, Green 523 nm, Red 623 nm and IR 850nm, each different types again evenly distributed across the dome. Their numbers vary from 44 to 48 LEDs per type (FIG. 2 and 3). A simulation of different distribution patterns obtained through an even permutation of 5 different LEDs yielded the patterns in FIG. 2. The most even and symmetric distribution was selected and implemented (FIG. 3). The arrangement of the LEDs enabled the removal of a segment of the dome without sacrificing the overall distribution.

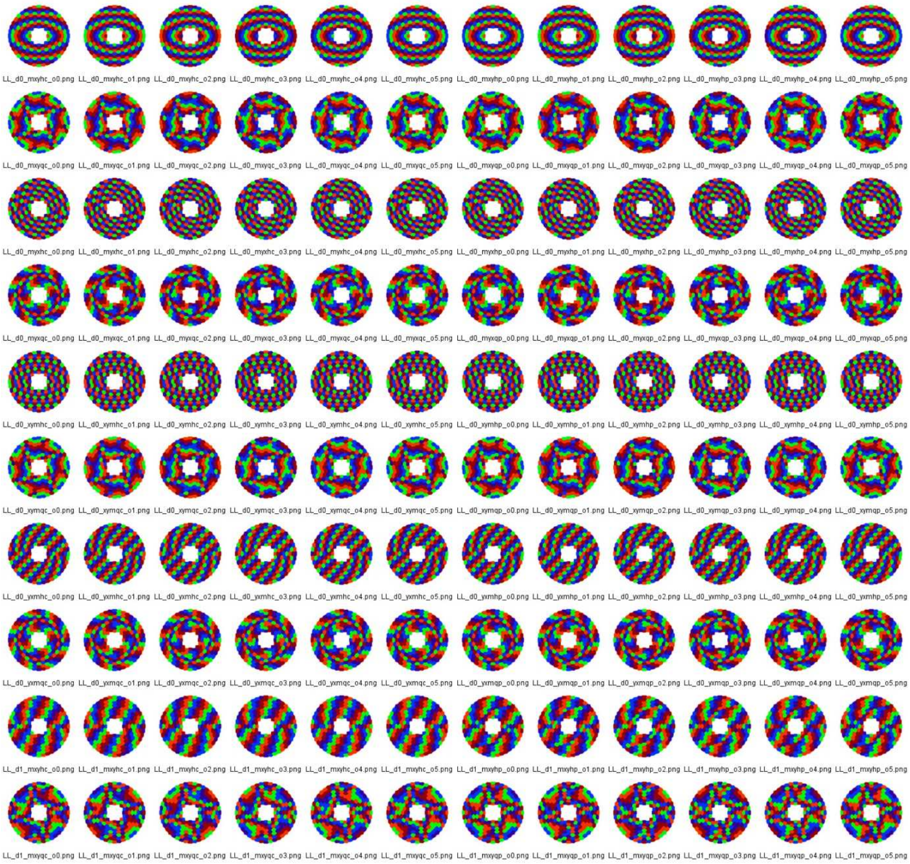

FIG. 2 - A choice of different permutations for the distribution of the 5 different LED emitters on the multispectral Microdome. (© RICH project & ESAT-VISICS, KU Leuven).

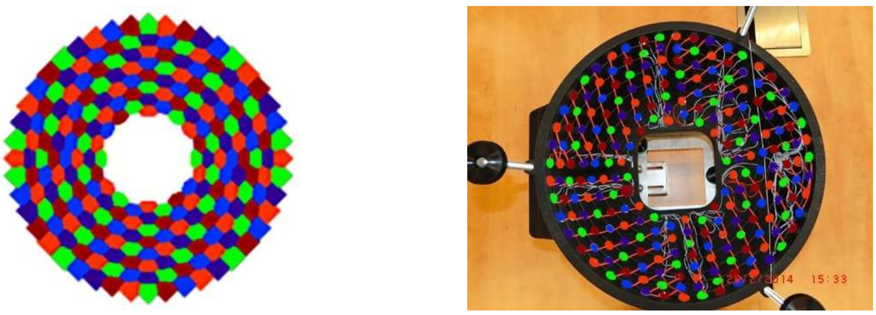

FIG. 3 - The selected distribution of the 5 different spectra implied on the inside of the Microdome. (© RICH project & ESAT-VISICS, KU Leuven).

4.4 Software

The results of the software package can be uploaded in a custom-made interactive (2D+) environment, the PLD viewer. The underlying methodology to determine the normal and surface information is based on the principles of Photometric Stereo (Woodham, 1980; Horn, 1986, Chapter 10-11; Verbiest and Van Gool, 2008). As opposed to Polynomial Texture Mapping (Malzbender et al., 2001; Earl et al., 2010), which tries to fit the observations with a mathematical function or description in order to mimic the appearance in a kind of make-believe visualization, Photometric Stereo methods recover the actual 3D shape and albedo of a surface using multiple images in which the viewpoint is fixed and only the lighting directions vary. The technique is based on the fact that the amount of light reflected by a surface depends on the orientation of the surface in relation to the viewpoint of the camera and the position of the light source. The dome-shaped devices that we developed, consist of a single, down-looking camera on top of a hemisphere with LED light sources covering the inside surface. With this setup, the position of the object and the camera can be kept constant, while varying the position and angle of the light source by subsequently activating the different LEDs. Traditionally this method has only been verified with LED light sources of the same type, by default white light. Our starting point for the proposed algorithm is the existing CPU-only implementation (initiated in Willems *et al.*, 2005; see also Watteeuw et al., 2013).

The recovered results allow for both photorealistic and non-photorealistic virtual renderings of the scanned surfaces. To represent the geometry and the colour effectively, the currently implemented algorithm produces three output images: a normal image, an albedo image and an ambient image (FIG. 4). The normal image is a two-valued representation of the geometric details of the digitized object. It contains the surface orientation for each pixel and thus yields information on the overall physical shape of the object through integration of the pixel-wise normals.

FIG. 4 - The normal (left), albedo (center) and ambient (right) result images for the scan of a moth. (© ESAT-VISICS, KU Leuven).

The albedo image contains the diffuse reflection coefficient for each pixel, providing information on the optical characteristics of the object's surface (Coakley, 2003). The amount of energy that is reflected by a surface is determined by the reflectivity of that surface, called the albedo. A high albedo means the surface reflects the majority of the radiation that hits it and absorbs the rest (FIG. 5).

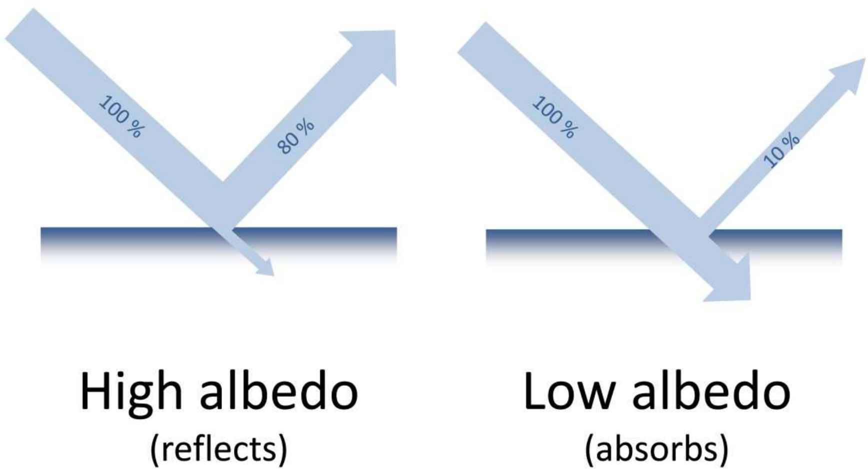

FIG. 5 - Example of the albedo principle (© EES project, RMAH Brussels).

The interactive ambient image calculated by the software of the PLD viewer mimics the surface's observed colour when illuminated under ambient lighting conditions, in this particular case it simulates the effect of all the dome LEDs lighting that surface simultaneously. The albedo and normal map are used to create an accurate, textured 3D model of the digitized object.

The ambient map serves as a comparison with (and alternative for) albedo, for inspection purposes for the users.

For the white light dome, the photometric stereo algorithm thus operates on a set of 260 images taken by the fixed camera – each with one LED activated – to produce the three output images, respectively containing the normal, the albedo and the ambient information for the observed object.

For the multispectral dome, the algorithm is subdivided for the different types of LEDs available, i.e. a similar algorithm operates on the IR, R, G, B and UV components. Alternatively, the formulation of photometric stereo can be reformulated to keep the normal constant. It is, however, interesting to observe that the normal information that is extracted clearly tends to get crisper for shorter wavelengths (UV) and shows a gradual sharpening up from IR to UV.

The physical phenomenon behind this is that electromagnetic energy at shorter wavelengths can detect smaller details (see FIG. 6 & 7).

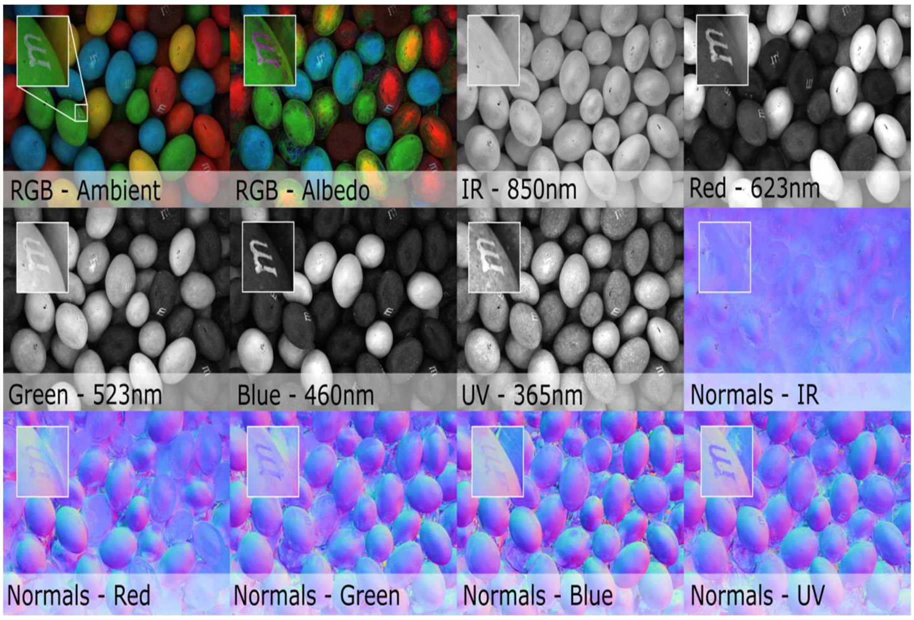

FIG. 6 - Overview of different visualizations of M&M's© by the PLD viewer software based on recordings by the MS Microdome, (©EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

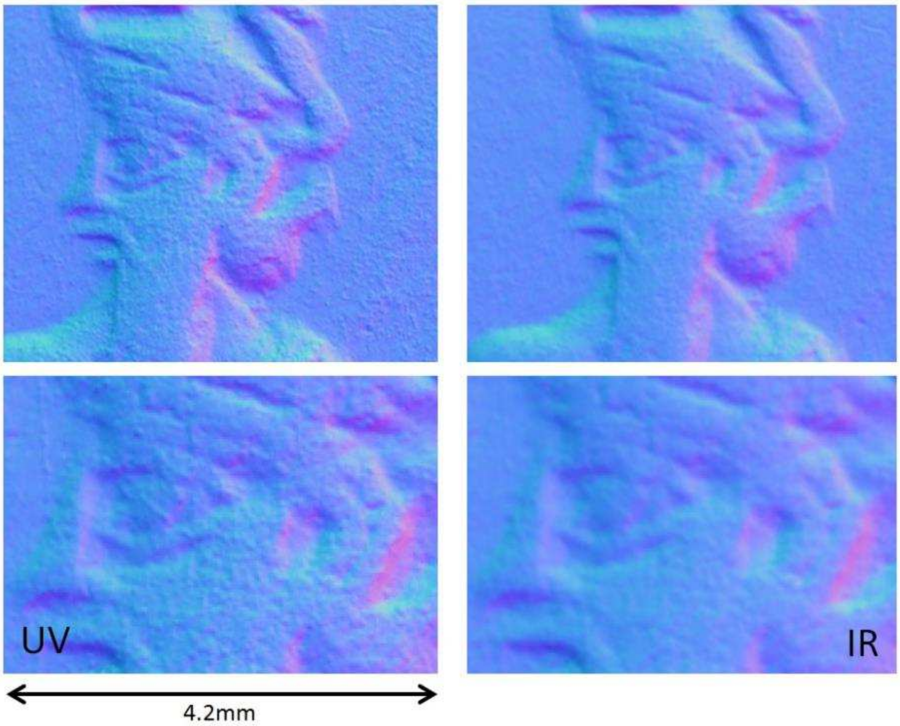

FIG. 7 - Difference in sharpness of the reconstructed UV and IR normal maps, for a detail of a seal impression on the reverse of cuneiform tablet NP 2 (© EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

5. Preliminary results

Art technical and conservation studies

Within the RICH project, techniques and conditions are explored on extremely delicate illuminations in medieval manuscripts. Condition and conservation assessments are combined and compared in the preliminary imaging protocol. In 2015, imaging with the MS Microdome focused on the "Anjou Bible", an illuminated manuscript created at the Royal Court of Naples for Robert I of Anjou by the illuminator Christophus Orimina (fl. 1230-1345) and his workshop around 1340 (KU Leuven, Maurits Sabbe Library, Ms 1). The leading illuminator was closely observing the techniques of Simone Martini (1284-1344), one of the most important panel painters in the south of Europe. Studies exploring the illuminating techniques (Watteeuw and Van Bos, 2010) revealed a complex and innovating palette for the first half of the 14^{th} century (analyses by micro-XRF and Raman spectrometry, study in collaboration with the Royal Institute of Cultural Heritage, Brussels). Moreover, the imaging with the MS Microdome revealed new characteristics illustrating the topography, characteristics and the density of the thin pictorial layers on the parchment. Some initial observations about FIG. 8: the king's throne is presented before a drapery with his coat of arms (azure, *semé-de-lys or*, a label gules). The visualization in false colour revealed that for painting the blue background, two blue mineral colours are mixed; azurite and most probably ultramarine, not detectable with XRF, but colouring red in the false colour MS Microdome image (FIG. 8: C).

FIG. 8 - Bible of Anjou, Naples, 1340 (KU Leuven, MSB, Codex 1, folio 1 v.), detail. Conventional image (left), followed by three images with the MS Microdome (© RICH project & ESAT-VISICS, KU Leuven).

Under false colour IR, the gilded areas on the dalmatic of the king are showing micro-cracks in the gold leaf foil caused by micro-movement in the parchment support (FIG. 9: A). The added red transparent dots in glaze on the kings belt, depicting gems (rubies), are visible with the shaded UV filter. The transparent layer of paint, spread over the top of the opaque gold leaf, is visible as raised gritty spots (FIG. 9: B).

As regards the inscribed figurines from the EES project case study, the virtual representations enable researchers to study more than the faded inscriptions on them. To understand the construction process of these archaeological objects, their geometrical characteristics play a prominent role (FIG. 10).

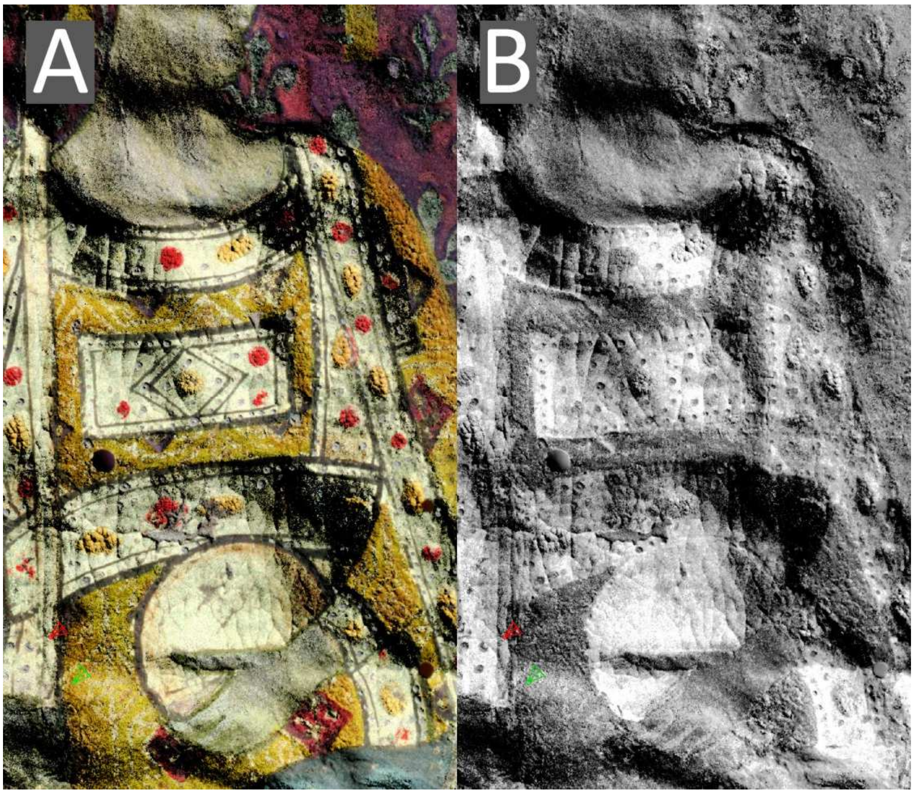

FIG. 9 - Bible of Anjou (detail), imaging with the MS Microdome. A) False Colour IR; B) shaded UV (© RICH project & ESAT-VISICS, KU Leuven).

FIG. 10 - 3D images of E.7465 based on a dataset from the white light Minidome, visualised in MeshLab version 1.3.4BETA, left to right: renderings with colour, with shader PhongUntextured, without colour (© EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

As can be seen on a data acquisition by the white light Minidome of a fragmented figurine such information can be extracted and interactively visualized in the PLD viewer as well. On FIG. 11, the individual parallel strokes left by the manufacturer's fingers during the smoothening of the surface become visible when applying the appropriate enhancement filter and virtual relighting condition. The different directions and actions executed by the manufacturer can be followed and examined (marked with arrows in different colours on

FIG. 11). This shows that, even though the figurines were roughly modelled, a certain amount of attention was paid to the smoothening of the recto. The back side of the figurines tend to have a very rough surface, even when the inscriptions continued on that verso. This suggests that the appearance of the back was to be less important.

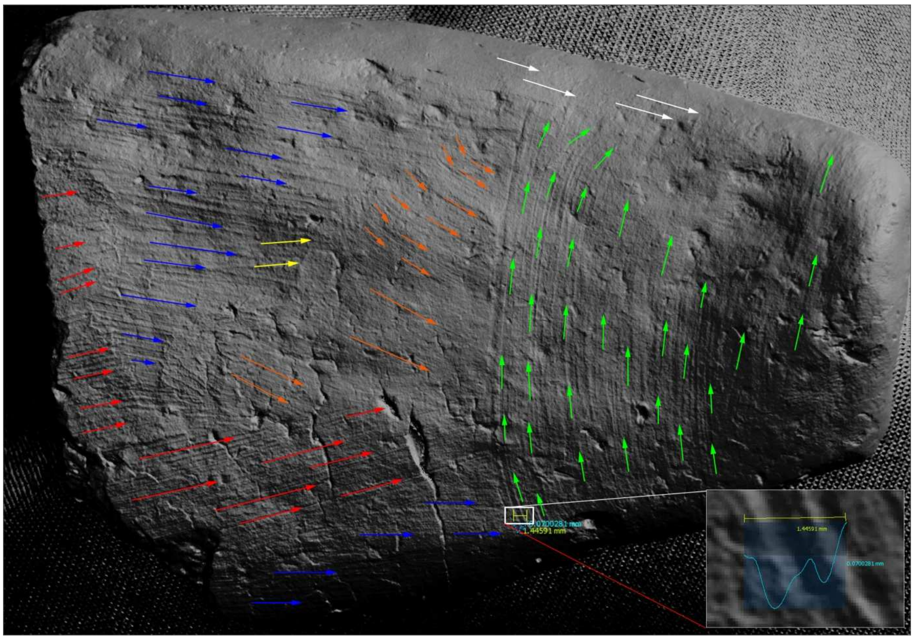

FIG. 11 - Directions of smoothing marks by fingers on the surface of E.7453 (recto), PLD viewer in shaded exaggerated mode (©EES project & ESAT-VISICS, RMAH Brussels & KU Leuven).

Throughout the EES project some other objects were also imaged for an art technical study with the MS Microdome, specifically to explore the system's potential with different kinds of materials. Tests were undertaken on a painted mummy portrait from Roman Egypt (one of the so-called Fayum portraits, see: Van der Perre and Hameeuw, 2015), but also on part of an Egyptian Late Period coffin (E. 2357) and on several ostraca (unpublished). Although these images require further research, preliminary results proved to be very promising.

Ancient inscriptions

One of the objectives of the EES project is to enhance the visibility of ink and pigment traces on (unbaked) three-dimensional clay objects

(FIG. 11). The figurines of our case study have been inscribed with two types of ink: red ochre and black ink. Literature studies (Danzing, 2010; Macfarlane, 2011, p.95) dealing with multispectral imaging – predominantly on parchment, papyri and ostraca – describe that black (carbon) inks tend to give the best results, whereas visualizing remnants of red ochre inks are often very problematic. The first tests with the MS Microdome, however, delivered some very promising results for the figurines inscribed with (red) ochre ink as well. When comparing the recordings from the first figurine processed with the MS Microdome with the original and conventional photographs, it was immediately clear that the legibility of the faded signs had improved significantly. It offered the ability to reconstruct parts of the inscription that were previously considered to be lost for good (FIG. 12).

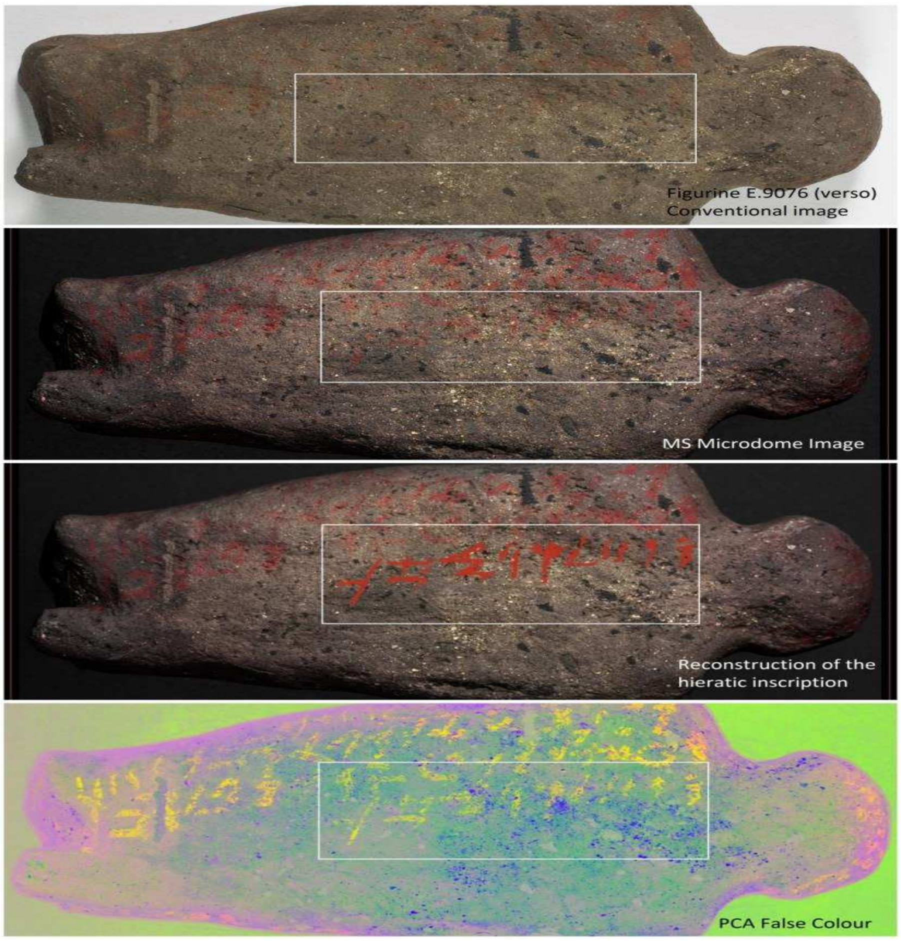

FIG. 12 - Reverse of an Egyptian execration figurine (RMAH E.9076), at the bottom a false colour PCA computation based on the images by the MS Microdome made with ImageJ software by R.B. Toth Associates and Equipoise Imaging (© EES Project & ESAT-VISICS, RMAH Brussels & KU Leuven).

In order to examine the quality, accuracy and adequateness of the multispectral component of the MS Microdome approach for the enhanced visualization of these inscriptions, the test artefacts were imaged and processed with both the MS Microdome and the spectral imaging tool by R.B. Toth Associates and Equipoise Imaging (Toth, 2015). The datasets of both acquisition systems were further processed using the custom ImageJ plug-ins by R.B Toth. The principal component analysis (PCA) false colour computations proved in both cases to give the best results (see also Baronti et al., 1997; France and Toth, 2011). As can be seen by examining and comparing the bottom representation on FIG. 12 and FIG. 13, their results are essentially comparable to ours.

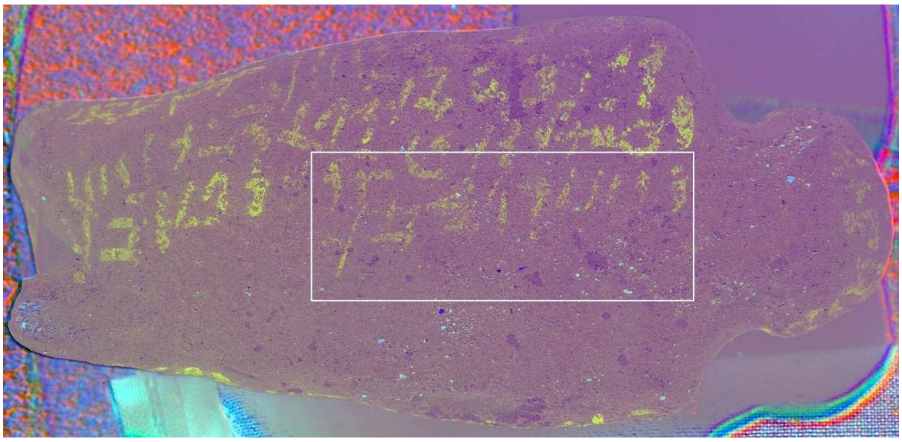

FIG. 13 - Reverse of RMAH E.9076, a false colour PCA based on both the images and the ImageJ computation by the Multispectral Imaging System by R.B. Toth Associates and Equipoise Imaging (© EES project, KU Leuven & R.B. Toth Associates and Equipoise Imaging).

6. Prospects

General prospects

In the next phases of development, we will consider more complicated material aspects for visualization such as BRDFs (Bidirectional Reflectance Distribution Functions). Dimensionality reduction and data mining techniques (e.g. PCA) will be considered to compress the data, and to automatically retrieve relevant content from the imagery. Corroborated by the current experiments, we foresee the possibility for adaptive photometric stereo, where the choice of lights can be controlled by the current observations.

Prospects for research on documentary heritage (RICH)

The ongoing studies on master drawings, prints, and medieval illuminations (the RICH, FINGERPRINT & ArtGarden Projects, 2016-2020) will explore and develop further the possibilities of the MS Microdome visualization. The combination with analytical micro-XRF mapping aims to benchmark reference data for inks, pigments and dyes captured in the false colour images. Standardization of these datasets aims to support non-invasive research and art technical interpretation on very difficult to access drawings and miniatures on paper and parchment. Apart from the variations of false colour images (combination of IR, R, G, B and UV images) further refined processing algorithms such as PCA and LDA (Linear Discriminants Analysis) will be added.

Prospects for research on archaeological artefacts (EES)

As stated above, several studies on the subject note that the best results are obtained for black inks, whereas red ochre inks are very problematic. Based on these observations, Egyptian execration figurines were expected to be a challenging case study given the fact that the vast majority bear red ochre ink inscriptions. Our tests, however, demonstrate the opposite: good results are obtained for red ochre ink, whereas black ink appears to be problematic. This contrasts strikingly with what is described in the literature, and thus calls for further research. An explanation may be found in the baked vs. unbaked condition of the medium. This will be further explored in upcoming final phases of both research projects.

References

Abate, F.; Menna, F.; Remondino, F. and Gattari, M.G. (2014), 3D painting documentation: evaluation of conservation conditions with 3D imaging and ranging techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. **XL-5**(V/WG2), pp.1–8.

Albrecht, F. (2014), A New Portable System for Multispectral and Full Spectral Imaging. In: Driscoll, M.J. (ed.) *Care and Conservation of Manuscripts* 14. Kopenhagen: University of Chicago Press, pp.237-252.

Allied Vision (2015) Prosilica GX 6600. *Allied Vision* [online]. Available from:https://www.alliedvision.com/en/products/cameras/detail/6600-1.html [Accessed 7th November 2015].

Anandan, V. (2015), Week 5 – Multispectral Imaging. *Roman Egyptian Mummy Portraits, Johns Hopkins Archaeological Museum* [online]. Available from: http://archaeologicalmuseum.jhu.edu/the-collection/object-stories/roman-egyptian-mummy-portraits/week-5-multispectral-imaging/ [Accessed 16th November 2015].

Archimedes Palimpsest (2010), core Archimedes data [online]. Available from: http://archimedespalimpsest.net/Data/ [Accessed 23rd November 2015].

Baronti, S.; Casini, A.; Lotti, F. and Porcinai, S. (1997), Principal component analysis of visible and near-infrared multispectral images of works of art. *Chemometrics and Intelligent Laboratory Systems.* **39**, pp.103-114.

Bay, S.; Bearman, G.; Macfarlane, R. and Wayment, T. (2010), Multi-Spectral Imaging vs Monospectral Infrared Imaging. *Zeitschrift fur Papyrologie und Epigraphik.* **173**, pp.211-217.

Bennett, T. (2015), Photogrammetry and Transmitted Infrared Imaging to Document the Support of a 19th c. British Landscape Painting. *COSCH e-Bulletin.* **2**, pp.1-10.

Boon, J. and Leonardt, E., (2015,) New Light on the Surface of Art Objects in the Conservation Studio with a 3D Digital Hirox Microscope Mounted on an XYZ Stand. *In: Practical Philosophy, or Making Conservation Work. Abstract book AIC 43rd Annual Meeting, May 13-16 2015*. Miami: AIC. Available from: http://www.conservation-us.org/docs/default-source/annualmeeting/2015am_poster_8.pdf [Accessed 19TH November 2015].

Booras, S.W. and Seely, D.R. (1999), Multispectral Imaging of the Herculaneum Papyri. *Cronache Ercolanesi*. **29**, pp.95-100.

Boschloos, V.; Devillers, A.; Gubel, E.; Hameeuw, H.; Jean, C.; Van Goethem, L.; Van Overmeire, S. & Overlaet, B. (2014), The Ancient Near Eastern Glyptic Collections of the Royal Museums of Art and History Reconsidered. *Bulletin des Musées royaux d'Art et d'Histoire*. **83**, pp.23-43.

Bülow-Jacobsen, A. (2008), Infra-red imaging of ostraca and papyri. *Zeitschrift für Papyrologie und Epigraphik*. **165**, pp.175-185.

Bülow-Jacobsen, A. (2011), Preface. In: Vahtikari, V., Hakkarainen, M. and Nurminen, A. (eds.) *Eikonopoiia: digital imaging of ancient textual heritage*. Helsinki: Societas scientiarum Fennica, pp.1-2.

Caine, M. and Magen, M. (2011), Pixels and Parchment: The Application of RTI and Infrared Imaging to the Dead Sea Scrolls. In: Dunn, S., Bowen, J. and Ng, K. (eds.). EVA London 2011: Electronic Visualisation & the Arts. Proceedings of a conference held in London 6-8 July. Swindon: British Computer Society, pp.140-146.

Coakley, J.A. (2003), Reflectance and Albedo, Surface. In: Holton, J.R. and Curry, J.A. (eds.) *Encyclopedia of the Atmosphere*. Corvallis: Academic Press, pp.1914-1923.

Corcoran, L.H. and Svoboda, M. (2010), *Herakleides. A portrait mummy from Roman Egypt*. Los Angeles: Getty Trust.

Cosentino, A. (2014), Identification of pigments by multispectral imaging; a flowchart method. *Heritage Science*. **2**(8), pp.1-12.

Danzing, R. (2010), Pigments and Inks Typically Used on Papyri. *BKM TECH* [online]. Available from: http://www.brooklynmuseum.org/community/blogosphere/2010/09/22/pigments-and-inks-typically-used-on-papyrus/ [Accessed 9th November 2015].

Dufy, C. (2015), Revealing the secrets of the burnt Magna Carta, [online]. Available from: http://www.bl.uk/magna-carta/articles/revealing-the-secrets-of-the-burnt-magna-carta [Accessed: 14th November 2015]

Dyer, J., Ambers, J. and Simpson, A. (2012) Analysis of pigment traces on a limestone sculpture of the Egyptian god Horus in Roman military costume (1912,0608.109). *British Museum* (unpublished). Available from:http://www.britishmuseum.org/pdf/AR2012_42_Horus%20in%20Roman%20military%20costume.pdf [Accessed 9th November 2015].

Earl, G.; Martinez, K. and Malzbender, T. (2010), Archaeological applications of polynomial texture mapping: analysis , conservation and representation. *Journal of Archaeological Science*. **37**, pp.1-11. (http://eprints.soton.ac.uk/156253/1/EarlMartinezMalzbender2010.pdf)

Easton, R.L. Jr.; Christens-Barry, W.A. and Knox, K.T. (2011), Ten Years of Lessons from Imaging of the Archimedes Palimpsest. In: Vahtikari, V., Hakkarainen, M. and Nurminen, A. (eds.) *Eikonopoiia: digital imaging of ancient textual heritage*. Helsinki: Societas scientiarum Fennica, pp.5-33.

Faigenbaum, S.; Sober, B.; Shaus, A.; Moinester, M.; Piasetzky, E.; Bearman, G.; Cordonsky, M. and Finkelstein, I. (2012), Multispectral images of ostraca: acquisition and analysis. *Journal of Archaeological Science*. **39**(12), pp.3581-3590.

Fisher, C. and Kakoulli, I. (2006), Multispectral and hyperspectral imaging technologies in conservation: current research and potential applications. *Reviews in Conservation.* **7**, pp.3-16.

France, F.G. and Toth M.B. (2011), Spectral Imaging for Revealing and Preserving World Cultural Heritage. In: Mestre, X., Hernando, J. and Pardas M. (eds.) *Proceedings of the 19th European Signal Processing Conference (EUSIPCO'11), Barcelona, Spain,* August 2011. Kessariani: EURASIP, pp.1450-1454.

Ganio, M.; Salvant, J.; Williams, J.; Lee, L.; Cossairt, O. and Walton, M. (2015), Investigating the use of Egyptian blue in Roman Egyptian portraits and panels from Tebtunis, Egypt. *Applied Physics A.* **121**(3), pp.813-821.

Giacometti, A.; Campagnolo, A.; MacDonald, L.; Mahony, S.; Terras, M.; Robson, S.; Weyrich, T. and Gibson A. (2012), Cultural Heritage Destruction: Documenting Parchment Degradation via Multispectral Imaging. London: Electronic Visualisation and the Arts (EVA).

Hameeuw, H. and Van Overmeire, S. (2014), The Seleucid bullae from Uruk in the Royal Museums of Art and History, Brussels. *Mesopotamia.* **49**, pp.113-142, pl. 5-13.

Hameeuw, H. and Willems, G. (2011), New Visualization Techniques for Cuneiform Texts and Sealings. *Akkadica*. **132**, pp.163-178.

Horn, B.K.P. (1986), *Robot Vision*. Cambridge (MA): MIT Press.

Jenoptik Inc (2015), CoastalOpt UV-VIS-IR 60 mm Apo Macro Lens. *Jenoptik Inc* [online]. Available from: http://www.jenoptik-inc.com/coastalopt-standard-lenses/uv-vis-nir-60mm-slr-lens-mainmenu-155/80-uv-vis-ir-60-mm-apo-macro.html [Accessed 7th November 2015].

Keats Webb, E. (2015), 3D & near-infrared imaging for object documentation. *SEAHA* [Poster] Available from: https://www.bartlett.ucl.ac.uk/heritage/programmes/mres-msc/mres-seaha/images/keatsposter2015 [Accessed 18th November 2015].

Kotoula E. (2012), Infrared RTI: Experimentation towards the development of multispectral RTI. *Archaeology Blogs Southampton University* [online]. Available from: http://acrg.soton.ac.uk/blog/1569/ [Accessed 25th November 2015].

Kotoula, E. (2015), Ultraviolet RTI. *Archaeology Blogs Southampton University* [online]. Available from: http://acrg.soton.ac.uk/blog/4175/ [Accessed 9th November 2015].

LED Engin (2015), LED Emitters, LZ Series. LED Engine [online]. Available from: http://www.ledengin.com/products/emitters#LZ1 [Accessed 7th November 2015]

Liang, H. (2012), Advances in multispectral and hyperspectral imaging for archaeology and art conservation. *Applied Physics.* **106**(2), pp.309-323.

Macfarlane, R.T.; Wayment, T.; Bay, S.M. and Bearman, G. (2011), Exploring the Limitations and Advantages of Multi-Spectral Imaging in Papyrology: darkened, carbonized, and palimpsest papyri. In: Vahtikari, V., Hakkarainen, M. and Nurminen, A. (eds.), *Eikonopoiia:*

digital imaging of ancient textual heritage. Helsinki: Societas scientiarum Fennica, pp.87-98.

Malzbender, T.; Gelb, D. and Wolters, H. (2001), Polynomial texture maps. *In: SIGGRAPH'01: Proceedings of the 28th Annual Conference on Computer Graphics and Interactive Techniques, 12-17 August 2001*. New York: ACM Press, pp.519-528.

Mazza, R. (2015), Making the Mummies Talk (without Palmolive soap!). *Faces & Voices* [online]. Available from: https://facesandvoices.wordpress.com/category/mummy/ [Accessed 16th November 2015].

Posener, G. (1940), *Princes et pays d'Asie et de Nubie. Textes hiératiques sur des figurines d'envoûtement du Moyen Empire.* Brussels: Fondation Égyptologique Reine Élisabeth.

Remondino, F. (2011), Advanced 3D Recording Techniques for the Digital Documentation and Conservation of Heritage Sites and Objects. *Change Over Time.* **1/2**, pp.198–214.

Shah, T. (2015), Week 2 – APPEAR. *Roman Egyptian Mummy Portraits, Johns Hopkins Archaeological Museum* [online]. Available from: http://archaeologicalmuseum.jhu.edu/the-collection/object-stories/roman-egyptian-mummy-portraits/week-2-appear/ [Accessed 16th November 2015]

Sober, B.; Faigenbaum, S.; Beit-Arieh, I.; Finkelstein, I.; Moinester, M.; Piasetzky, E. and Shaus, A. (2014), Multispectral Imaging as a Tool for Enhancing the Reading of Ostraca. *Palestine Exploration Quarterly*. **146**(3), pp.185-197.

Toth, R.B. (2015), *Applying New Technologies to Cultural Studies*. Website R.B. Toth Associates [online]. Available from: http://www.rbtoth.com/ [Accessed 12th November 2015].

Van der Perre, A. and Hameeuw, H. (2015), La création d'images multi-spectrales: les portraits romains du Fayoum. In: Delvaux, L. and Therasse, I. *Sarcophages. Sous les étoiles de Nout.* Brussels: Racine, pp.164-165.

Verbiest, F. and Van Gool, L. (2008), Photometric stereo with coherent outlier handling and confidence estimation. *In: Proceedings IEEE Conference on Computer Vision and Pattern Recognition, June 24-26, 2008, Anchorage*. New York: IEEE, pp. 2886-2893.

Watteeuw, L. and Van Bos, M. (2010), Illuminating with Pen and Bruch. The Techniques of a Fourteenth-Century Neapolitan Illuminator Explored. In: Watteeuw L. and Van der Stock J. (Eds.), *The Anjou Bible. Naples 1340. A Royal Manuscript Revealed.* Corpus of Illuminated Manuscripts, vol. 18. Paris - Leuven - Warlpole: Peeters, pp.147-170.

Watteeuw, L.; Vandermeulen, B.; Proesmans, M. (2014), See the Surface. Imaging and measuring surface characteristics of medieval library materials by photometric stereo (RICH Project). Arts Digital Humanities Summer School. Leuven, 8-19 September 2014.

Watteeuw, L.; Vandermeulen, B.; Van der Stock, J.; Delsaerdt, P.; Gradmann, S.; Truyen, F.; Proesmans, M.; Moreau, W. and Van Gool, L. (2013), Imaging Characteristics of Graphic Materials with the Minidome (RICH). *In: Paper Conservation. Decisions & Compromise. ICOM-CC graphic documents working group interim meeting. Vienna, Austria*, 17-19 April 2013. Vienna: ICOM- CC & Austrian National Library, pp.140-141.

Watteeuw, L.; Vandermeulen, B.; Van der Stock, J.; Truyen, F.; Proesmans, M.; Van Gool, L.; and Gradmann, S. (2014), Imaging the topography of illuminations and bookbindings with reflectance transformation imaging. In: *ICOM-CC 17th Triennial Conference.*

Building Strong Culture through Conservation. Melbourne, 15-19 September 2014. Melbourne: ICOM, Abstract No. 543.

Willems, G.; Verbiest, F.; Moreau, W.; Hameeuw, H.; Van Lerberghe, K. and Van Gool, L. (2005), Easy and cost-effective cuneiform digitizing. In: Mudge, M., Ryan, N. and Scopigno, R. (Eds.), *The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2005). International Symposium on Virtual Reality, Archaeology and Cultural Heritage. Pisa, 2005*. Aire-la-Ville: Eurographics Assoc, pp.73-80.

Woodham, R.J. (1980), Photometric method for determining surface orientation from multiple images. *Op.*

Marroquim, R.; Coutinho, D.; Granato, M. (2016), Digitizing 3D historical scientific instruments with laser and photographic technologies. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.193-210

DIGITIZING 3D HISTORICAL SCIENTIFIC INSTRUMENTS WITH LASER AND PHOTOGRAPHIC TECHNOLOGIES

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ABSTRACT The digitization of 3D tangible cultural heritage is becoming a widespread process. It assists in the creation of physical replicas for preserving the original object, for conducting studies, precise documentation and enhanced exhibition, among other purposes. Nevertheless, some objects still present major challenges due to their complex geometry, difficult access, or materials that are not compliant with most acquisition technologies. The Digital Bamberg project was conducted in collaboration between the Computer Graphics Lab of UFRJ (Universidade Federal do Rio de Janeiro) and MAST (Museu de Astronomia e Ciências Afins), to digitize a historical meridian circle. One of the main goals was to study how 3D scanning technologies behaved when confronted with important challenges, such as: dark and shiny materials, a mechanical instrument, and of historical value. The digitization process used a laser scanner for geometry acquisition, and high-resolution photographs for appearance retrieval. Most of the challenges were due to the use of these two light-based technologies. The laser spreads when hitting a metallic surface introducing a high frequency noise, which results in imprecise geometry. Moreover, removing the light influence when taking photographs to acquire the true surface appearance is another critical issue, mainly due to reflections that are difficult to eliminate completely. We discuss the main light-based challenges confronted during this project, as well as solutions to these issues. This contribution sheds light on how to efficiently acquire quality geometric and photographic data of complex metallic mechanical instruments, while at the same time, preserving the integrity of historical object.

KEYWORDS Laser scanners; Digitization; Historical scientific instruments

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1. Digitizing cultural heritage artifacts

The digitization of historical artifacts has gained popularity in the last two decades. With new technologies it is possible to accurately capture the geometry and appearance of physical object (Ikeuchi and Miyazaki, 2008). The virtual replica can be used for a variety of purposes (Stanco et al., 2011). A few examples are given below.

Documentation: the 3D object can complement traditional documentation and annotation methods. The visual state of the object is readily available, and details are preserved for inspection. It also facilitates the physical description and is much richer than photographs.

Dissemination: the 3D model can be visualized and manipulated remotely, from computers or mobile devices. Furthermore, it can be used to elaborate animations and renders to enhance the museum's expositions.

Study: virtual models can be shared around the globe, facilitating the study by historians and other interested professionals, such as curators.

Conservation: the 3D object is very useful during restoration campaigns, where it can support tasks during the planning, the restoration process, and comparisons before and after the intervention.

3D physical replica: when an artifact is removed from an exhibition to be restored or for a temporary exhibition, a physical replica can be printed from the virtual model to serve as a temporary replacement. Missing fragments can also be replaced by 3D prints (Scopigno et al., 2015).

A common digitization session starts by acquiring the geometry using laser scanners or photogrammetry, for example. Some initial alignment is usually done on site, while a finer alignment in carried out in a post-processing phase, followed by a surface reconstruction method to achieve a digital model.

In a second stage, texture, or color, is acquired from a photography session. Each photo is carefully aligned with the model to project the pixels onto the geometry. As a last step, all the photos are combined to generate a single texture for the model.

It is important to note that there is no silver bullet in the digitization domain. No single technique or equipment can handle all types of geometric surfaces and materials. There are also some approaches to acquire geometry and appearance in one pass, but they still lack maturity and robustness (Schwartz et al., 2011, Nöll et al., 2015). Furthermore, the practical experience of the digitization group is still essential for an efficient and successful acquisition campaign. Finally, most of the used technologies are light-based and passive, and works by emitting and/or capturing light without physical contact.

There are a few worth-mentioning points about the digitization of historic artifacts. On one hand, the technology is becoming more mature, and many objects can be digitized without great complications. On the other hand, many objects present specific challenges that are not trivially handled, such as its size (too large or too small), its color (too dark or too reflective), its geometry (lots of concave and hidden regions, or highly symmetrical parts), or its access (difficult or impossible to move the object or to place the scanner around it).

Given this scenario, scientific historical instruments present significant challenges, especially due to their predominantly metallic and reflective surfaces, and in some cases their size and weight. The straightforward solution for scanning generic reflective materials is to paint or cover it with white powder. For historical instruments, this procedure is obviously improper, so other ways must be found to digitize them.

Some alternatives might include, for example, specific or high-end scanners. But usually museums and restorers do not have access to multiple scanning equipment or very expensive scanners; thus, they must get along with more generally available digitization technologies. Another issue with mechanical instruments are the symmetrical or flat pieces, that make the geometry alignment a great burden.

Finally, even though scanning hardware and software can accomplish great results, there is still a great deal of post-processing and manual intervention required to achieved quality virtual replicas. Alignment, texturing, cleaning and smoothing are some of the common post-processing stages of producing a virtual object.

One of the goals of the Digital Bamberg Project was to investigate approaches to safely and reliably digitize historical scientific instruments without requiring specific hardware. It should serve as a general guide to future similar digitization campaigns.

In this article we describe the approaches experimented during the digitization of this historical instrument, and the important role of light-based technologies in this process.

2. The Bamberg

The Bamberg meridian circle belongs to the MAST (Museu de Astronomia e Ciências Afins – Museum of Astronomy and Related

Sciences) collection. MAST is co-located with the National Observatory campus, in Rio de Janeiro, and is responsible for the preservation and restoration of a collection of around two thousand technological and scientific cultural heritage artifacts.

Meridian circles are used to determine the positions of stars. To achieve such measurements these instruments are tailored with maximum precision, and are composed of many small and large mechanical pieces.

The Bamberg (FIG. 1) was fabricated in Germany in the beginning of the twentieth century, and was in operation at the National Observatory in Rio de Janeiro until the seventies. During this period, it played important roles in the determination of latitude and longitude, and the official Brazilian time.

FIG. 1 - A photo of the Bamberg Meridian Circle.

The digitization of the Bamberg was aligned with its disassembly, that had among its goal the inspection and assessment of the current state of its components. It was a good opportunity to scan and photograph each part separately in order to later re-assemble the instrument physically and digitally. Note that the goal was not to reproduce its mechanical functionality digitally, but to have a as faithful as possible digital replica in the geometrical and appearance sense.

The disassembly (FIG. 2) and close inspection of the instruments also led to a series of interesting discoveries about its components, such as details of how it worked, and clues about its history, since for example, some manual markings were discovered in some points of the instrument.

FIG. 2 - The Bamberg's lower base completely disassembled. Each part is labelled and kept in its respective place to guarantee the correct assembly afterward.

The Bamberg contains an enormous variety of pieces, ranging from metal bases that weight around forty kilograms each, to very tiny components such as bolts, springs and plates. Moreover, the material range includes metallic parts, some very well conserved while others had deteriorations such as rust and wearing, as well as some plastic and glass pieces. Thus, we were facing a case were no single technique would handle all pieces.

2.1 Geometry acquisition

To acquire the geometry a Konica-Minolta Vivid 9i laser scanner was used (FIG. 3). This is a mid-price scanner that is known to tackle a broad range of geometric and reflective properties. It can handle objects ranging from a few centimetres up to a few meters.

FIG. 3 - The Konica-Minolta scanner during a digitization session of the Bamberg's lower base.

Due to the reflective and dark material properties of the Bamberg, the time to scan the larger parts was considerably longer than it would be with the same geometry and a more scanner-friendly material, such as diffuse and light colors. Each scan was only able to retrieve a small amount of geometry, and accompanied by significant noise. To alleviate this problem, we scanned each part from different viewpoints (FIG. 4), since the scanner would only capture the reflected laser from a few incident angles. We also manually set the focus distance to avoid problems with the auto-focus.

FIG. 4 - Two registers from the scanner. Note how there are many missing parts and holes due to the material dark color. The laser is also unable to reach inside the base's apertures.

Furthermore, due to the weight of the larger parts, manipulation and orientation was limited, making it difficult to acquire the geometry from some viewpoints. A turning table was crafted to support the instruments weight, so it could be easily rotated without moving the scanner around. For each base, for example, we scanned in three full cycles, facing down, facing up, and sideways, in order to capture the geometry as thoroughly as possible.

There were two main issues with the two bases. The first is that, due to its predominantly flat geometry, no single scan can capture a part of the bottom and top planes at the same time. In other words, only the lateral faces were present on both scans, the rest was complementary. An important implication is that it leads to severe alignment issues since the upper and bottom scans can almost freely slide vertically as the lateral walls have no singular geometry to prevent this from happening.

The second issue is that the smaller apertures that form the base design were almost impossible to reach with the laser. It left holes that were large enough to cause problems for the surface reconstruction algorithm that was unable to correctly fill the missing parts.

To tackle these two problems some placeholder geometry was manually inserted in the digital model to force the alignment and hole filling algorithms to behave as expected. Since most of the geometry is flat, the inserted plane patches did not cause major inaccuracies on the final model.

When we moved to the main body, the alignment and holes were not the main issue, but we were faced with a significant amount of noise due to the metallic parts. Smoothing the geometry caused it to deviate from the physical measures, so we had to find another solution. Thus, as a final pass, we converted the pieces to CAD geometry, by implicitly defining the geometry with basic primitives (spheres, cylinders, planes, etc.) and Boolean operations (subtraction, intersection, addition). Most of the pieces had to be measured manually and checked against the scanned data (FIG. 5).

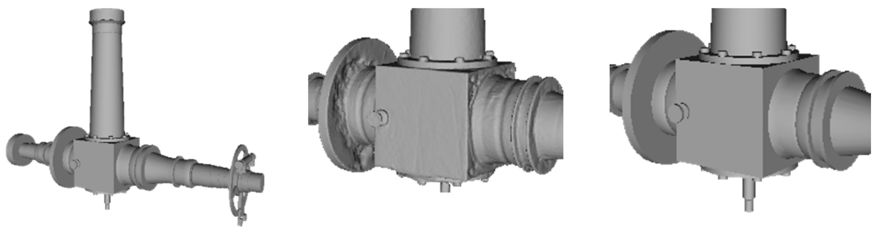

FIG. 5 - The detail of the scanned and CAD model. Notice how the scan model has plenty of noise, but still preserves the overall location and measurements of the pieces.

In fact, one might ask if scanning the model in the first place was a useless effort. As it turned out, it was just the opposite, the scanned model was crucial to validate the CAD model. In many occasions measurement or conceptual errors during the CAD model design were only noticeable when overlaid with the scanned model. Therefore, even if it took a considerable effort to produce two models, the scanned data provided the correct measurements, positions, and orientations, while containing a high degree of noise, while the CAD model was noise free but was strongly prone to deviations from the physical measurements.

Finally, smaller pieces, such as bolts, screws, and the micrometer (FIG. 6), among others, were directly modelled using the CAD system, since they were too small to be captured by our scanner. Since there was no scanned data to compare against, sometimes when assembling the virtual model sometimes the pieces would not fit correctly, and we had to go back and revise the CAD model. This was another advantage of having the larger parts scanned.

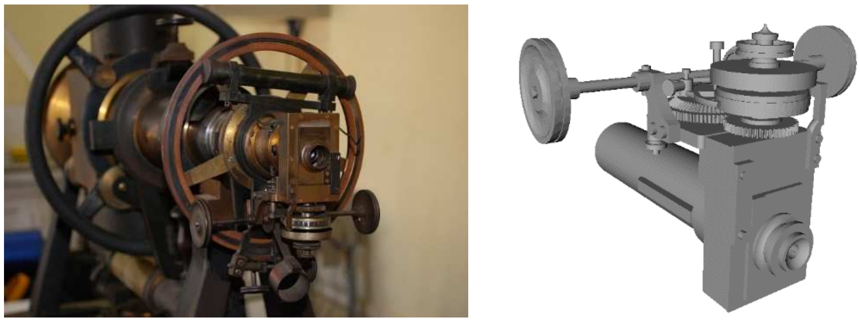

FIG. 6 - A photo and the 3D CAD model of the micrometer. Since it contains so many small pieces, the scanner was unable to capture the geometry and it was manually model using a CAD software.

2.2 Texturing the model

The geometric acquisition was a big challenge, that was mostly solved by placing extra efforts in the process: scanning multiple times to deal with the acquisition of reflective and dark materials, inserting plane patches to fill holes, and building a CAD model in parallel. All the same, the color acquisition required even greater care.

To texture the 3D model a series of photos are acquired that fully cover the model. These are individually aligned with the 3D model and projected onto the geometry, using methods such as (Corsini et al., 2009). In a final pass, all the projected pixels are blended into a single texture (Callieri et al., 2008) (FIG. 7).

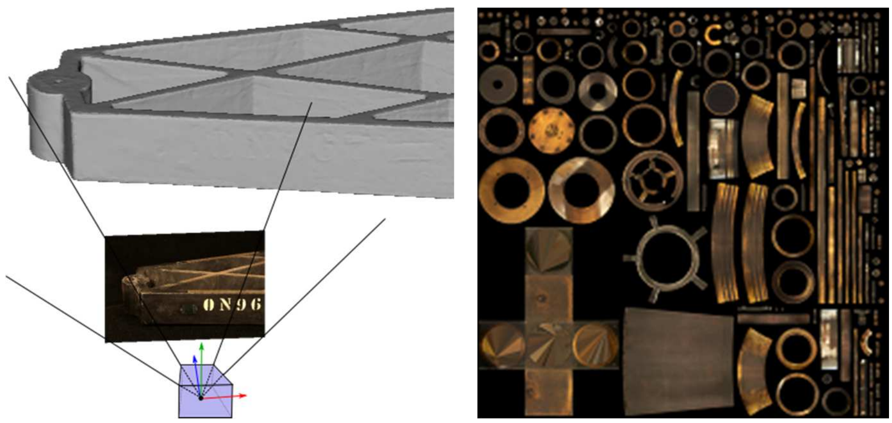

FIG. 7 - To project an image onto the geometry they must be aligned, the image is placed at the exact same position in regards to the virtual model as the camera was when the photo was acquired. The final texture is a composition of all the images that cover the model. The texture shown here is of the main body of the Bamberg.

One desire with texturing the model is to acquire the color with the least environment light influence as possible. This mostly means, avoiding highlights, reflections and high/low exposed parts, as to not carry these effects to the final texture. One common goal with digital objects is to relight it from different directions or different light sources, or place it in different scenarios within a virtual world, thus highlights should be produced by the visualization according to the virtual light and objects, and not imprinted on the texture beforehand.

To avoid highlights, usually diffuse light sources are used and direct illumination is avoided, which can be achieved using diffuse boxes or panels. For the smaller parts, we used an off-the-shelf white box (FIG. 8), while for the larger parts we improvised a tent to place the Bamberg's main body and bases during the photo sessions, in order to create a diffuse environment. As light sources, we used two studio lights with diffuse panels.

FIG. 8 - A photography session using the small diffuse white box and two light sources.

Even with such setup, it is almost impossible to completely remove highlights from metallic or highly reflective surfaces. We then decided to take photos with more overlap, and manually eliminate regions with strong highlights before the texturing phase. The extra overlap was to ensure that at least one, or a few, photos would capture the same region without highlights.

Acquiring more photos has a drawback, however. Apart from the extra effort to align each photo with the geometry, it also means that it is more prone to misalignment in regards to the other photos. This causes ghosting artifacts when creating the final texture. Again, this required extra care during the alignment procedure.

2.3 The final Bamberg digital modelling

The final model contains over 100 pieces of different sizes and geometric properties. Each piece was stored as a separate model with its texture (FIG. 9).

FIG. 9 - Four different digital parts of the Bamberg, including metallic supports, bolts and the lower base.

Using a modeling software we reassembled the virtual Bamberg by placing each part in its corresponding place. Since they were scanned or modeled with accurate precision, the final model fits perfectly (FIG. 10).

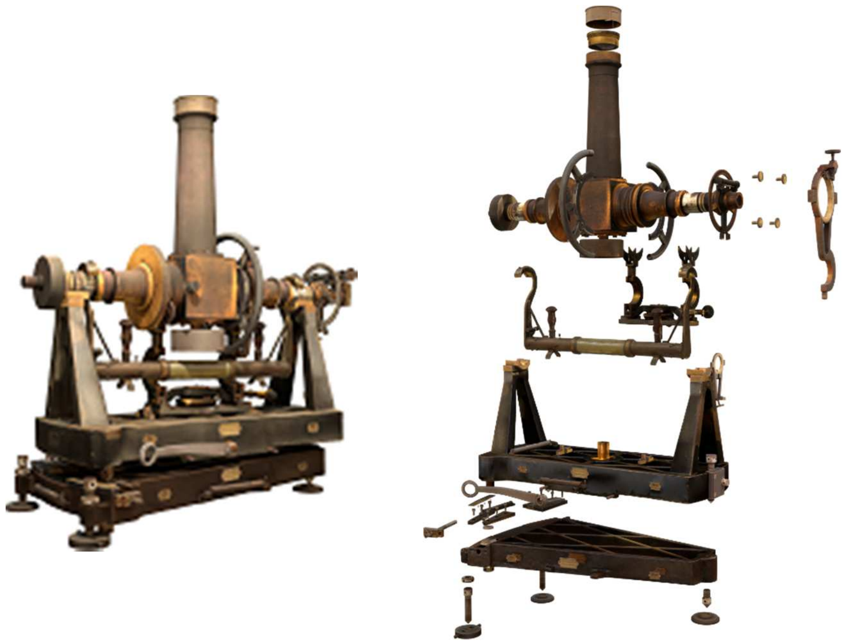

FIG. 10 - The final assembled virtual model and an exploded view of all the pieced of the virtual model.

This virtual model has already been used to generate an animation explaining how the Bamberg worked, and how it was used to measure stars' positions. The digital model is also helping with researchers studying this instrument. A 3D print of the Bamberg (scale 1:5) was also fabricated to be exposed at an exhibition featuring 3D technologies in the cultural heritage domain.

3. The importance of light-based techniques

Both acquisition approaches, for the geometry and the texture, are light based. The scanner emits a laser scanline and captures the reflection of the laser on the surface to determine distances, while the camera works by capturing general light reflected on surfaces and entering the camera lenses.

On one hand, this is extremely important because light-based approaches are passive in the sense that there is no physical-contact. Moreover, the light emission is usually not harmful, except in extreme cases were the material may be deteriorated if exposed to light sources such as lasers.

On the other hand, light-based equipment implicitly carries the challenges to control the light and its behavior when confronted with the objects surface material. The goal is to capture the surface properties and not its behavior in a particular environment.

As we have learned, or in many cases reaffirmed during the Digital Bamberg project, laser technologies perform poorly with metallic and dark surfaces. Reflective surfaces spread the laser, introducing high frequency noise during the registration, while dark surfaces absorb the light and are not captured by the scanner or the camera, leaving holes on the digital surface. In fact, structured light equipment also has problems dealing with this kind of material. Photogrammetry, is a little less sensitive, but has much lower precision in its measurements, and would be unsuitable for the desired goals of this particular project.

Another obvious problem with laser technologies is that it cannot reach some hidden parts of the object, and consequently leaves holes or inaccuracies on the final model. This is of course, also common with most surface light approaches. Volume-based techniques, such as computerized tomography, are able to reach hidden parts, but carry along a list of drawbacks, such as cost, inaccessibility, lack of portability, and lower precision among other problems.

As for texturing, the quality of the acquisition depended more on controlling the light environment, than the photography technology itself. Specular light is difficult to control during the acquisition, but it is even more problematic to solve *a posteriori*. That is why we made a strong effort to control the light during the photo sessions, to avoid as much as possible editing the photos to remove the highlights.

Another drawback with this type of texturing technique, is that we are not really acquiring the surface properties, that is, we are not capturing the reflectance function (also known as BRDFs) that dictates how light behaves when confronted with the material (Dorsey et al., 2008, Weyrich et al., 2009). This function determines how much light is reflected in a direction given an incident light direction. Differently, photos only capture the surface color given a light setup, that is, how the function behaved in that given scenario. In this manner, color only tells a small part of the story, and is very biased with regards to the acquisition conditions. Nevertheless, albeit the recent efforts to create more generic and inexpensive BRDF acquisition methods, it still requires an even more controlled light setup and sometimes specific hardware. It also requires much longer acquisition sessions.

4. Conclusions and future directions

With the Digital Bamberg project we have mapped some important points concerning a digitization campaign of scientific historical instruments.

Passive technologies are essential to prevent physical contact with the artifact, and avoid unnecessary degradation. Thus, light-based techniques are highly appropriate for digitizing museum collections.

Nevertheless, surface light-based technologies are not perfect for acquiring the usual metallic and reflective material of mechanical instruments, but with an extra coordinated effort to fill missing parts and cancel noise it can be done. In this case, the extra effort implied modelling some pieces manually, while using the scanned data as validation, and manually filling some holes.

Finally, to avoid light effects, such as highlights and reflections, being transported to the final textures, a as controlled as possible light environment is required, and probably some post-edition. Most of the approaches to control the light environment are common directives for studio photography, such as using diffuse white boxes.

With the lessons learned during the Digital Bamberg, we are currently working on new directions to alleviate the effort of digitizing other similar artifacts. We are searching solutions that can, at the same time, continue using equipment that are accessible, such as laser scanners and photographic cameras, and that are efficient and ease to use. The last point is important, since we would like the technology to be used by the museum staff themselves, and not only by digitization specialists.

With these perspectives in mind, we are investigating the use of primitive fitting approaches to post-process the scanned models (Schnabel et al., 2007). One may think of it as an automatic CAD converted, where primitives such as spheres, cylinders and planes are automatically retrieved using statistical methods, and the model is created from operations on these analytical surfaces. This would greatly reduce, or even completely dismiss, the need of manually modelling some parts.

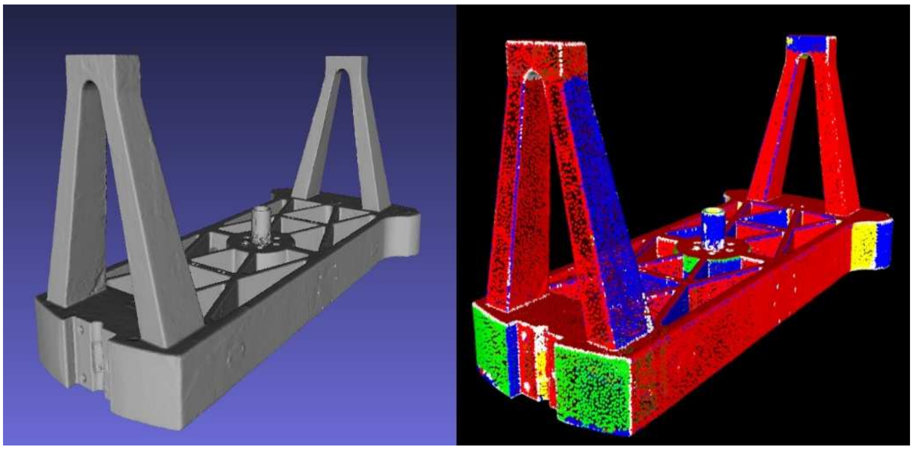

FIG. 11 - The Bamberg's middle base digital model, and some primitives patches automatically extracted. The color code is as follow: green for sphere patches; blue for cylindrical patches; red for planar patches; yellow for inverted cylindrical patches. Sometimes a planar patch is mistaken by a patch from a very large cylinder, for example. But this is ongoing research and we are seeking methods to render it more robust.

As for the texturing part, we are researching ways to capture the underlying reflectance function, instead of the static color from the photos. This implies in extra work, since more photos need to be taken, but results in a much superior digital model, that has embedded the reflective function, and, consequently, is free of light artifacts captured during the acquisition session. We would like to achieve this with off-the-shelf technology, such as camera and light source, and a guided acquisition to accelerate the process.

References

Callieri, M.; Cignoni, P.; Corsini, M. & Scopigno, R. (2008), Masked Photo Blending: Mapping Dense Photographic Data Set on High-resolution Sampled 3D Models. *Comput. Graph.,* 32**,** pp.464-473.

Corsini, M.; Dellepiane, M.; Ponchio, F. & Scopigno, R. (2009), Image-to-Geometry Registration: a Mutual Information Method exploiting Illumination-related Geometric Properties. *Computer Graphics Forum,* 28**,** pp.1755-1764.

Dorsey, J.; Rushmeier, H. & Sillion, F. (2008), *Digital Modeling of Material Appearance,* San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.

Ikeuchi, K. & Miyazaki, D. (2008), *Digitally Archiving Cultural Objects*, Springer.

Nöll, T.; Köhler, J.; Reis, G. & Stricker, D. (2015), Fully Automatic, Omnidirectional Acquisition of Geometry and Appearance in the Context of Cultural Heritage Preservation. *Journal on Computing and Cultural Heritage (JOCCH)*.

Schnabel, R.; Wahl, R. & Klein, R. (2007), Efficient RANSAC for Point-Cloud Shape Detection. *Computer Graphics Forum,* 26**,** pp.214-226.

Schwartz, C.; Weinmann, M.; Ruiters, R. & Klein, R. (2011), Integrated High-Quality Acquisition of Geometry and Appearance for Cultural Heritage. *The 12th International Symposium on Virtual Reality, Archeology and Cultural Heritage VAST 2011.* Eurographics Association.

Scopigno, R.; Cignoni, P.; Pietroni, N.; Callieri, M. & Dellepiane, M. (2015), Digital Fabrication Techniques for Cultural Heritage: A Survey. *Computer Graphics Forum*.

Stanco, F.; Battiato, S. & Gallo, G. (2011), *Digital Imaging for Cultural Heritage Preservation: Analysis, Restoration, and Reconstruction of Ancient Artworks,* Boca Raton, FL, USA: CRC Press, Inc.

Weyricht, T.; Lawrence, J.; Lensch, H.P.A.; Rusinkiewicz, S. & Zickler, T. (2009), Principles of Appearance Acquisition and Representation. *Foundations and Trends in Computer Graphics and Vision,* 4**,** pp.75-191.

INTEGRATED RISK MANAGEMENT. PREVENTIVE CONSERVATION

Ashley-Smith, J. (2016), Risk management: Fashion and uncertainty. In: Homem, P.M. (ed.)
Lights On… Cultural Heritage and Museums!. Porto: LabCR | FLUP, pp.212-230

RISK MANAGEMENT: FASHION AND UNCERTAINTY

Jonathan Ashley-Smith[1]

ABSTRACT

Preventive conservation is taught as if it were a systematic and scientific subject. This positive view neglects uncertainties and the fact that all fields of management are subject to fashion. One sign of being up to date with the latest management fashion is fluent use of the appropriate vocabulary. But the introduction of a new phrase may not mean a clearer definition of the appropriate way to think and act. 'Integrated risk management' is an example. The word 'integrated', used in museum, can mean a variety of things related to the extent of involvement and understanding within the organisation. In a specific field, such as pest management 'integrated' means following all of the necessary steps: setting action thresholds, monitoring and identification of pests, prevention and control. In risk assessment 'integration' can mean looking at the interactions between hazards, such as synergies between pollutants.

Lighting in museums and historic houses involves all the meanings of the word 'integrated'. Although it is easy to teach simple conservation guidelines for lighting it is also easy to overlook the uncertainties in the underlying principles. Fashionable technologies such as the microfader are adopted without a full appreciation of these uncertainties. Museum lighting solutions go through changes apparently driven by technology and legislation, but are also subject to the same influences that drive fashions in clothing and hairstyle. There is no simple solution to the balance between the demands of the conservator and the needs of the viewer. Moreover, even when all the immediate needs of objects, visitors and budget are taken into account, the lifetime of the solution is limited. No matter how good a gallery display looks now, it will go out of fashion.

Although masquerading behind an academic format, this paper expresses a personal view making frequent use of first person pronouns.

KEYWORDS Preventive conservation; Risk management; Uncertainty; Fashion; Wicked problem

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1. Introduction

Twenty years ago, I attended a meeting near Lisbon. One of the participants announced the intention to start a Masters-level course in preventive conservation. Someone in the audience retorted that there would be nothing left to teach after the first week. Here are two very different views of the same thing. Either, preventive conservation is so simple and straightforward that you can teach all there is to know in one week. Or, preventive conservation is a subject worthy of reflection and research, suited to postgraduate study. Twenty years ago, my personal opinion was probably nearer to the first view, but in the intervening years I have become increasingly aware of the uncertainties associated with science in general and conservation science in particular. Whereas I used to oversimplify things, I now favour admitting that things can be complicated. I know that the unexpected can happen and I realise that fashion, as a driving force for change, adds to complexity and unpredictability.

2. Fashion

We are probably all aware of fashions in conservation. I remember when conservation materials such as Paraloid B-72 and Klucel G became the products of choice, rapidly becoming ubiquitous and used in all situations, whether appropriate or not. They are still available, but no self-respecting student would admit to using them these days when there are newer products with more exciting names available. Cradling, lining and re-lining have all been popular ways of treating paintings. They were over-used in the past because they became part of the unquestioning zeitgeist; they were the thing to do. Preventive conservation, despite a name that suggests thoughtful caution, has been subject to fashion: 50%RH ± 5% started out as 55% ± 5%. Now the Bizot recommendation of 40-60%RH is becoming popular in some quarters (Burmester and Eibl, 2012). The arbitrary figure of 50 lux as a lighting standard started as a recommended maximum illuminance and then became a recommended minimum. Now that total light dose is used to ration display parameters (National Trust) there is little need to specify a maximum or minimum.

If you believe that preventive conservation is firmly based in accepted science, you might argue that these changes are not due to the whims of fashion but are evidence of progress brought about by increased understanding. But if you consider the enthusiasm with which some changes are adopted and the vehemence with which others can be resisted, it is obviously not a simple matter of rational decision-making. We can learn something by studying trends in clothing and other aspects of personal appearance that can stimulate discrimination and ridicule.

Take facial hair. In recent years, beards were mostly restricted to men deemed to be old and wise, if somewhat scruffy. The recent 'hipster' fashion means that young and well-dressed males now sport luxuriant beards. Even the police in London are bearded (look up 'Hipster cop' on a image search engine). The beard/no beard fashion cycle seems to have a period of several decades. The point is that it is cyclic; what was quite acceptable becomes unacceptable and then reverts to acceptability. People develop extreme views about differences that have little or no effect on the important things in life. The thing to remember is that constant change is not the same as progress.

Take clothing. I can remember wearing flared trousers and thinking I was cool. Styles like Hippie, Mod, Punk, and Goth are easily distinguished one from another and you can easily put a date to their heyday. It is not hard to put these dates in chronological order. They all look 'dated'. But an acknowledged time sequence is not a sign of progress. The drivers of change are:

- Competition for attention.
- A desire for change.
- The need to be different.
- And yet be *in* with the *in-crowd.*

These are needs expressed from the point of view of the fashion victim. In addition, there is always someone who, for their own monetary gain, is driving the victims feeling of inadequacy. Gallery and exhibition designs are subject to the same forces.

Museum lighting goes through changes that are supposedly driven by:

- New technology.
- Economy (sometimes disguised as 'sustainability').
- Legislation.

But like other fashions, even with necessary or desirable influences such as sustainability or legislation, there is always someone in the background who can make money by driving the change.

3. Integrated risk management

For the 'Lights On' conference I was asked to talk about 'Integrated Risk Management'. This was an expression I had not heard before, and at that time neither had Wikipedia. I had heard of integrated management in the expression 'Integrated Pest Management' (IPM) though I was never sure that the people who practised it knew what it was that had been integrated. I knew the meaning of 'risk' because I was granted a sabbatical year in which to study and write a book about it (Ashley-Smith, 1999a). I knew the meaning of 'management' because for twenty-five years I was paid to manage the conservation department in a large museum.

That was a long enough time to observe changing fashions in management. Styles of management could favour development and delegation, or concentrate more on economy and control. The terms used to describe management activities tend to change faster than the activities themselves. The introduction of a new phrase does not always mean a clearer definition of the appropriate way to think or act. Even the word 'management' means different things in different situations. No matter how dictatorial your management style, you would not manage your staff in the way that you 'manage' pests.

The word 'integrated' means different things in different situations.

It can mean:

- All departments in an institution are aware and involved.
- All stakeholders are consulted (and listened to).
- More than a piecemeal tactical approach to individual threats.
- A strategic view, maximizing benefits and minimizing the downside.
- Following all the steps: eg identification, prevention, control
- Looking at interactions and synergies.

Integration recognises that a solution to one problem may increase risk from other hazards.

4. Fashions in risk

Concepts of risk do not stand still. In the two groundbreaking books on collections risk (Ashley-Smith 1999a, Waller 2003) Rob Waller and I both adhere to the principle that risk is proportional to <u>loss</u> in value. That is to say risk is all about <u>bad</u> things happening. However, in his excellent book about misunderstandings in the study of risk, Terje Aven says it is a misconception that risk relates to negative consequences only (Aven, 2010, p.93). This is in line with the International Standards Organisation definition of risk: risk is the effect of uncertainty on objectives. The definition goes on to say that an effect is a deviation from the expected - positive and/or negative (ISO, 2009). If you believe that risk is a single entity that can be calculated by multiplying the probability of an event by the severity of the consequence:

$$\text{Risk} = \text{Probability} \times \text{Consequence}$$

it is obvious that the mathematics do not care whether the outcomes are good or bad. Whatever answer you get, positive or negative, it is still the 'risk'. But perhaps it's wrong to combine the two factors in a single concept.

In the early 1990s Silvio Funtowicz and Jerome Ravetz considered that risk assessment was dependent on the uncertainties inherent in the system under consideration and the magnitude of what was at stake (Funtowitz and Ravetz, 1993). Their approach moves away from the idea of an objective quantification of risk toward a discourse that recognises differences of opinion. They propose that where the outcomes of events are very important to the participants (strong value commitments) and where the behaviour of a system is uncertain, then consensual science (where everyone agrees to agree) is not applicable. A more holistic appreciation of the relationship between human stakeholders and the physical system is appropriate. Where both decision stakes and systems uncertainty are high then 'post-normal science' is the appropriate means of discourse. The name distinguishes this new science from the traditional 'normal science' as defined by Thomas Kuhn (Kuhn, 1962).

What you learn on the one week course in preventive conservation is not likely to be helpful in the real world, where the uncertainties are not negligible and, rightly or wrongly, people invest a great deal of subjective value in heritage decision outcomes.

In research areas that interest me post-normal science has come and gone in a cyclic fashion over the past 25 years. The expression was first proposed between 1990 and 1993, I discussed it in my book in 1999, and it appeared in a publication on climate change ten years later (Hulme, 2009, p.79) and now it may be on the verge of fresh popularity. In June 2015 Frederick Grinnell proposed a rethink of the approach to assessing risk, saying that the 'post-normal science' framework could make risk-based regulation more efficient. (Nature, 2015)

5. Uncertainty

Real progress is driven by new inventions and new understanding. The influence of fashion is to add unrelated pressures to the rational process. This increases the uncertainty about the way individuals and institutions will react to proposed change.

However, below this level of uncertainty is the basic problem of the unpredictability of chemical and physical processes. In preventive conservation, you want your advice and actions to lead to known desirable outcomes. In the real world, you cannot always accurately predict what the outcome will be.

For me, the 'gold standard' of unpredictability has always been the observation reported on the IIC congress in Ottawa (Gryzywacz and Tennent, 1994). A photograph in the conference preprints shows" Two shells of the same species stored in the same drawer. Only one is affected by Byne's disease." That is to say that although the two apparently identical shells were subjected to the same levels of temperature, humidity and volatile organic acids from storage materials, only one of them reacted. Although the difference in behaviour may be explained by small chemical differences between the two shells, this does not ease the burden on the preventive conservator. Prediction is not possible unless every shell is analysed.

When it comes to damage by light it is possible to find examples of similar levels of unpredictability. Paintings that were similar to start with, and which you would expect to react with the environment in similar ways, have faded at different rates and now look very different. The rate of fading caused by the chemical degradation of indigo in some seventeenth century paintings turns out to be dependent on physical factors such as particle size and layer structure (Hendriks, M. Van Eikema Hommes and Levy Van Halm, 1998). Only a thorough technical examination of a painting would allow a prediction. Even this might not be accurate because there are so many variables to consider.

6. Uncertainties in predicting light damage

The three obvious participants in the museum lighting scenario are the light source, the object and the viewer. Their nature, needs and susceptibilities each contribute to damage to objects caused by light. When it comes to predicting light damage a fourth, less obvious, factor is the environment. Levels of humidity and pollutants affect the rate of fading.

The relevant variables in the source are intensity, spectral power distribution and the duration of exposure. The variables in object vulnerability are the materials and manner of construction of the object, as well as its position and orientation relative to the source. If we take the needs of the viewer seriously we may have to add to the amount of damage by increasing the intensity of illuminance. Older people need stronger lighting to see the details and colours that younger people see. Scholars and conservators may need stronger light to discern diagnostic surface features (Michalski, 1997).

The uncertainties that we need to be aware of can be considered under the same headings. Unless we take careful records, we will not know the levels of temperature, humidity and pollution that the object is subject to. Even if we start taking readings now, we will not know much about the environments with which the object has interacted during its lifetime. The intensity and spectral power distribution of a light source change as it grows older. If there is any contribution by natural daylight to the overall illumination there will be large variations in the intensity, spectrum and duration of exposure, depending on the seasons and the weather. The unknowns in the object may be in the original materials and construction. But there may be further uncertainties due to the poorly recorded history of exposure to light, pollutants and conservators.

The viewer is one of the people who will assess damage. Different people will have different definitions of what constitutes damage. The viewer's familiarity with the collections and with signs of change will be important in determining whether damage has actually taken place. The viewer's ability to detect changes in surface colour and texture are critical factors. Scientific measurements may be used instead of the viewer's eyes to detect change. Instrumentation is subject to many uncertainties (to be discussed in the section on microfading) but there will always be the need for human interpretation. Measured change does not always correlate with perceived damage (Ashley-Smith, 2013; Strlic, 2013)

7. Fashions in museum lighting policies

Museum lighting policies usually rely on the ability to categorise objects by their sensitivity. Broad categories are defined using words such as permanent, durable or sensitive or by specifying groupings bounded by reference to international blue wool (BW) standards e.g. BW 3-4. Once the object has been categorized, a combination of intensity and duration of illumination can be specified that will lead to a estimated rate of fading. The fashions vary in the number and description of categories, in the recommended light intensities and in the method of determining an acceptable rate of damage. Further fashionable distinctions can be made based on the value (significance) of the object and the degree of precaution implicit in the recommended regimes.

The V&A lighting policy was developed around the year 2000 and published as a work in progress (Ashley-Smith et al, 1999b, 2002). It had a brief period of popularity around the world (Tait et al. 2000). But soon it was found to be too precautionary and not discriminating enough. The National Museum of Australia published a new policy that overcame some of these difficulties and added the refinement of two bands of object significance, ‘high’ and ‘average’ (Ford and Smith, 2011). But even this improvement could not avoid some subjective uncertainty, recommending specified ranges of light intensity while advising that lighting should be “as low as possible consistent with good display”.

8. Microfading

The latest fashion accessory to complement your museum lighting policy is the microfader. The logic is compelling. If you actually measure the rate of fading of a selected spot on your object at a known light intensity, you can exactly place the susceptibility of your object in a tightly defined category. The microfader uses a very high intensity light concentrated on a very small area. The result is no longer a vague "probably between BW 2 and 4" but a scientific certainty "exactly BW3"! A few (hundred) measurements and you have the makings of a meaningful lighting policy based on the actual properties of real objects in your collection.

The discussion that follows is based on the work of Bruce Ford (Microfading website) but in the interests of balance and impartiality it should be noticed that other microfading systems are available. It should also be noted that I have no practical experience of the technique. Bruce Ford on the Art & Archival-Microfading website is seen wearing a T-shirt with the slogan "Microfaders: We may be small but we are very, very bright". If I had a website and a T-shirt, the slogan would read "it's never that simple".

Ford is very upfront, if not over the top, in discussing the costs and benefits:

"While there is no doubt that the approach will initially be more time consuming and difficult than enforcing rules, the up-front cost will be far outweighed by the long-term benefits to the museum and its public in terms of improved access, better-looking exhibitions, more fulfilling collaboration between curators and conservators, more targeted conservation interventions, and value for money."

Microfading is described as “a semi-quantitative risk assessment tool rather than predictive”. I’m not sure that there can be a risk assessment (estimate of the effects of events that have not yet happened) without some element of prediction. One of the exemplary reports on the website states:

“the microfading results indicate: 4 years of UV free exposure 8 hours a day at 80 lux would be sufficient to cause 1 Just Noticeable Fade (JNF) and it would take approximately 120 years (30 JNF’s) to destroy it completely”.

This is surely a prediction.

9. Sources of uncertainty in microfading.

The sources of uncertainty relate to the light source; the nature of the object being studied and the interpretation of the results.

The spectrum and intensity of the light source will fade over time as it ages. The UV-free Xenon light source spectrum may not be directly comparable with actual display lighting conditions. The object related uncertainties relate to surface topography and sample homogeneity. The technique is much better on flat even surfaces such as prints rather than the uneven topography of textiles. The sample spot is very small and the number of test measurements must be limited, which might lead to non-representative results with heterogeneous subjects.

The uncertainties of interpretation of the measurements involve the problems of reciprocity failure and the limits of valid extrapolation. The accelerated light testing of materials for conservation use, and most museum lighting policies, assume the reciprocity principle. The same amount of damage will occur from a bright light for a short exposure and dim light for a long exposure. In the days when photographers selected shutter speed and aperture size on their cameras this principle was well understood. However, as Bruce Ford says:

"the relationship between what is observed at very high test intensities and what is likely to occur in a particular instance on display is uncertain."

Microfading relies on the assumption that it is valid to extrapolate from the small amount of change induced during the test to the effect of much greater light doses. This assumes that the algebraic nature of the dose-response curve is fully understood. The microfading curves are described as predicting "a more or less exponentially declining rate with continued exposure". Presumably, if the curve is assumed to be exponential, the prediction by extrapolation will be "more or less" accurate.

10. The wicked problem

Does it matter if it's all very uncertain? Surely all you have to do is follow the precautionary principle and err on the side of caution.

It depends which side you are on. If you want as many living people to get the maximum benefit of looking at your object, you may need a lot of light. Erring on the side of caution would mean ensuring maximum enjoyment and avoiding visitor complaints by keeping things bright. If you see yourself as protector of the object, you don't want too much light to fall on it. Erring on the side of caution means turning the levels down. If you want people not yet born to get some benefit, you may be able to shine a little less light. But there is no point in greatly reducing levels if you want current viewers to gain something from their museum experience. Low light levels could lead to object damage without any compensating benefit.

The lighting dilemma is a typical example of what is known as a 'wicked' problem. The term was coined in the early 1970s (Rittel and Webber, 1973). The characteristics that make a problem wicked are:

- The solution depends on how the problem is framed
- Stakeholders have radically different world views and different frames
- The constraints and the resources change over time.
- The problem is never solved definitively.
- Optimal is meaningless

The third point about constraints and resources is relevant to the current museum lighting situation, as legislation adds constraints to lighting choices (withdrawal of incandescent bulbs). And while museum funding has always been precarious, it is probably worse now than it has been for a long time (Museums Association, 2015).

The concept of 'optimal' is meaningless if no-one is happy with a compromise. These days museums seem to favour heroic leadership in their senior management rather than consensual democracy. The modern museum director is likely to favour a large and happy present-day audience as a sign of success. Whatever the director concludes is the optimal solution, will certainly be considered sub-optimal by cautious colleagues such as curators and conservators.

There are thought to be three possible approaches to solving wicked problems, each with its own limitations (Roberts, 2000). Firstly, there is the 'authoritative' approach where an expert (or a director) declares what is best. But experts may not actually have a broad enough perspective. Secondly, a 'competitive' approach could be tried where different options are pitted against one another. But an adversarial approach may create an unhappy confrontational environment in which knowledge sharing is discouraged. Needless to say, the third approach is 'collaborative'. Communication and collaboration are the constantly promoted and rarely followed maxims of the management consultant. All stakeholders are engaged in seeking the best solution for everyone. Typically, this approach involves numerous meetings (and flipcharts); which may be why an authoritative approach is often resorted to.

An optimal lighting decision should balance the needs and desires of all those allowed an opinion and who variously promote the causes of preservation, access, interpretation, showcase design, gallery design, lighting design, sustainability and budget. If you study changes in the appearance of museum galleries over time you can see that the views of different people dominate at different times in history. Sometimes the simple whim of a curator wishing to return a gallery to a historically accurate former state can overrule the interests of several stakeholder groups (V&A website).

11. Gallery fashion

Even if, at one point in time, all stakeholders do agree that the new gallery looks beautiful and that all the compromises are worth it, it can't last. Just as fashions in clothes can be dated, because they look 'dated', so it is with gallery and exhibition design. Galleries that do not use the latest technology in lighting or showcase construction are deemed to be 'tired' and must be refitted as soon as money allows. Remember that fashions can change in cyclically or sequentially while continuing to fulfil an unchanging basic purpose. In the case of clothes this purpose is to cover the body, in the case of galleries it is to display objects. New technologies allow changes in display appearance, for instance fibre optic cables make it easy to direct light onto an object from many more angles than just straight down. But it is questionable whether this radically alters the basic relationship between viewer and object.

12. Conclusion

It is undeniable that preventive conservation, as a part of a risk management strategy, should be included in the training of any museum professional. It is certain that there has been progress in the knowledge that supports preventive conservation (Ashley-Smith, 2015). Further technical research is needed to reduce scientific uncertainty. Further social, psychological and historical research is needed to understand why some attitudes just seem right today but will appear old-fashioned and therefore wrong tomorrow, even though their validity is unchanged. So you need more than a week to understand the problems and possible solutions. And it is valid to treat preventive conservation as a postgraduate research topic. But it is wrong to teach conservation without mentioning the uncertainties. It is wrong to think that the unpredictable human element can be tamed or eradicated. You should always remember that:

- Everything is subject to fashion and uncertainty.
- Uncertainty cannot be eliminated.
- Fashion means change, but change may not mean progress.
- The optimal solution may not please you.

And just when you think that everything has been settled, you realise that everything is subject to fashion…

References

(all URLs accessed 17/10/15).

Aven T. (2010), *Misconceptions of Risk.* Wiley. p.93.

Ashley-Smith J. (1999a), *Risk Assessment for Object Conservation.* Butterworth Heinemann.

Ashley-Smith J. and Derbyshire, A. (1999b), 'A Proposed Practical Lighting Policy for Works of Art on Paper at the V&A.' *ICOM-CC Pre-prints of the 12th triennial meeting*. Lyon, pp.38-4.

Ashley-Smith, J.; Derbyshire, A. and Pretzel, B. (2002), The continuing development of a practical lighting policy for works of art on paper and other types of object at the Victoria and Albert Museum, *ICOM-CC Pre-prints of the 13th triennial meeting Rio de Janeiro*, pp.3-8.

Ashley-Smith J. (2013), Report on newly gathered knowledge on damage functions. *Website of EC funded research project 'Climate for Culture',* pp.8-10.
http://www.climateforculture.eu/index.php?inhalt=furtherresources.projectresults

Ashley-Smith J. (2015), Progress in Preventive Conservation. *Sammlungsplege – Collection Care.* Vienna: Ed. Gabriela Krist. Bölhau Verlag, pp.19-29.

Burmester A. and Eibl.M. (2012), The Munich Position on Climate and Cultural Heritage.
http://www.doernerinstitut.de/en/projekte/Bizot/bizot_1.html

Ford B. and Smith N. (2011), The development of a significance and risk based lighting framework at the National Museum of Australia, *AICCM Bulletin,* vol. 32, pp.80-86.

Funtowicz S.O. and Ravetz J.R. (1993), Science for the post-normal age. *Futures,* **25,** pp.739–755.

Gryzywacz C. and Tennent N. (1994), Pollution monitoring in storage and display cabinets. *Preventive Conservation: Practice, Theory and Research.* IIC, pp.164-170.

Hendriks E.; Van Eikema; Hommes M, and Levy Van Halm K, (1998), Índigo used in the Haarlem Civic Guard group portraits by Frans Hals. *Painting Techniques: History, Materials and Studio Practice.* IIC.

Hulme M. (2009), *Why we disagree about climate change: understanding controversy, inaction and opportunity.* Cambridge University Press.

ISO (2009), ISO Guide 73:2009, *Risk management – Vocabulary.*

Kuhn, T. S. (1962), *The Structure of Scientific Revolutions*. University of Chicago Press.

Michalski S. (1997), The Lighting Decision. *Fabric of an Exhibition: an interdisciplinary Approach - Preprints.* Canadian Conservation Institute, pp.97-104.

Microfading website. *http://www.microfading.com*

Museums Association (2015), *http://www.museumsassociation.org/advertise/campaigns/funding-cuts/fighting-the-cuts*. National Trust. Preventing light damage at our places. *http://www.nationaltrust.org.uk/article-1356397215469/*

Nature (2015), *http://www.nature.com/news/rethink-our-approach-to-assessing-risk-1.17765*.

Rittel, H.W.J.; Webber, M.N. (1973), Dilemmas in a General Theory of Planning. *Policy Sciences*, 4, pp.155–169.

Roberts, N.C. (2000), Wicked Problems and Network Approaches to Resolution. *International Public Management Review.,* Vol. 1, p.1.

Strlic M.; Thickett D.; Taylor, J; Cassar M. (2013), Damage functions in heritage science. *Studies in Conservation*, 58(2) pp.80-87.

Tait R.; Hughes, J.; Hallam, D (2000), Light levels guidelines at the National Museum of Australia (NMA), *AICCM National Newsletter*, vol. 74, pp.22–3.

Waller R. (2003), Cultural Property Risk Analysis Model. Development and Application to Preventive Conservation at the Canadian Museum of Nature' *Göteborg Studies in Conservation,* 13. Acta Universitatis Gothoburgensis.

V&A website.
http://www.vam.ac.uk/content/articles/r/refurbishment-of-the-paintings-galleries/.

Starkey, A. (2016), Lightening the levels – controlling daylight in challenging spaces. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!*. Porto: LabCR | FLUP, pp.231-244

LIGHTENING THE LEVELS - CONTROLLING DAYLIGHT IN CHALLENGING SPACES

Anna Starkey [1]

ABSTRACT The National Trust for Scotland (NTS) cares for over fifty properties with historic material culture collections on open display. These properties range from Scottish baronial castles to thatched cottages; each houses collections that are susceptible to light damage. For the past forty years, the NTS has been investing in light protection measures, including ultraviolet (UV) absorbing window film and roller blinds. This work has been undertaken on an ad-hoc basis, leaving some properties with little or no protection. To address this problem the NTS has funded 'Lightening the Levels': an accelerated project to achieve in two years what would take twenty at the current rate.

This paper explains the various ways the NTS is managing light across its portfolio, showing the scale and scope of the project. It will focus on the challenges that the more unique properties create, such as geographic location, access, the Scottish weather, and the limitations of working in historic interiors. It will also examine the installation and decision-making behind UV film and blinds in these interesting spaces. It will look at the installation of LED lighting in display areas and the collaborative approach the Collection Conservation Services (CCS) team has taken with other departments. A key driver of the project is how we plan to engage staff and volunteers with the practical aspects of light management. An important part of this has been the introduction of property specific light plans, which empower staff and volunteers to control light effectively.

Finding the right combination of protection measures for each property has been very important and there is no 'one size fits all' solution. The project is learning as it goes along; increasingly the importance of getting staff and volunteers engaged has been shown to be vital to the success of the project.

KEYWORDS National Trust for Scotland; Daylight; Control; Historic houses; Ultraviolet

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Introduction

Light as an agent of deterioration can be difficult to manage; we require light to view the historic interiors and enjoy visiting historic properties. Often daylight is the most appropriate lighting for these spaces but it also causes objects to deteriorate, colours to fade or darken, and structures to weaken (FIG. 1 and 2).

FIG. 1 - Light damage to chair leg. © National Trust for Scotland.

FIG. 2 - Light damage to textile. © National Trust for Scotland.

The National Trust for Scotland (NTS) cares for over fifty historic properties with in-situ collections that are susceptible to light damage. For the past forty years, the NTS has been investing in light protection measures such as roller blinds and ultraviolet (UV) absorbing window film. This work has been conducted on an ad-hoc basis, leaving some properties with little or no protection. To address this problem the NTS has funded 'Lightening the Levels': an accelerated project to achieve in two years what could take upwards of twenty years with the existing ad-hoc approach.

Lightening the levels

Lightening the Levels is an accelerated two-year project to improve daylight management across the NTS portfolio. To improve how daylight is managed sounds a broad, unspecific aim, but the project has definite objectives and outcomes. The first of these objectives involves ensuring that each property has the physical measures in place to manage daylight effectively. The second objective focuses on ensuring that staff and volunteers are aware of light damage and have enough training and knowledge to use these physical measures effectively. Additionally, other smaller work-streams exist for the project, such as gathering information on light-emitting diodes (LEDs) and low-energy lighting; updating information on light and light management at properties; and future-planning for the replacement of UV film. The intended outcomes of the project are summarised as follows:

- To provide adequate UV film and blinds to relevant NTS properties within two years, where no provision currently exists.
- To replace and repair, within two years, all ageing or damaged daylight protection measures that would need replacing in the next five to ten years.
- To provide all relevant properties with light management protocols to ensure effective use of blinds.
- Produce a long-term plan for cyclical maintenance to allow future-planning of replacement UV film.
- Investigate low-energy, low-UV solutions to the re-lamping of historic light fittings.

Background to the project

Planning and information gathering for 'Lightening the Levels' started much earlier than the commencement of the project in February 2015.

In 2011/12, light and light management was the work placement focus of a year-long Institute of Conservation (Icon) internship funded by the Bute Memorial Fund at the NTS. One of the aims of the internship was to raise the profile of light as an agent of deterioration within the NTS and to begin gathering information on what light protection measures were in place at each of the fifty properties. A basic light audit exercise was undertaken for each historic house to record information about current measures in each room with collections. Spot readings for lux levels were taken and UV film was inspected to ensure it was functional at under seventy-five µW/lm (PAS:198, 2012, p.23). This information was then presented in a short report providing clear recommendations for improvements. From the light reports, each property was given a traffic light colour-code to classify the adequacy of existing light protection measures.

- Grade 1- Property has good control measures in place, such as blinds, shutters, and UV film. They are used in an effective and systematic manner.
- Grade 2- Property has some control measures and they are occasional used, but generally on an ad-hoc basis, with little or no system in place.
- Grade 3- Property has little or no control measures in place and has no system or plan relating to their use.

In February 2015, seven properties were rated Grade 3, which have little or no control measures in place and require the installation of new protection measures. Twenty-seven properties were rated Grade 2 and required some work to bring the protection measures up to standard. Nearly all properties require a light management plan; light plans are clear, simple procedures for staff and volunteers to follow to ensure light levels are acceptable through judicial use of blinds, shutters and curtains. An effective light plan should take into account property staffing, opening hours, orientation of rooms and material collections. To address the lack of light protection highlighted by the light audits, the 'Lightening the Levels' project was proposed as a one-off initiative to look at light protection as a whole within the NTS and was supported by the Senior Management Team. The project is led by a Project Conservator and funded from a discrete conservation deficit fund.

Project planning

From the information in the light audits and light reports, twenty properties were highlighted as not having adequate protection measures and would require work to bring the current protection measures up to standard. For the project, adequate protection measures are defined as follows:

- All standard windows in collections areas have functioning UV film that is in a good condition, i.e. not peeling or bubbling and not over fifteen years old.
- The property has clean working blinds in appropriate collections areas and these are in keeping with the historic environment.

The timescale for the project is two years and has been split into two phases, each phase lasting a year and with ten properties requiring installations in each phase. This has allowed the project to combine the larger and smaller properties, as well as group the work in terms of geographical location, organising the work into one or two-week slots. Most installations, particularly those requiring new UV film, are organised between April and October, as the installations are less likely to be hampered by poor weather. The project will focus on light plans in the winter months of December to February, preparing them for the start of the new season in late March.

Scope and scale

Managing daylight in historic houses using UV film and blinds is nothing new: these are standard protection measures found in many properties. What is notable about this project is the scale and scope: the improvement of light management across fifty properties, spanning the length and breadth of Scotland in only two years (FIG. 3). Each property is very different in size, scale and type of collection, and each therefore has different requirements for light protection. Some properties require completely new UV film and blinds throughout, whereas others require maintenance or repair (i.e. fixing damaged blinds, or replacing failed or missing UV film). Some properties already have the relevant protection measures in place, though need to improve on how they use the existing blinds. Each property needs to be assessed individually and decisions made on what is the most appropriate and useful measure for that particular property.

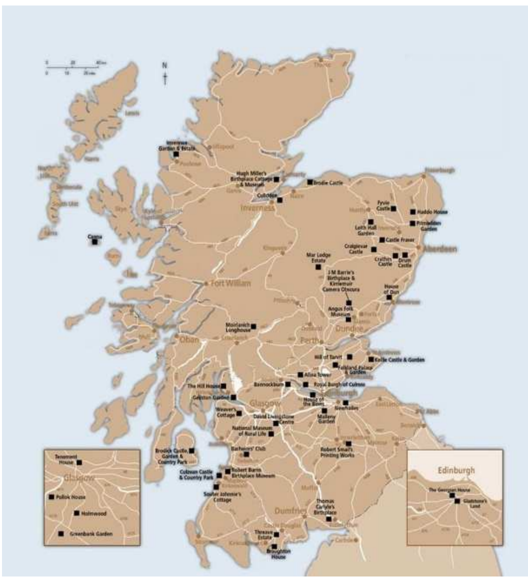


FIG. 3 - Map showing properties covered by the project. © National Trust for Scotland.

Tendering for contractors

From the initial light audit data, it was clear that at least twenty properties required some level of installation or repair of UV film and blinds. Because of the cost threshold, it was necessary to tender for an experienced contractor. The tender stipulated a contractor with experience of working in historic houses, who could remove and apply UV from/to old or historic glass, and also install traditional sun blinds. There are few companies who offer the installation of both UV film and blinds, and who also have the relevant experience. A total of three suitable contractors from across the United Kingdom were identified as meeting the tender criteria. As part of the tender process all three contractors were subsequently invited to visit a property, submit an example quote, and provide documentation specifying how they met the criteria of the tender. Each contractor's quote and documentation was marked according to a NTS-agreed matrix, with four criteria, including experience of working in a historic house, cost, and quality of documents submitted. Once rated, and after agreement from the CCS team and Procurement team, the contractor with the highest score, that met all requirements, was awarded the contract.

Lessons were learnt during this process. At the start of the project it was anticipated that the tender process would only take three months, but from start to finish the process took around five months to complete. The tender process was much longer and more involved than first expected and this had an impact on the project's schedule and meant installation work at properties did not begin until late summer. The importance of getting the right contractor with the correct skills and experience cannot be underestimated and is vital to the success of the project.

Installation and challenges

Each property has its own challenges for getting light protection measures installed, such as access, geographic location, the Scottish weather, or just the historic environment itself. Many of the properties in the north region can be difficult to access when the weather is poor and their closed season often reflects this. Some properties are located on islands, making access difficult and reliant on weather. Other properties are busy with functions and events and do not have a long closed period when work can be undertaken, requiring that the work takes place when the property is open to the public. Most often the historic houses themselves bring challenges, including the environmental conditions, as properties can be cold and damp places to work in the winter months; from antidote evidence at other NTS properties this is not an ideal environment for applying UV film. Not all properties have electric lighting, meaning that any work must be done in daylight hours. Often large items need to be moved to allow access to windows, and smaller items carefully packaged and stored away from the area of work. Some properties require scaffolding to reach high-level windows. Many properties have very few non-collection areas or storage space, making it difficult to set up or store equipment in a safe spot. Other properties are so small that moving ladders and any large equipment can be difficult.

Arranging the installations can also have challenges. Some properties are so small that the work may only take a few hours and need to be grouped with others to make the best use of the contractors' time, using economy of scale. Others properties are large enough that work may take over two weeks to complete and need to be carefully scheduled to suit the operation of the property. All of the twenty properties planned for installations will have one or more of these challenges to overcome for a successful installation (FIG. 4).

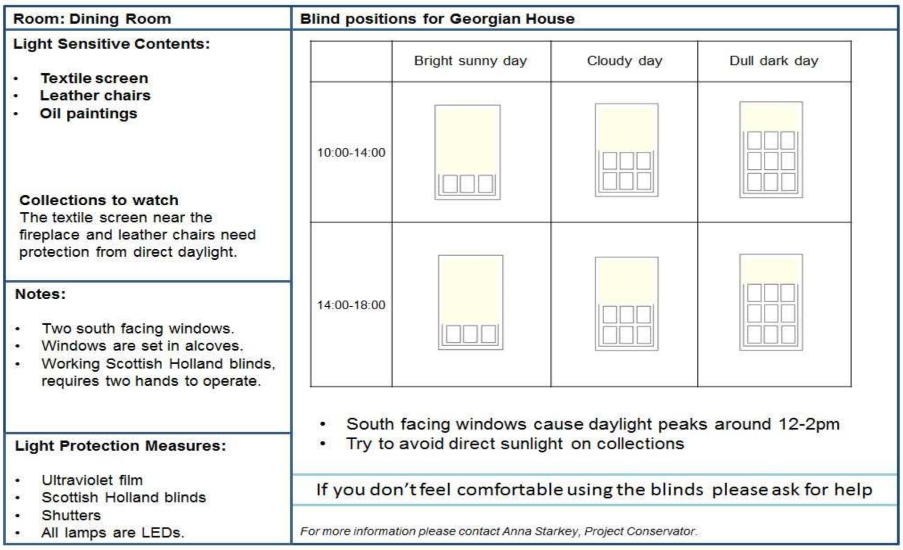
FIG. 4 - Removing UV film for an installation. © National Trust for Scotland.

'Light Plans' – how we can use our blinds more effectively

As well as installing new blinds at properties, it is also important to engage staff and volunteers in using the blinds systematically and effectively. A blind left up all day is no better than no blind at all. Currently the NTS has no standard documentation or protocols for light plans; a small number of properties do have them, though this is as a result of staff at individual properties being particularly industrious and these pockets of good practice will often change when staff move on or other priorities take over.

In Phase One, it was necessary to pilot a light plan at a property to allow the project to start putting together protocols for using blinds. The light plan needed to be simple to understand and adaptable for other properties, as well as it being effective. The Georgian House was used as a pilot: this is a medium-sized property in the centre of

Edinburgh and four principle rooms were chosen to pilot the light plan. Two visits were made to the property to take spot readings; this, combined with Hanwell lux data and the Sunseeker mobile application, gave a good indication of light levels room by room at various times of the day during the open season. Visiting the property also allowed time to speak to staff and volunteers about light in the rooms and how the property was staffed. This was invaluable for getting a realistic working light plan. From this pilot exercise a draft template was produced, as well as a methodology on how to put a light plan together (FIG. 5 e 6).



Room: Dining Room

Light Sensitive Contents:

- **Textile screen**
- **Leather chairs**
- **Oil paintings**

Collections to watch
The textile screen near the fireplace and leather chairs need protection from direct daylight.

Notes:

- Two south facing windows.
- Windows are set in alcoves.
- Working Scottish Holland blinds, requires two hands to operate.

Light Protection Measures:

- Ultraviolet film
- Scottish Holland blinds
- Shutters
- All lamps are LEDs.

Blind positions for Georgian House

	Bright sunny day	Cloudy day	Dull dark day
10:00-14:00			
14:00-18:00			

- South facing windows cause daylight peaks around 12-2pm
- Try to avoid direct sunlight on collections

If you don't feel comfortable using the blinds please ask for help

For more information please contact Anna Starkey, Project Conservator.

FIG. 5 - Light Plan front for the Georgian House. © National Trust for Scotland.

FIG. 6 - Light Plan back for the Georgian House. © National Trust for Scotland.

Putting together the documentation for the light plan is only half of the task. For a light plan to be effective it must be used by property staff and volunteers as part of the day-to-day operation of a property. This can be difficult to achieve; some properties have very limited staff and volunteers and will not always have someone in the rooms to look after the blinds. For some properties, this will be a culture change, getting staff and volunteers to think differently about how they use the blinds. Below are a few examples of ways the project is trying to encourage the use of light plans at properties.

- Extra time will be spent visiting the properties when they are open to provide an informal opportunity to speak to seasonal staff and volunteers.
- It was found that although housekeepers often open up the rooms for the day, volunteer guides were the people most likely to be using the light plan during opening hours. Knowing who to target with the light plan at each property is important.
- Key members of staff will be involved in the production of the light plan, which should be seen as a collaborative effort and not something thrust on the property staff without their input.
- Getting the property manager to 'buy in' to the advantages of using the light plan is extremely important, and they will be involved in the process wherever possible.
- Pre-season meetings will be attended by the project to introduce the light plans to staff and volunteers.
- Light plans will follow the installation of new blinds and UV film wherever possible, ensuring that the new protection measures are used effectively.

Getting the light plans accepted as part of the everyday care of the property is one of the biggest challenges the project faces and requires a variety of methods and strategies to achieve this. Getting light plans accepted at properties will not happen overnight and will require operational changes at many properties.

Low energy lighting

As well as managing daylight, the NTS is interested in finding low-energy, low-UV lamps for its historic display rooms. This has the two-fold benefit of lowering energy costs and reducing the damaging UV radiation which some lamps can emit. Choosing a lamp for a historic property is not straightforward: the look of the lamp, its colour temperature, colour rendering index (CRI), weight, and the amount of UV it emits, all have to be taken into account. The low-energy lamp market is constantly changing and expanding, and the project is looking at various different options, but there is no 'perfect' lamp that meets all requirements. Other departments within the NTS are also interested in looking at low-cost lighting and we are working together to share knowledge and experience to establish a robust plan for re-lamping historic properties.

Public engagement and social media

From the outset of the project, communication and public engagement have been seen as important. This has been both internally within the NTS – ensuring property staff and senior management are aware of the project – and externally to visitors at properties. The project has its own blog, which is updated regularly to keep track of the installations and other work at properties. The NTS Twitter feed and Facebook accounts have also been utilised to increase views of the blog, and widen the audience. The project has an internal intranet page and has been represented at a number of NTS events, such as conservation days and the Annual General Meeting. Also, where work has been carried out when a property has been open to the public, there has been an effort to engage the visitors and explain about how we protect collections from light damage.

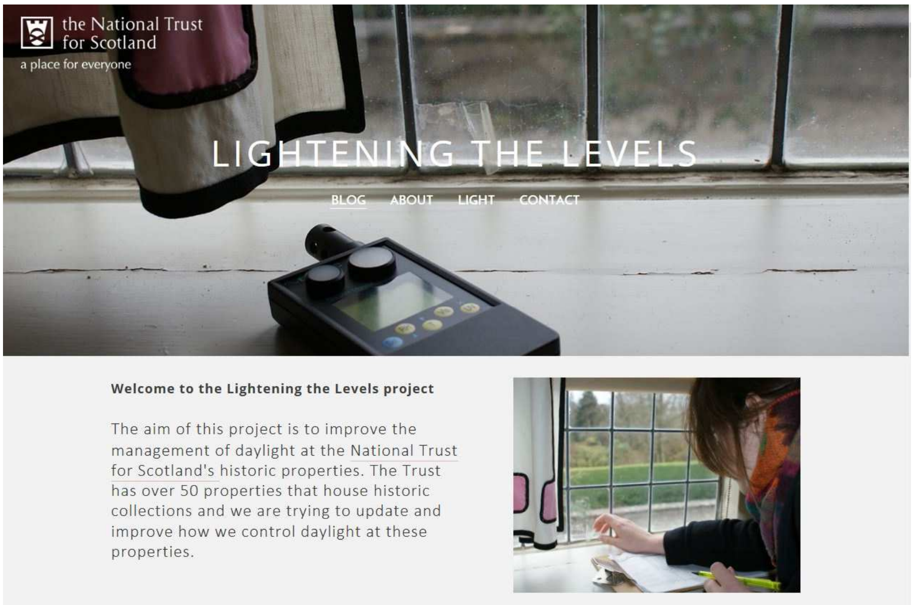


FIG. 7 - Project blog. © National Trust for Scotland.

Conclusion

The installation of daylight protection measures in historic properties presents many challenges: access, geographic location, weather, cost, size, or the historic environment itself. With collections that require moving or protecting, longer opening hours, visitors and functions all must be taken into account when improving the management of daylight in these spaces. The scope and timescale of the project means that these are done on a property-by-property basis. The installation of protection measures is a large part of collections care, but is only effective when the protection measures are maintained and used as part of the normal operation of the properties. Ensuring that properties have light plans, and that staff and volunteers understand the type of damage light can cause, is key to limiting light damage. Engaging staff and volunteers with light management is the most challenging aspect of the project, as well as the most important, and requires different strategies to implement at different properties. Changing the working habits at properties does not happen overnight, but requires time and repeated effort. The success of the project rests on getting staff and volunteers engaged with light management at properties, using blinds to limit light damage.

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References

British Standards Institute (2012), PAS:198 2012 Specification for managing environmental conditions for cultural collections. London. BSI.

National Trust for Scotland (2003), Conservation Principles [Online]. Available from: http://www.nts.org.uk/conserve/downloads/ConservationPrinciples2003.pdf [Accessed 1ST June 2015].

National Trust for Scotland (s/d), Environmental Parameters. [Unpublished internal document].

Thickett, D. (2016), Managing natural light in historic properties. In: Homem, P.M. (ed.) *Lights On… Cultural Heritage and Museums!.* Porto: LabCR | FLUP, pp.245-264

MANAGING NATURAL LIGHT IN HISTORIC PROPERTIES

David Thickett [1]

ABSTRACT

Natural light is an essential feature of many historic interiors and significant views from rooms must often be retained. This paper will detail procedures developed to manage it and also elucidate the negative effect it can have on showcase performance and solutions.

Light plans have been developed to manage daylight. Monitoring natural daylight is challenging and blue wool dosimeters have been adopted. The preparation and measurement of these can significantly affect results and improved procedures have been developed. Monitoring of three hatchments at Lyddington Bede House indicated that in the position the hatchments, light and UV were sufficiently controlled by the stained glass in the windows. Mesh materials and neutral density films have been used to retain views whilst controlling daylight.

Within English Heritage's estate many historic properties contain showcases. Careful design is required to ensure adequate performance environmentally. In such situations the room environments are frequently far from ideal and showcases are often required to perform environmental remediation for safe display of their contents. At St Peters church the surface temperature of archaeological bone displayed in showcases under stained glass windows found to have significant daily increases with predicted damaging decreases in surface RH. Simple geometry can indicate when direct sunlight can fall on showcases, mobile apps can dramatically reduce the time needed for calculations. Daylight even filtered through double blinds can affect some sensitive environmental control equipment. Examples of problems encountered and solutions will be presented. Light can dramatically increase off-gassing from showcase materials. At Apsley House allowing too much daylight onto showcases containing supposedly light insensitive objects chemically degraded the woolen display fabrics dramatically increasing the silver tarnish rate.

KEYWORDS Historic properties; Natural Light; Showcases

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Introduction

Natural light is an essential feature of many historic interiors (Cannon-Brookes and Perry, 1996). Most of the interiors now in care, were designed before the advent of electric lighting in 1880 (Swan patent) and were either day-lit and used fires, gas lighting and candles at night. Depending on a property's history electricity will have been introduced to varying degrees. For example, the great hall of Audley End House, has only two electric points. Its presentation relies on side lighting from the magnificent windows.

Historic House collections are often rich in textiles and other light sensitive materials. The original owners of many luxury country and town houses were well aware of the damaging effects of light on their expensive furnishing. Many of the practices of housekeeping developed in those situations have been modified and used in collections preventive conservation. A good documented example is the National Trust (UK) approach, with houses allocated as 1000, 1200, 1400 hours opening per year, generally April to October (Lloyd, 2002).

Vulnerable objects are covered in the closed period with traditional case covers. Most room lighting is through UV filtered side windows with sun blinds or sun curtains and shutters, to totally exclude light outside of opening and service hours. The dose is set equivalent to 50lux for a national museum, with opening 3000 hours per year. Light levels are therefore determined by the number of hours opening, so for a 1000-hour house, 150lux. This level is achievable in such situations by manually adjusting the blinds. Lower levels such as 50lux are only very rarely achievable in side lit historic interiors, without rendering some areas very dark. The presentation of historic interiors is based on historical evidence. Many houses are presented as if the occupants had just left, which is possible if the furnished house is acquired directly from the family. Alternatively, inventories, descriptions, prints or photographs are used to recreate rooms. This historical association places items in certain rooms and often locations within the room. These locations may not be ideal for light sensitive objects. Additionally, most historic houses do not have large reserve collections, so the opportunities for object rotation are very limited. The gardens of many houses were designed to present views from particular windows. It is highly desirable that these views remain visible from within some rooms. This presents significant challenges for keeping light exposure to sufficient levels for conservation of the collections in those rooms. Even if this can be achieved for the particular rooms (which are often only furnished with more robust material), these historic views destroy the eyes' natural acclimatisation and present issues for adjoining rooms.

Light plans

Light plans have been developed by several institutions to manage daylight. Essentially, a large number of measurements are taken ideally over several months. These guide the selection of measurement points that are then used to manually adjust the blinds and any artificial lights present to achieve set lux levels. Overall, the objective is to achieve a particular annual dose across a collection in a room. The plans often include indicative blind positions, sometimes for different times of the year and different sky conditions. An example is shown as FIG. 1.

Selection of the measuring points is critical. Two general approaches have been used. If the room contains a particularly significant or vulnerable object, then this can be defined as one of the points. The alternative is to try to define representative points.

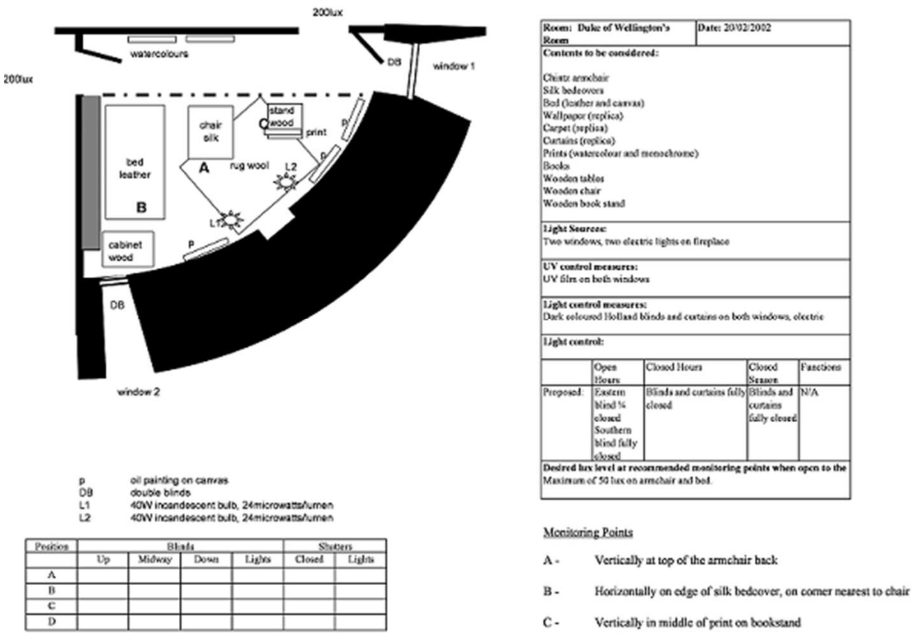

FIG. 1 – Example of a light plan.

The height, direction and orientation of the meter must be defined as well for each point. In some situations, different points will be required at different times or day or the year. Depending on the opening hours, location, orientation and surrounding landscape, up to 40% of the annual light dose can be received when the room is closed to the public. Complete blackout is essential to meet conservation standards. Many historic properties have, or had, shutters that are ideal for this purpose, as well as providing enhanced security. Maintenance is essential and blind and shutter mechanisms need to work easily. The performance of UV films need checking annually and replacement can be required from between seven and fifteen years at 75µW/lumen. Many heritage institutions have lowered UV levels to 25 or even 10µW/lumen. Most new UV films will struggle to achieve 10µW/lumen with daylight. Additionally, as there is no standard for integrating the energy over the different wavelengths of the UV (unlike visible light), it is possible that under the same circumstances, one calibrated UV meter will read below that level, whilst a second from a different manufacturer will read above it. Tests with three commercial meters indicated significant discrepancy at low UV levels. Above 2010µW/lumen the meters read similarly within their reported errors. Without further standardisation, which does not appear likely, the only solution would be to use very expensive UV meters that record the power distribution. Even at 25µW/lumen, UV films will need replacing very frequently to maintain this level.

The light doses used are based on lighting standards. Thomson's (1988) original work was based on experiments by Lowe, which identified two levels:

- A very minimum, 50lux, at which a significant proportion of a population can discriminate when their eyes have acclimatized (generally this takes a few minutes);

- An optimum, 200lux, above which, for the majority of a population, no further benefit is achieved.

Above 300-500lux, more light actually reduces peoples' perception of detail. It is important to realise, that no light level is 'safe' and standards are about managing the rate of damage (Ashley-Smith et al., 2002). These levels have been expressed as doses in four sensitivity classes in the recent European technical specification, 'Conservation of Cultural Heritage - Guidelines and procedures for choosing appropriate lighting for indoor exhibitions standard' (BSI, 2014). The specification's no-sensitivity class, recommending no illumination limit for conservation, should be used with care. There is evidence that several of the materials listed can be affected by high light levels (Thorn, 2005; Thickett 2013; Thickett et al., 2013A). Recent developments have subdivided the sensitivity classes (Ruess, 2005), which is useful for practical implementation. The increasing use of micro-fading is a welcome development. It often proves a particular object is less sensitive than its type would suggest. This can be caused by the exact way it was manufactured or by previous exposure; destroying light sensitive dyes, pigments or reaction centres. Knowing an object's exact sensitivity can be especially helpful, because of the very limited opportunity for object rotation in historic interiors. The technique has recently been applied in situ for large, difficult to move objects such as state beds and carpets (Thickett et al., 2013B).

Light plans need to take into account the visitor route (which ideally will be influenced by the light sensitivity and levels of the different rooms). For example, at Osbourne House the nursery and Queen Victoria's bedroom have very sensitive black dyed silk textiles requiring a light level of 50lux. Other rooms prior to these on the tour route are at 200lux. The light plan has the lux level stepping down to 150 and then 100lux in the prior two rooms to acclimatise the visitors' eyesight to the low light levels.

Monitoring daylight

Monitoring natural daylight is challenging. In totally artificially lit spaces, the lighting needs to be set up once' and then only monitored very periodically to measure bulb aging and slipping of fixtures. It should be mentioned that a robust system is required to replace with the same bulbs and ensure fixing angles and dimming etc. are retained. Regular calibration is required for all monitoring equipment and light meters have been observed to under or over-read by up to 50%, without calibration. The intensity of daylight in a building can change rapidly and constantly. Whilst some data is generally better than no data, spot illumination readings can be misleading with daylight. Several organisations have suggested one, two or three manual readings a day, if continuous data is not available (Council for Museums, Libraries and Archives, 2004). Forty continuous reading data files from six English Heritage properties were examined. Annual lux doses were calculated from the hourly data. The data was then reduced such that readings from 9am, 12am and 3pm only were used to generate the annual exposure. The calculated doses are shown in FIG. 2.

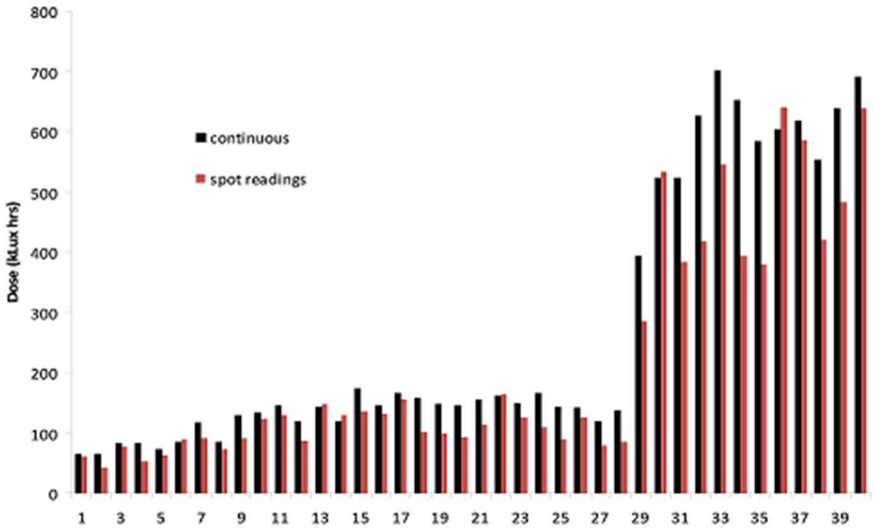

FIG. 2 - Doses from daily readings.

As can be seen, the spot readings differ significantly from the continuous doses, by up to 36%. In most instances (85%) they are lower and frequently much lower, which would give a falsely re-assuring estimate of the light exposure.

The impact of frequency of automatic measurement was also assessed. Twelve loggers were set to run at 60s intervals. Additionally, two yearly sets of monitoring compared loggers running at 60minute intervals with old proportional dose monitors. All loggers were calibrated using dimmable fibre optic lights at 50, 200, 500, 1000, 5000 and 10 000lux against a recently purchased light meter with calibration certificate.

The doses measured, using different intervals of the data and with the proportional dose monitor (FIG. 3), show less than 5% difference.

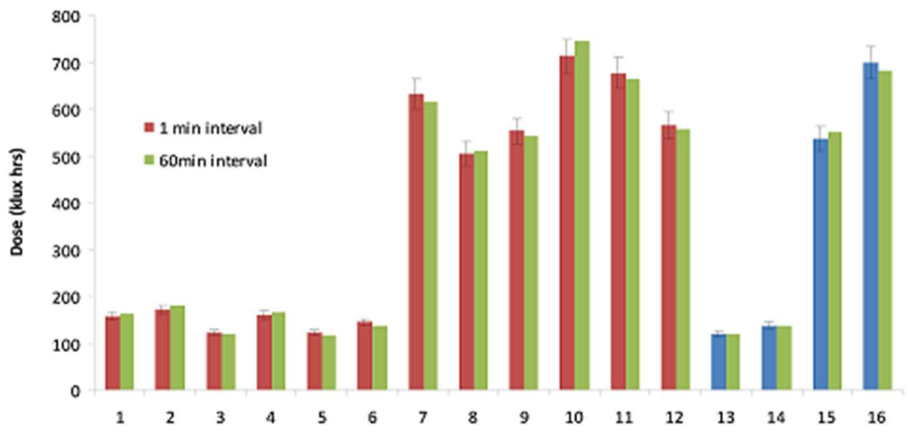

FIG. 3 - Doses from collecting data continuously, every minute and every hour.

The frequency of measurement for automatic equipment appears to have little affect when above hourly. However, where blinds, shutters or curtains are used the relative timing of measurements can dramatically affect the dose, especially with limited opening hours. For example, if a room has the shutters open four hours a day, the measurement interval is hourly, on the hour and the shutters are opened at 12.01 and closed at 15.59, the dose will be underestimated by almost 50%.

Light exposure is the most difficult environmental parameter to measure accurately for an object. The dose will depend heavily on the exact position, and it is generally only possible to at best measure at the edge of an object. In historic interiors, the presence of modern monitoring equipment is more intrusive than museum and gallery settings, and locations are often the subject to much debate. For paintings and works of art on paper, it is often curatorially acceptable to locate equipment at the top of the frame, but less so at the edges and underneath. With side lighting from windows, this position will often under-represent the light dose experienced by the lower portions of the object.

Blue wool, BW dosimeters have been adopted to monitor light doses in historic houses (Bullock and Saunders, 1990). Whilst it is possible to assess the results by visual comparison to grey scales, and this is the method they were initially designed for, the discrimination is very coarse and of limited use for the relatively low annual doses required in most historic houses, even with the most sensitive BW1. Reading after several years gives much better results. Colorimetry gives much finer discrimination and removes observer bias. As the wool surface is uneven, the measurements will vary with position and direction of the colorimeter head, relative to the weave of the wool. The most accurate measurements will be achieved by re-produceably repositioning the colorimeter head over the same area. Several colorimeters have viewing windows that aid in this and English Heritages blue wools incorporate a Melinex mask with a 3mm diameter hole to allow accurate repositioning. The dyes used on BW1 appears to have some pH sensitivity, and direct contact with some acid free cards causes a colour change. It is prudent to test any materials used in the dosimeter with accelerated aging, in direct contact with the BW to avoid this effect. English Heritage use Melinex masks to reposition the colorimeter head and Conservation by Design M8733 2-ply card. Location of BW dosimeters will affect the fading observed. The dosimeter should be aligned at the angle of the object surface of interest. Otherwise the cosine effect can introduce large errors in measurements. If the object presents several differently aligned surfaces, several dosimeters may be required if accuracy is desired.

The original publication for using BW as a light dosimeter, published a calibration curve using a Microscal tester. Each batch of BW requires separate calibration and can vary by as much as 50% in response to a given light dose with defined spectral distribution. That work found little effect of RH on the response curve. However, more recent work in actual historic houses has shown up to 20% difference between BW dosimeters response and measure lux doses (Thickett et al., 2007). This may be due to temperature, and partly explained by the presence of oxidising pollutants; nitrogen dioxide and ozone. The sources of these pollutants are such that if one is present at a low level, the other is likely to be present at a higher level. Ozone is most frequently naturally derived (in the absence of high exposures of sunshine, so certainly in northern Europe), so is likely to be higher in rural locations. Nitrogen dioxide is mainly derived from traffic, so is present in higher concentrations in urban centres. The inverse relationship found in many locations between the two pollutants has been recognised (Roberts-Semple et al., 2012). Calibration of a batch of BW can be undertaken with a standard daylight fastness tester, Microscal or Xeno. It can also be undertaken using natural daylight if suitable windows exist in historic properties. If the BWs are placed close to the window, it is likely that cooling will be required, as temperatures of up to 60ºC can be reached and this will alter the calibration and lead to much apparent higher doses from BW at room temperature. Small peltier type units provide a convenient way to cool BW for calibration. This approach has the advantage of exposing the BW to similar pollution levels.

High dynamic range imaging has recently been applied to historic house interiors. This measurement method uses a series of digital camera images at different exposures to produce an image of a large portion of a room calibrated for lux levels on the surfaces (Mardaljevic et al., 2009).

Light Control

Stained glass has some ability to reduce light and UV transmission. Monitoring of three hatchments at Lyddington Bede House indicated that their positions were such, that light and UV were sufficiently controlled by the stained glass in the window and shading from other buildings and trees. The exact exposure at any point in a room is determined by the room and window dimensions, reflectivity of internal surfaces, the room's orientation and surrounding features. Manual calculations have been developed to assess this (Cannon-Brookes and Perry, 1996; Thorn 2005). The detail of when a point will be in direct line of the sun depends additionally on opening times of shutters and potentially foliage on trees at different times of year. Apps, such as Sunseeker, are now available to show the sun's position at any time on any day of the year. This means the calculations are now trivial, instead of several hours work. The smart phone or tablet is placed at the position of the object of interest and pointed towards each window in turn. It is possible to calculate on what days the blinds will need to be lowered to block direct sunlight. Sunseeker can be used to estimate the blind positions for each day.

Full modelling is now possible for the illumination levels in day-lit interiors (Eibl, 2015; Mardaljevic, 2015). Unlike hygro-thermal building modelling the building fabric does not introduce large amounts of uncertainty, as only measured surveys are required. The transmission properties of historic glazing will often need to be measured, as they can vary from published glass values. Such modelling requires careful validation with measurements to ensure accurate results. However, once complete, the model can be used to investigate different scenarios, use of different blinds, positions, neutral density films, etc. It can be used to position light monitoring in the most effective location.

The library at Brodsworth Hall has particularly significant views of the gardens and the blinds are only lowered to just above eye level. A neutral density film (Sun-x MT65) was applied to the window to reduce light doses. For most of the room this was successful, although doses within 2m of the window are reduced, but still higher than desirable. A survey of visitors indicated that they had perceived no visible difference in the view, to that from other different orientation rooms without neutral density film.

Several historic houses are moving towards mesh blinds, often fixed to allow some perception of views whilst facilitating light control. In most situations, such materials will not reduce the light levels to 200lux without the additional use of adjustable black out blinds. There is also a concern that the exact geometry of the mesh cross section may cause light to reflect into the room, with high albedo materials. English Heritage is presently undertaking testing on 60 blind materials. The tests will assess transmittance at several angles and UV and NIR transmission also.

Amongst the earliest uses of mesh, were the Victoria and Albert Museum in the mid-1990s. Mesh blinds were first used in English Heritage for the Whitby Abbey visitor centre, in 2003. The Victoria and Albert Museum selected a Mermet Matt blind. This was combined with two layers of MT20 film to reduce daylight transmission to 0.5%, giving an average of 250lux near the window and 50lux deeper into the gallery. The same material was used at Kenilworth Castle gatehouse in 2009. Reinstatement of the sixteenth century garden, made opening the view from the second-floor gatehouse desirable. The material was installed in a compression mount in the lower half of the window, with the blinds down to just above eye level. This arrangement kept light levels below 200lux in the showcase less than 1m away, experiencing direct light from the window. Unfortunately, this material is no longer available.

Historic Royal Palaces have been testing Smart Tint since early 2015. This is a clear polymer material (85% transmittance), that turns translucent (41% transmittance) when an electrical current is applied. The film also offers protection for ultraviolet (99%) and infrared (90%) radiation. This material is being trialled using a compression mounting on clear glass windows at the Great Watching Chamber in Hampton Court Palace as part of the Tudor tapestries environmental protection research project (Vlachou, 2015).

Impact of daylight on showcase environments in historic buildings

Within English Heritage's estate, many historic properties now contain showcases. Careful design is required to ensure adequate showcase performance environmentally. In such situations, the room environments are frequently far from ideal, and showcases are often required to perform significant environmental remediation for safe display of their contents. At St Peters church, the surface temperature of archaeological bone displayed in showcases under stained glass windows found to have significant daily increases with predicted decreases in surface RH, within 2% of damaging levels (Thickett, 2008). This emphasizes the care needed with such situations. The intrinsic nature of historic properties can limit installation of light control. The stained glass could not have films adhered to it, the window framing was architecturally important, so blinds could not be fitted, and the light filtering through the stained glass was thought an essential component of the interior. Simple geometry can indicate when direct sunlight can fall on showcases, FIG. 4. As described previously, mobile apps can dramatically reduce the time needed for calculations.

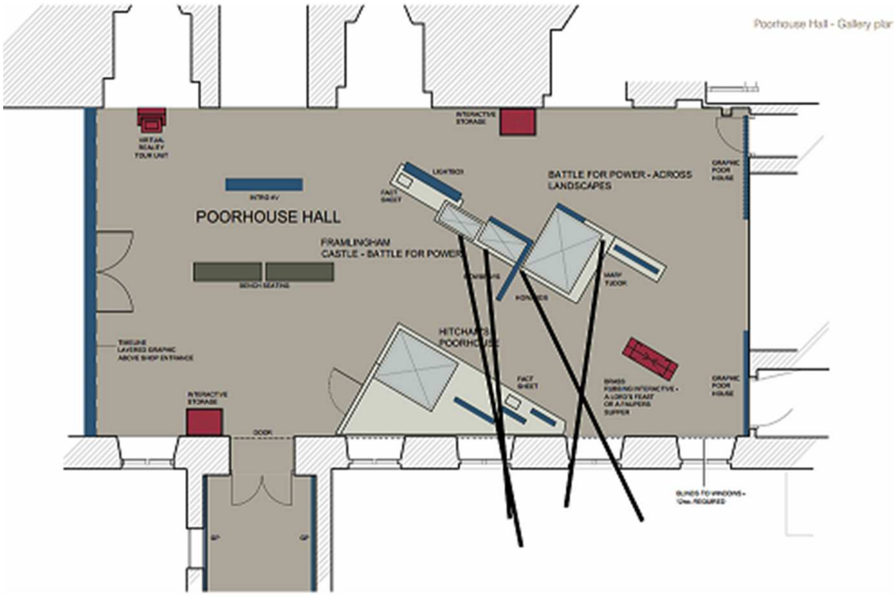

FIG. 4 - Framlingham.

Daylight, even filtered through double blinds can affect some sensitive environmental control equipment. An exhibition in Kenilworth Castle gatehouse uses Miniclima EBC08 and EBC09 units to provide tight control of the RH (±3%) in six showcases.

The majority of the cases easily met the loan specifications. One showcase initially showed short-lived RH peaks between 2 and 4 p.m. on most days, taking it out of specification for the loan object in it. No obvious temperature perturbation was associated with these RH changes. Sunlight had been observed to strike the plinth containing the Miniclima unit at around this time in the afternoon during installation, before the blinds were lowered.

Although visible light was kept below 200lux, it was suspected that infrared emission from the heated blind was heating the dark brown plinth. The surface temperature was measured on the outside and inside of the plinth using Pt 100 sensors and a SR007 datalogger, and the internal air temperature inside the plinth was monitored with a Meaco transmitter. FIG. 5 shows a 24-hour period with the effect observed.

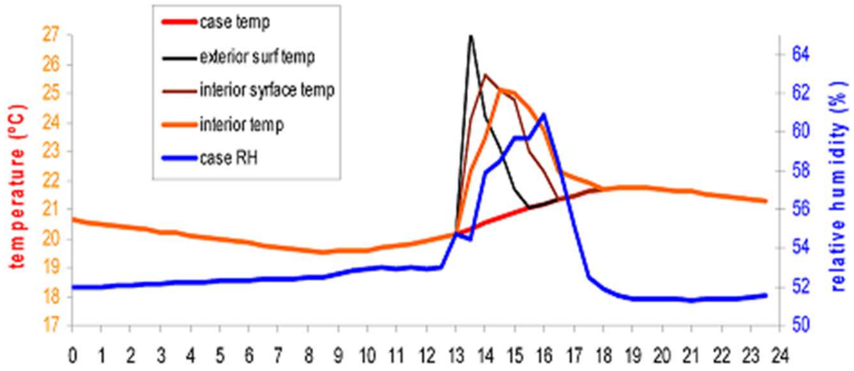

FIG. 5 - Kenilworth.

As can be seen, the exterior surface temperature of the plinth rises sharply around one pm. The interior surface temperature follows this increase more slowly and is heated for longer. The air temperature inside the plinth rises by 3°C and the RH in the case rises. The problem was solved by adding two fans to the plinth casing to ensure sufficient air-flow to remove the heat swiftly. Opening the view from the window with the mesh did not impact on the case performance with the fans running.

Light can dramatically increase off-gassing from showcase materials. At Apsley House, London, a significant collection of silver is displayed in original 1840s, and recent replica showcases. As the gallery contains mainly silver and china, light control was not a priority under the previous management regime.

English Heritage took over management of Apsley House in 2005 and instigated a light plan to manage the exposure of silk banners displayed at high level in the room. Monitoring of silver tarnish rates and hydrogen sulfide concentrations inside the showcases and room were undertaken to optimise preventive conservation for the silver collection. A blue woollen fabric had been installed in the showcases in 1992 and tests had shown it was unsuitable for use with silver (Daniels and Ward, 1982). Tarnish rates were measured in all ten cases containing silver, to prioritise replacement of the fabric, which was relatively expensive to achieve. FIG. 6 and 7 show the silver tarnish rate and hydrogen sulfide concentration in showcases, between windows for 30 day periods under the old regime, with the blinds raised and the new regime using the light plan.

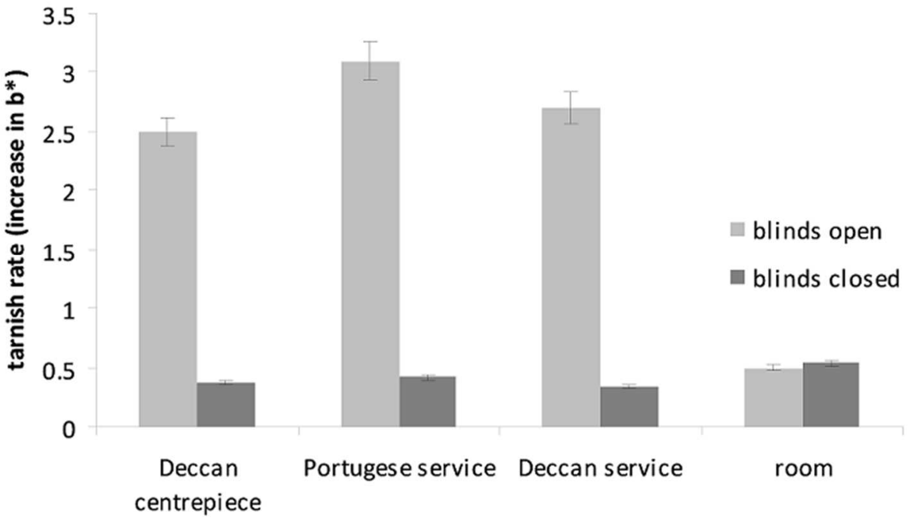

FIG. 5 – Silver tarnish.

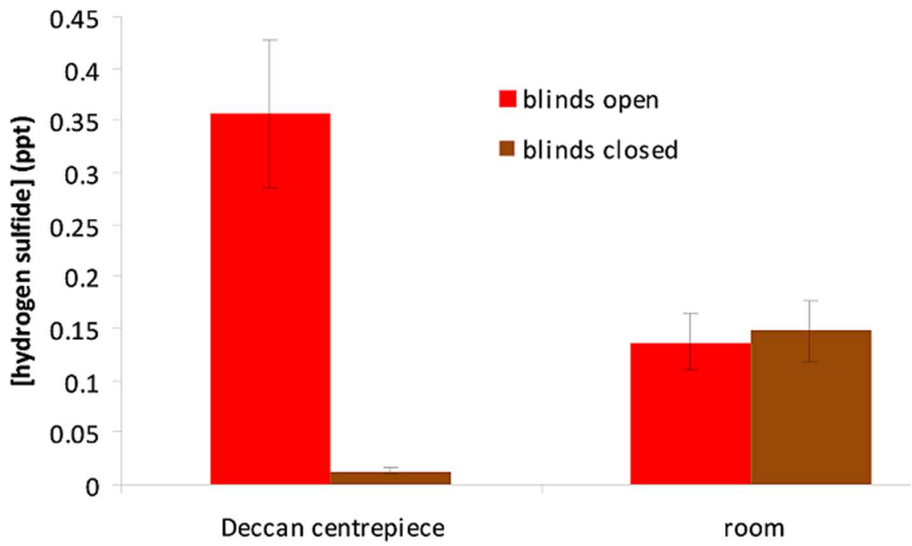

FIG. 6 - Hydrogen sulfide concentration.

As can be seen, the hydrogen sulfide and tarnish rates are significantly higher when the showcases are exposed to UV filtered sunlight. The hydrogen sulfide and tarnish rates are similar in the room over the two periods. To further investigate small samples of the blue fabric were taken from areas exposed to light and those under card labels. The samples were analysed with Fourier transform infra-red spectroscopy and the area of the cysteic acid peak in the second derivative at 1046cm^{-1} determined as a measure of wool degradation (Odlyha et al., 2007). Results are shown in FIG. 7.

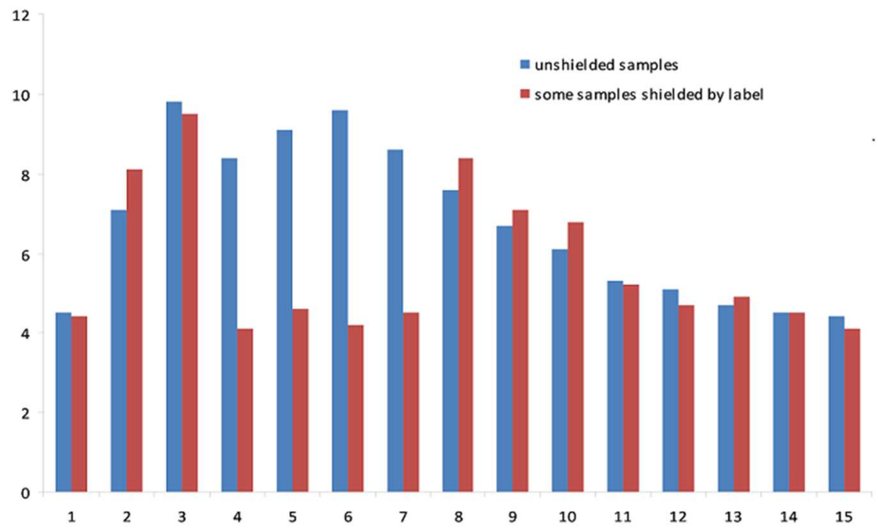

FIG. 7 - Cysteic acid area.

Points 2-11 experience sunlight, whilst points 1 is shielded by the case frame and points 4-7 are under a label. The unexposed wool is significantly less chemically degraded.

Conclusion

Managing daylight to provide conservation conditions in historic properties presents a number of challenges. Light plans have been developed to overcome many of these. Measurement of light doses with automated systems is mainly accurate at hourly and more frequent measurement rates. Manual measurements can however, significantly underestimate doses. Blue Wool dosimeters measured with colorimeters are a convenient method. Their preparation and measurement can significantly affect results and strict procedures need to be adapted for accurate and precise results. Mesh materials and neutral density films have been used to retain historic views, whilst controlling daylight. Modelling can significantly improve both measurement and optimise control.

Daylight can have negative effects on showcase performance. Excessive surface temperatures risk vulnerable organic materials even when showcase RH values appear not to be too low. Near infra-red heating through double blinds can impact the performance of Peltier based dehumidification systems (which are very common), through heating the compartment with the equipment. Off-gassing can also be dramatically increased under daylight illumination.

References

Ashley-Smith, J.; Derbyshire, A. and Pretzel, B. (2002), The continuing development of a practical lighting policy for works of art on paper and other object types at the Victoria and Albert Museum. In: Preprints of ICOM-CC 13th Triennial Meeting, Rio de Janeiro, pp.3-8.

Bullock, L. and Saunders, D. (1999), Measurement of cumulative exposure using Blue Wool standards. In: Preprints of ICOM-CC 12th Triennial Meeting, Lyon, pp.21-26.

Cannon-Brookes, S. and Perry, M. (1996), Daylighting dosage prediction for side-lit interiors in museums, galleries and historic buildings. In: Preprints of ICOM-CC 11th Triennial Meeting, Edinburgh, pp.19-26.

Council for Museums, Libraries and Archives (2004), *Government Indemnity Scheme Guidelines for Non-National Institutions*, London: Council for Museums, Libraries and Archives.

Daniels, V.D. and Ward, S. (1982), A rapid test for the detection of substances which will tarnish silver. *Studies in Conservation,* 27(2), pp.58-60.

Eibl, M. (2015), The development of the museum building from the perspective of preventive conservation, PhD, Technical University of Munich.

Lloyd, H. (2002), Strategies for visitor management at National trust properties. In: *Postprints of 4th European Commission Conference, Research for protection, conservation and enhancement of cultural heritage, Strasburg 2000*. Luxemburg office for official publications of the European communities, pp.166-171.

Mardaljevic, J.; Painter, B. and Andersen, M. (2009), Transmission illuminance proxy HDR imaging: A newtechnique to quantify luminous flux. *Lighting Research and Technology*, 41(1), pp.27–49.

Mardaljevic, J. (2015), Climate based daylight modelling [online]. Available from http://climate-based-daylighting.com/doku.php?id=academic:climate-based-daylight-modelling [accessed 30th November 2015].

Odlyha, M.; Theodorakopoulos, C. and Campana, R. (2007), Studies on woollen threads from historical tapestries. *AUTEX Research Journal* 7(1), pp.9-16.

Loe, D.L.; Rowlands, E. and Watson, N.F. (1982), Preferred lighting conditions for the display of oil and watercolour paintings, *Lighting Research and Technology,* 14, pp.173-192.

Robert-Semple, D.; Song, F. and Gao, Y. (2012), Seasonal characteristics of ambient nitrogen oxides and ground–level ozone in metropolitan northeastern New Jersey. *Atmospheric Pollution Research,* 3, pp.247-257.

Ruess, M.; Scott, G. and MacKinnon, F. (2013), Conservation of exhibitions: making a maintenance programme. In: Preprints of ICOM-CC 14th Triennial Meeting, Lisbon, pp.693-699.

Thomson, G. (1988), *The Museum Environment.* London, Butterworths.

Thorn, A. (2013), Predicting the solar impact of the restored glazing regime of the Domed Reading Room, State Library of Victoria. In: Preprints of ICOM-CC 14th Triennial Meeting, Lisbon, pp.716-725.

Thickett, D.; Rhee, S. and Lambarth, S. (2007), Libraries and archives in historic buildings, in *Museum Microclimates*, Copenhagen: Bogtryk, Hvidovre, pp.145-156.

Thickett, D. (2008), Presentation in situ through microclimates. In: Postprints of Conservation and Access, 22nd biennial meeting of IIC. London: IIC, pp.98-103.

Thickett, D. (2013), Effects of light on silver tarnishing. In: Preprints of ICOM-CC Triennial Meeting, Lisbon.

Thickett, D.; Chisholm, R. and Lankester, P. (2013A), Development of Damage Functions for Copper, Silver and Enamels on Copper. In: Climate for Collections, Postprints of the Munich Climate Conference, pp.325-336.

Thickett,D.; Luxford N. and Lankester, P. (2013B), Environmental Management Challenges and Strategies in Historic Houses. In: The Artifact, its Context and their Narrative, joint conferences of ICOM-DEMHIST and ICOM-CC, Los Angeles: Getty Conservation Institute, Los Angeles: Getty Conservation Institute.

Thickett, D.; Fletcher, P.; Calver, A. and Lambarth, S. (2007), The effect of air tightness on RH buffering and control, in *Museum Microclimates*, Copenhagen: Bogtryk, Hvidovre, pp.245-252.

Vlachou, C. (2015), Personal communication, 3 July.

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