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Digital Lighting for the Analogue Museum

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Exhibition lighting in museums and galleries usually strives to render the true nature of the surface of the exhibits. This would normally include using light sources that provide the most accurate rendering of colour and tone - white light sources with an appropriate colour temperature and high colour rendering index scores. This has been the traditional approach to exhibition lighting for decades, but in the era of solid state lighting, is there now an opportunity to rethink how we illuminate our precious and fragile historic artefacts? Should we be questioning our whole knowledge base for conservation lighting and looking for new ways to maximise visibility and minimise damage to our most fragile artefacts?

Dimensions of Light

The commonly available metrics that attempt to quantify the quality of white light are well known. An experienced practitioner will understand how the metrics for colour temperature and colour rendering can help to describe the visual effect of seeing objects under that illumination, but we also recognise that these metrics have never been enough to capture the subtle differences between light sources.

Correlated Colour Temperature (CCT), can describe the subtle tint of white between warm and cool. Historically, most exhibition lighting was based around spotlights using tungsten or tungsten halogen light sources and would typically have a CCT between 2700K and 3500K. Unless it was used in an area with natural light, any fluorescent wash lighting would most likely be using lamps with similar CCT's to tungsten sources. Whilst the act of dimming tungsten sources lowered the CCT and created a warmer glow, for fluorescent lamps, the range of available CCT's in typical museum use was usually limited to 2,700K, 3,000K, 3,500K and 4,000K and dimming did not alter the CCT.

The limited range of CCT's available for fluorescent lamps has been replicated in the world of Solid State Lighting with most white LED sources having a defined colour temperature. It is not surprising that white LED sources tend to mimic the common colour temperature options as remote phosphor LED sources and fluorescent sources are using a very similar technique to produce white light. This limited range of CCT's would seem to work for most general lighting situations, and certainly where LED is being used to replace or sit alongside existing light sources, but could conservation lighting be improved with different CCT options?

As my own previous research demonstrated (Innes 2011, Innes 2013), with tungsten halogen sources, even a relatively small difference in colour temperature of 150K can make a significant difference in the perceived brightness of illuminants at museums lighting levels. When faced with two monochrome photographs illuminated with tungsten halogen spotlights of different colour temperatures[1] and asked to brightness match the two sources, participants adjusted the cooler CCT source to create a visual match. The results were surprisingly clear. Over a range of target illuminances from 43 lux to 172 lux, the participants set a visually equivalent illuminance that averaged 27% lower than the target light source. In this experiment, it was clear that even with a relatively small colour temperature increase of 150K, participants were perceiving this as a brighter light source.

These results could have significant implications for conservation lighting where illuminance restrictions mean we are always working at the lower limits of acceptable illumination. Despite the predominance of fixed CCT sources, there are a number of white LED sources that have variable colour temperature. This means that we now have the tools available to adjust colour temperature in a very precise way. This could be advantageous as research into colour temperature preferences for viewing artworks under artificial illumination has produced varying results including 3,600K, 3,700K and 5,100K (Dangol 2013, Pinto et al. 2006, Pinto et al. 2008, Scuello et al. 2004a, Scuello et al. 2004b). It should be noted that none of these figures are standard CCTs. Whilst we can, with white tuneable LED sources, select a specific colour temperature, that will not be enough to ensure a good quality of light.

A colour appearance metric like CCT tells us nothing about the ability of a light source to accurately render colours. By its very nature, CCT is a comparison of two light sources with different spectral compositions. For example, the colour appearance of a remote phosphor white LED is compared to a theoretical black body source to determine the CCT; the colour temperature appearance may be very similar, but due to metamerism, the spectral composition of the sources could be

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[1] The experiment compared a dimmed 50w lamp and a dimmed 20w lamp. The colour temperature difference was the result of the 50w lamp having to be dimmed more to achieve the same illuminance.

radically different. This is why we have long combined CCT and Colour Rendering qualities in our assessment of lighting quality.

Conventional wisdom in exhibition lighting says that high colour rendering (CRI Ra) is important to deliver the best colour accuracy of the exhibits. However, some of the severe limitations of the original CIE Colour Rendering Index were particularly exposed by the introduction of white LED sources of dubious quality, and there have been many attempts to improve the metrics since then. In a comparative evaluation of thirteen different colour quality metrics, Smet et al. (2011) determined that, "the CIE R(a) performed the worst". They also concluded that, "a complete description of the colour quality of a light source probably requires more than one metric".

This conclusion is reflected in many current attempts to provide some meaningful quantification of the colour quality of light that genuinely reflects the human visual experience of white light. One such promising development is the IES Method (David et al. 2015)(see also Houser, Royer & Aurélien *The IES Method for Evaluating Light Source Colour Rendtion* elsewhere in this publication). This method combines two dimensions of measurement for colour rendition, colour fidelity and gamut, along with a new expanded set of reference colours. This system is likely to produce much better results than any version of CRI or Gamut Area Index but as it is still based on a reference light source, it may still not be enough for museum lighting. Not all wavelengths of light contribute equally to brightness perception (Wilkerson, 2013), so the optimal light source for conservation lighting in museums (where 'brightness' is often in short supply) may not be the same as the highest scoring light source in a rendering metric for general lighting tasks.

The relighting of the Sistine Chapel involved the creation of an artwork specific colour rendering index (Osram, 2014). Instead of CIE reference colours, the palette of pigments used in this Renaissance fresco was taken as the reference and the lighting system was measured to gauge the fidelity of rendering the precise colours present in the artwork. The dramatic effects of tuning the lighting to suit the artwork is also evident in the many exhibition lighting projects by Francesco Iannone and Serena Tellini of Consuline (Ritter et al. 2013). These kinds of exhibit specific lighting solutions have been made feasible by solid state lighting with digital control to mix multiple colours with white LEDs to create a customised spectrum. Whilst this is perhaps not feasible for every museum, it does show the level of personalisation that is achievable and a new digital future for exhibit lighting.

The strict requirements of conservation lighting adds another dimension to the qualification of light sources - damage potential. We know that many museum exhibits are sensitive to light as photochemical damage can be caused to many materials when exposed to light. It is for this reason that illuminance levels are so restricted in museum environments. The low illuminance levels do not prevent photochemical damage, but are intended to slow the damage to what is seen as an acceptable rate - it is a compromise between the longevity of the exhibit and the need to actually see the exhibit. However, the common and long trusted standard of a maximum illuminance of 50 lux for sensitive exhibits (Thomson 1986) is a crude and potentially misleading benchmark as not all wavelengths of light cause equal damage and different light sources can have very different spectral power distributions.

The very damaging effects of Ultra Violet radiation has been well known for a long time (Thomson, 1957) and therefore museum grade light sources have tended to be heavily filtered to minimise wavelengths below 400nm, leaving only visible light and the maximum illuminance recommendations. However, illuminance is not

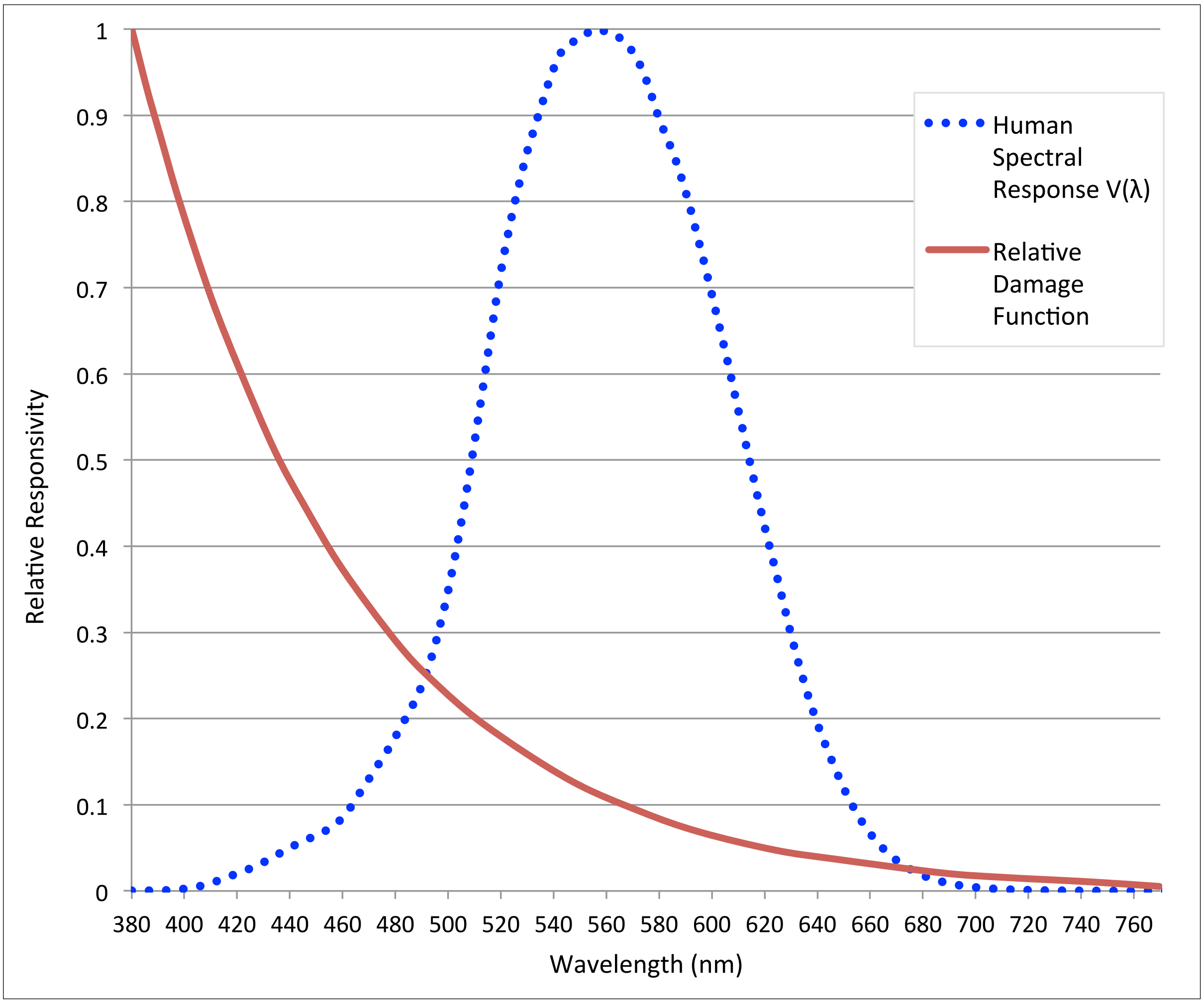

figure 1: wavelength dependant damage

a good measure of potential damage that a light source could be causing to an artwork. Whether measured in Lux or Foot-candles, illuminance is based on the Lumen, an SI unit that does not quantify an absolute physical quantity of light, but an average human response V(λ), by an observer at photopic light levels. As Cuttle (2013, p15) puts it, "instead of being a physical quantity, the lumen is a psychophysical quantity". As can be seen in Figure 1, the Vλ curve bears no relationship to the CIE defined relative spectral sensitivity of typical exhibits.

The Berlin spectral responsivity function (CIE, 2004) records the relative sensitivity of typical categories of museum materials to different wavelengths of visible light. From a low level of responsivity at the red end to the spectrum, the relative sensitivity increases exponentially as wavelength decreases (and radiometric energy increases) towards the blue end of the spectrum - the resulting curve is a very different shape from the Vλ curve. This is hardly new information as the US National Bureau of Standards noted in 1951, "energy of wavelengths shorter than about 500 millimicrons [nanometers] contributes very materially to the deleterious effect while its usefulness in seeing (as represented by the luminosity factors) is not as great as that of longer wavelengths" (National Bureau of Standards 1951, p14). Nevertheless it is only relatively recently that this kind of data has begun to be commonly used to assess the relative damage potential of different light sources (Padfield).

Whilst this kind of information allows for the selection of light sources that minimise potential damage to artefacts, it too is perhaps a relatively crude measurement. Damage functions tend to represent an average relative spectral sensitivity and experiments are often based on testing the type of paper substrate that an exhibit may be painted or printed onto (National Bureau of Standards 1951), rather than the artwork itself. It is easy to see that the exponential shape of the curve suggests a fairly equal absorption of wavelengths by the test materials (remembering that the energy level of the photon increases as wavelength decreases). This response does not represent many museum exhibits. A material appears coloured to us because it reflects certain wavelengths more strongly than others (Figure 2a). As can be seen in the reflectance spectra in Figure 2b, a bright

figure 2a: fabric samples

blue fabric reflects shorter wavelengths more strongly than the red ribbon does. In reflecting the blue light, this object is therefore less prone to damage than a red material that absorbs blue and reflects red. To add more detail to this topic, Edinburgh Napier University and The Centre for Textile Conservation at the University of Glasgow are beginning a research project to explore the unique wavelength dependant fading characteristics of a range of coloured dyes used in historic fabrics. This information will allow for much more detailed and informed decisions to be made about the choice of specific light sources to illuminate specific dyed fabrics.

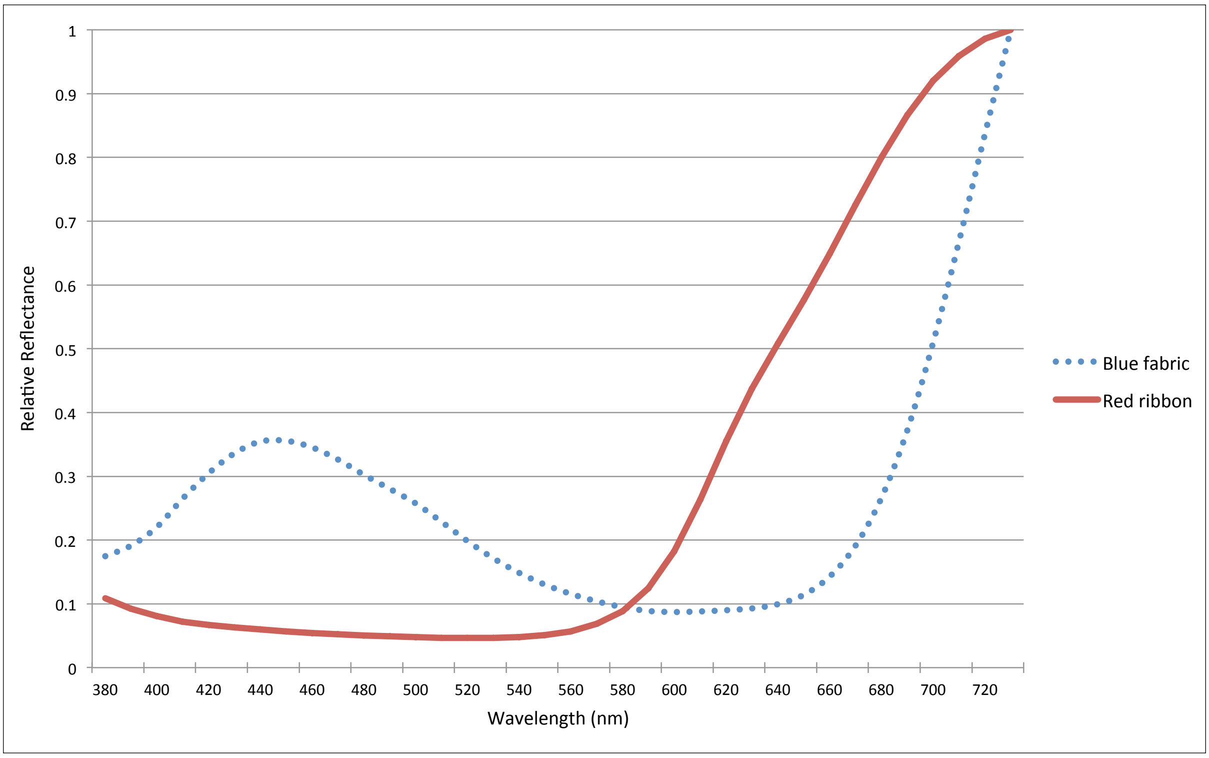

figure 2b: reflectance of fabric samples

As we saw with the Sistine Chapel and projects by Consuline, customised lighting solutions are becoming more common. At the moment, these projects still use broad spectrum sources, but there is scope to further reduce damage potential by reducing or eliminating wavelengths that are not reflected by the exhibit - after all, if they are simply being absorbed by the exhibit they are contributing nothing to human vision, but are still damaging the object. Our fabric dye research project aims to produce an experimental 40 band lightsource that will allow the custom boosting and attenuation of 10nm bands of the visible spectrum. This luminaire would be impractical for gallery use, but the reality of a controllable, wavelength tuneable light source may not be too far in the future.

Virtual Restoration

Good quality white light can be the ideal medium to accurately reveal the surface colour and material qualities of exhibits. But, sometimes the current surface appearance of the object does not represent what the object should look like. Despite the almost unanimity of white light use in exhibition lighting, there is sometimes scope for a different approach.

In contradiction of most casual viewers expectation of a monochromatic past, many of the stone exhibits in our museums were once highly decorated with bold and vibrant colours. An ongoing research project by Edinburgh Napier University for Historic Scotland is exploring using projected light for the virtual restoration of stone artefacts from Elgin Cathedral (figure 3). Using digital projection techniques, it is possible to selectively illuminate parts of the exhibit and use changes to intensity, colour and projected pattern for interpretive purpose.

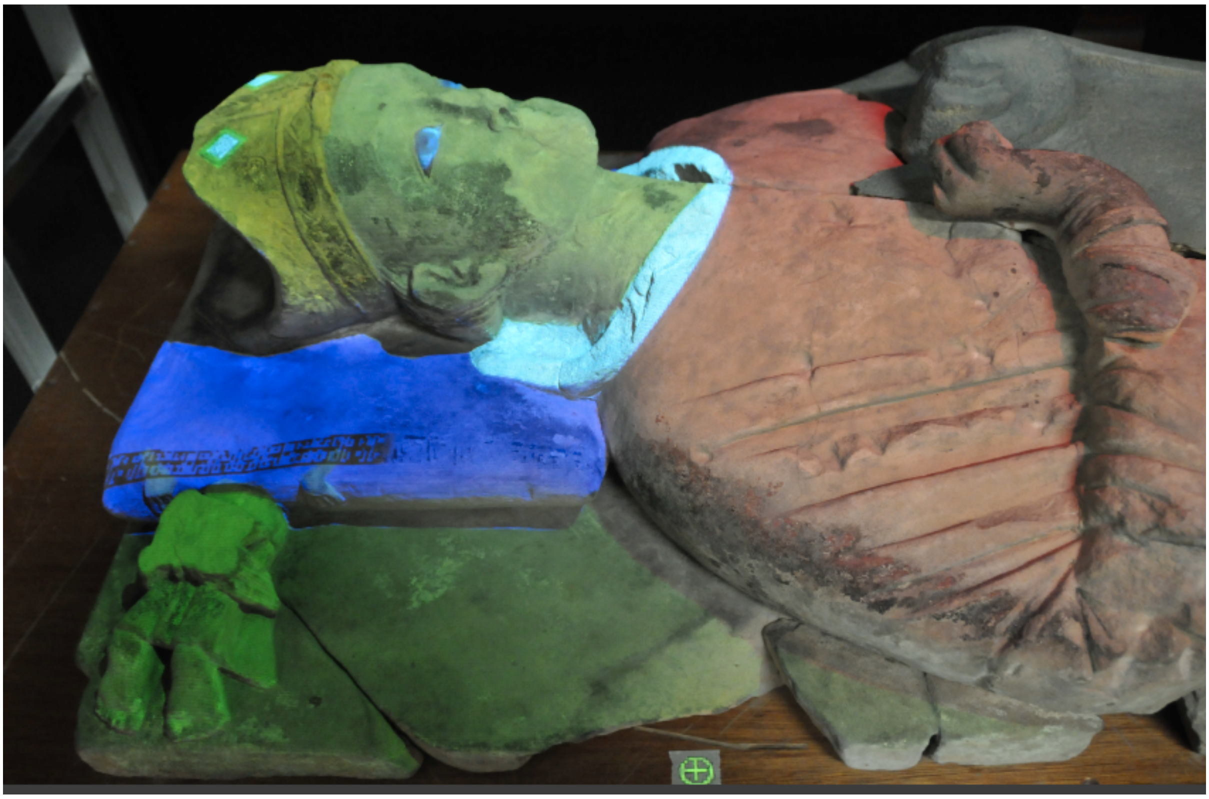

figure 3: virtual restoration of colour using projected light 2012

The advent of reasonably bright LCD/DLP video projectors that use LED and Laser light sources means that these digital projectors sporting low power and extended lamp life (greater than 5 years in typical exhibition use), means that LED/ Laser projectors can be used to illuminate exhibits without the problems of changing very expensive lamps every few months. This technology shift has encouraged the author to explore how digital projectors can be used to virtually restore some essence of the original polychrome look of stone artefacts or woven fabrics and tapestries that have lost their surface decoration over the centuries.

The use of digital projectors also begins to open up that other possibility - illuminating different parts of an exhibit with only the wavelengths that will be reflected. Technically, digital projectors are not narrow band light sources as they use fairly broadband sources or filters to create different colours, much like an RGBW luminaire. Nevertheless this kind of virtual restoration is a reality as can be seen by the recent work to relight the famously sun damaged Harvard murals by artist Mark Rothko (Walsh, 2014). This approach is not without its ethical questions over the authenticity of projecting imagery onto existing artworks (Menand, 2015), but the opportunities are intriguing.

New metrics for new technologies?

Digital projectors do not produce high CRI whites, but perhaps CRI is actually less important than we used to think. After all, London's National Gallery tested many, many LED sources and settled on their perfect solution, a source that did not have a CRI score in the 90s (Erco, 2011). Independent tests from research in many countries is often revealing preferences amongst the viewing public for exhibition lighting that may score poorly in our existing colour quality metrics (Innes, 2013).

Perhaps white is not enough and there is more to be gained from the use of tinted or fully saturated coloured light in some exhibition situations. But in this case, will the current lighting standards and guidance used in museums and galleries still be fit for purpose in the age of digital lighting? I would say no, but how should we be quantifying light and damage if we want to define the very best conservation lighting? It is a debate that we need to be having now.

A brighter future?

It seems like we are now surrounded by mature solid state lighting technologies, but tungsten sources dominated lighting for 100 years, so we are still only just beginning to reveal the possibilities of digital lighting technologies in museum environments. At the same time as improving the visibility of sensitive exhibits for the audience, through clever use of all the available technologies, we have the opportunity to reduce light induced damage. The convergence of digital technologies, new approaches to customised lighting solutions and new ways of quantifying light quality and damage, means that the future for exhibition lighting could well be much brighter - at least perceptually brighter.

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