Spatial Light Risk Mapping
A Planning Tool to Minimise Fading of Light-Sensitive Objects Exhibited in Day-Lit Exhibition Spaces*

The Preservation Department of the Royal Library in Copenhagen, Denmark has long since been involved in exhibition activities. So far, these activities have been set in designated exhibition areas and at a changing rate, which the conservators could keep up with. Nowadays, other areas of the library have been designated as areas where ad-hoc exhibitions take place. The exhibition areas have a huge range of values of visible light and UV radiation, while the library exhibits a variety of objects having a wide range of light sensitivities. In order to deal with the risk for fading associated with the new exhibition approach, a tool for curators and exhibition editors has been developed to ease and enhance the decision making process. The emphasis is placed on identifying the objects that can be exhibited and the maximum allowed exhibition time in different building locations with the goal of reducing the risk of experiencing a just noticeable fade. This light risk map has been developed using meteorological information about hours of daylight during the seasons, measured maximum light levels in different locations and taking into account the light sensitivity of different materials compared to the ISO Blue Wool Fading Standard scale. The map gives an easy understandable overview of the time each type of material can withstand perceivable colour change in different locations. The calculations and the resulting light map have been received with interest and goodwill since they provide a useful tool for curators allowing them to better understand the possible impact of exhibition lighting. This means that instead of just being restrictive, conservators and curators can work together on identifying risk for light sensitive materials, which are planned to be exhibited, in order to take preventive measures.

Introduction
When the new library building, The Black Diamond of The Royal Library in Copenhagen, Denmark, opened in 1999 the main objective was to expand the existing facilities and to open up the research library to a wider audience. Visitors typically consisted of researchers who had specific academic reasons for accessing the collections. The spectacular building, the general atmosphere and the huge entrance hall serve as an open invitation to the general public.

Two new exhibition halls in the basement of the building resulted in a large improvement as the old library building only had two showcases. The approach for the new exhibition rooms was traditional with exhibition of objects in showcases and on the walls of rooms and with controlled light exposure. Unfortunately, it was difficult to attract random library users down into the basement; only dedicated visitors with the intention to see the exhibitions descended the steps. Therefore, a new vision on how to exhibit the collections for a wider audience was developed in 2008, in parallel with the traditional exhibition scheme. It was established that the large number of library users and other visitors, who visit the library every day without ever looking at the exhibitions in the basement, should experience the cultural heritage objects on their way through the library in an open and light atmosphere with little references to the traditional design of exhibition rooms and without paying an entrance fee (Fig 1).

As a result of this approach, conservators were more often faced with situations in which precious objects were planned to be exhibited in bright public areas mainly lit by daylight. The light sensitivity of the objects was typically considered in a very late phase of the planning. Consequently, decisions such as the use of copies or selection of less sensitive objects led to perpetual struggle between curators/exhibition designers on one side and conservators on the other when attempting to reach a balanced solution without compromising the exhibition idea, access to the collections and long-term preservation. As the vision from the library was clear, conservators were faced with the challenge of combining exhibition of light sensitive objects with extreme daylight conditions in a helpful and responsible way facilitating the discussions regarding sensitivity and light damage of heritage objects.

From exhibiting at 50 lux in incandescent light to displaying in daylight, for instance at 300 lux, the lighting guidelines used by the conservators were challenged. To avoid loss of value caused by fading the idea was to map and quantify the risk associated with exhibition in the day-lit areas. The concept of a graphically simple light risk map of the exhibition areas emerged which could be a helpful tool for exhibition designers and collection managers. This tool should summarise the risk of fading by combining illumination, sensitivity of specific materials and the many possible locations of an object and thereby help
the exhibition producers to display the objects in a more resource-fully and less risky way.

The light risk map at The Royal Library was created in 2009 but similar approaches have since been made by other cultural institutions (del Hoyo-Meléndez et al. 2011) as exhibiting in daylight has become a trend – not the least in modern buildings with large glass facades. Also various authors (Colby 1992; Ashley-Smith et al. 2002) have made practical guidelines in order to improve management of risk related to light exposure, and risk mapping combining vulnerability and environment in an institution has among others been published by Bradley (Bradley 2005).

Impact of Light

The impact of light is cumulative and builds up in the object exposed which makes it important to manage the exposure continuously.

Light doses and variety of artificial light levels are challenges faced in any exhibition with light sensitive exhibits. By exhibiting in day lit areas, it was in addition necessary to deal with the damaging effect of daylight in comparison to that of the incandescent light sources (traditional and quartz halogen) employed in traditional exhibition rooms. As the Royal Library always display artefacts in UV protected exhibition cases this form of radiation is not a concern.

Daylight holds more energy than light from incandescent lamps, traditionally used in exhibitions, because it has higher levels of energy rich blue wavelengths. Therefore, 50 lux of incandescent light does not have the same degrading effect as 50 lux of daylight. To quantify the degrading effect of visible daylight the standard ‘CIE 157:2004 Control of Damage to Museum Objects by Optical Radiation’ (CIE 2004) was used. In this publication, daylight (behind glass and without UV) has been estimated to be twice as aggressive on sensitive materials compared to incandescent lamps. However, this may be a simplified statement as daylight has a variety of behaviours depending on whether the object receives direct sun light or not (Padfield <www.conservationphysics.org>). Also, each material reacts differently depending on the spectral power distribution of a given source making the estimation of degradation a complex task. And in addition to that temperature, relative humidity, oxygen and air pollution are known to affect the colour stability when exposed to any light.

Natural daylight has on the other hand advantages over electric light as the colour rendering may be more pleasant due to its spectral power distribution. Besides, daylight is a more sustainable option since it allows reducing CO₂ emissions. The difference in spectra and colour rendering between quartz halogen light and daylight in the library building is illustrated in (Fig 2a, b).

Sensitivity of Materials

To libraries and archives the colour stability of paper is highly relevant. Launer and Wilson (1943), Lee at al. (1989) and Vávrová et al. (2008) have examined the light stability of different kinds of paper and all found that lignified paper is sensitive to light whereas paper without lignin is quite stable. Even paper with optical brighteners is only moderately sensitive to the visible light spectrum (Connors-Rowe et al. 2007). Pioneer work in light fastness of natural dyes was done by Padfield and Landi (1966) and several sensitivity tables have derived from this work.

A well-known classification of materials in terms of their light responsivity has been made by Michalski (Michalski 1987) and adopted in the international guideline for museum lighting (CIE 2004) to quantify the amount of light that a coloured material can receive before a just noticeable fade (jnf) occurs. This classification table is still viable (Michalski 2011) with a division of materials into four categories; ‘high sensitivity’ (ISO Blue Wool 1-3), ‘medium sensitivity’ (ISO Blue Wool 4-6), ‘low sensitivity’ (ISO Blue Wool 7-8), and ‘no sensitivity’. The high and medium sensitivity categories in this table represent many materials in the Royal Library, but to cover the majority of library materials it was necessary to expand the otherwise useful table. Vegetable and chrome-tanned leather as well as parchment are considered low sensitive materials belonging to the Blue Wool –7-8 category (CIE 2004) and therefore were not included in the light risk mapping.

The table was thus supplemented according to recommendations and research made by Colby (1992), Reissland and Cowan (2002), Vávrová et al. (2008) and CIE 2004 regarding iron gall ink, paper and other materials. To this a new category, namely ‘extremely sensitive materials’ was added with the aim of including materials that have extremely low colourant stability identified by the authors. Based on colour measurements made before and after a exhibition period (Tab 1) some modern coloured leather bindings and glazed paper have been found to be ‘extremely sensitive’ and are thus placed in this category (Figs 3a, b). Other colourimetric measurements conducted by the authors have shown colour changes in the range 2-3 ΔE for blue-green and green leathers, which were exhibited for less than 1Mlx·h. These leather dyes have also proven to be light sensitive having similar properties to those of the tinted paper listed in the category ‘high sensitivity’. The materials relevant to the library are categorised and presented in Tab 2.

Wagner et al. (2000) have proposed an extensive list of light sensitivity properties of photographs which has not been
Included in the table. In this list a category for extremely light sensitive materials has also proven to be necessary.

The use of published heuristic light sensitivity tables has limitations as they may contain vague information such as ‘many cheap synthetic colourants’ which is not easy to decide which is the case. Also, many coloured objects have already been exhibited and thus may in some cases no longer fade as fast as indicated in these tables where the colour loss is calculated from pristine condition. Another trap is if conservators and exhibition designers do not sufficiently consider the qualities of individual objects because they think the light map is sufficient to provide reasonable protection. In order to estimate the right sensitivity the current best method is the use of micro-fading technique which is getting more and more use in the field of exhibiting cultural heritage.

**Mapping of Light Levels**

Measurements of the visible light in all possible exhibition areas of the library were carried out in sunny summer days around noon with the aim of indicating the maximum exposure level. Showcases in the library are heavy and only occasionally and randomly placed in the public areas so therefore no systematic measurements were taken from behind a case glass. However, for comparison, one pair of measurements were taken outside/inside an exhibition case (Fig 4) with a 1.3 cm glass thickness and UV-filter, which gave the out/in lux readings 350/317. This specific glass filtrates out around 10% of the light. We decided not to deduct 10% in general as some cases have thinner glasses.

**Calculation of Maximum Exposure Time**

The point of reference has been to determine when 1 just noticeable fade may occur and the intention of the light risk map is to present this. This does not mean that exhibition producers can exhibit endlessly until a colour change has occurred so along with the production of the light map it was necessary to come up with a reasonable limit. As a rule of thumb it was, in collaboration with curators, decided that 20% of a cautiously predicted

**Tab 1** Colour measurements by spectrophotometer Gretag MacBeth SpectroEye (illuminant D65, angle 10°, No filter, Abs. white). Five measurements taken before and after exhibition period. Spectrophotometer lifted after each measurement and new measurement taken in another spot close by. CIELab \( \Delta E \) calculated from the average of \( L^* \), \( a^* \), and \( b^* \) respectively.

<table>
<thead>
<tr>
<th>Object</th>
<th>Lux hours</th>
<th>Colour change ( (\text{CIELab} \Delta E) )</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hans Christian Ørsteds Billedbog (1869) made by Hans Christian Andersen</td>
<td>&lt; 25,000</td>
<td>3.8</td>
<td>glazed orange paper</td>
</tr>
<tr>
<td>Paul Bonet bound by Ole Olsen in 1974</td>
<td>800,000-1,000,000</td>
<td>10.7</td>
<td>turquoise maroquin (goat skin)</td>
</tr>
</tbody>
</table>
This approach was chosen as a way of reducing exposure without having to maintain a database with strict documentation of exposure for all exhibited items and their numerous possible openings. Objects being especially vulnerable and/or of special significance will be followed continuously by documentation of light dose and sometimes even with colour measurements as the simple ‘20%’ light map approach might be inadequate for long-term preservation for these items. In that way a dual approach is applied.

The actual colour of the object is the point of reference for using the light risk map. It does not take earlier exposure into account, but only relates to future colour changes.

When calculating the exposure limits (1 jnf) for each sensitivity group the lowest Blue Wool sensitivity, belonging to the head category (including three Blue Wool numbers), was chosen to represent all objects in the category. This approach was used to counteract for the uncertainty regarding the actual light sensitivity which is not straightforward to predict. So even if a certain colour may be as stable as a Blue Wool 3 it is regarded as sensitive as Blue Wool 1 (red rings in table 2).

The next step was to calculate how many hours of daylight public areas can possibly receive under the most unfavourable lighting conditions measured earlier. Data on the maximum number of hours of sunshine per month was obtained from the Danish Meteorological Institute (Fig 6) and was used to calculate the maximum average time of sunshine for each quarter of the year (instead of each month).
The data allows devising a floor plan for which exhibition areas could be classified using red, yellow and green colours to illustrate the differences in exhibition capacity in terms of light exposure according to the previously described material categories. Similar to the light table, red markings indicate that exhibition is recommended less than 20 days in this specific location. The yellow markings show locations with a threshold of 21-90 days, while the green markings illustrate areas with threshold from 91 days and upwards. The green category has a wide spread in threshold; from 91 days up to 83 years. This is specified in the table printed on the opposite side of the light map where specifications for each location, light sensitivity category and season of the year are presented.

The light risk map for ‘extremely sensitive’ objects (Fig 10a) shows mainly red areas and a few areas in yellow. In the category of ‘highly sensitive’ objects (Fig 10b), exhibition is not a reasonable option in the front hall area or close to the windows. However, red markings turn into yellow in the inner areas of the building with the exception of locations underneath the skylights. Some locations are suitable for longer exhibition periods and are thus marked in green. With regard to the ‘moderately sensitive’ objects (Fig 10c) the majority of the public areas are shown in green and classified as safer zones.

It can be seen that the light risk map allows making informed decisions during the exhibition planning stage taking into account the light sensitivity of each object. For instance, the map gives useful information for making important decisions such as moving a sensitive object into a darker position as well as choosing a less sensitive item to be exhibited in a brighter zone.

**Experiences with the Light Risk Map**

It is evident from the light risk map that illumination of many objects must be restricted in some way in order to exhibit the collections for a reasonable period. The light map was used during the planning stage of the exhibition Carsten Niebuhr and the Arabian Journey in 2011. In the early planning of the exhibition, the light map was introduced and the exhibition architects became aware of the effect of daylight and the importance of placing the exhibition cases...
away from the highly illuminated areas. To reduce or avoid exposure of some light sensitive drawings, these objects were duplicated, printed on transparent film and adhered to the glass wall. In this innovative way the daylight was included in the exhibition design (Fig 11) reducing the light levels as the photostats had an overall darkening effect in the exhibition area. Another solution, to lower the light levels, was to install huge awnings that help to reduce the light coming from the upper parts of the building (Figs 12, 13). In addition, a part of the horizontal top component of the exhibition cases was covered with dark felt to supplement the light protection by the awnings. Some of the exhibition cases were built up with deep, dark inner boxes for providing additional protection to the more sensitive objects and a group of original items were repositioned in darker exhibition areas.

Design of exhibition cases in the library has, as a result of the work with the risk from light, developed into incorporation of magnetic removable side covers to be used as flexible light shielding or to be attached when the library is closed.

## Conclusion

The light risk map offers a new approach to communicate detailed and complex knowledge to museum professionals which has proved very effective so far. Traditionally conservators have been the messenger of restrictions, but the responsibility and the anxiety for the objects is, however, now shared among the staff had an overall darkening effect in the exhibition area. An innovative way the daylight was included in the exhibition design (Fig 11) reducing the light levels as the photostats had an overall darkening effect in the exhibition area. Another solution, to lower the light levels, was to install huge awnings that help to reduce the light coming from the upper parts of the building (Figs 12, 13). In addition, a part of the horizontal top component of the exhibition cases was covered with dark felt to supplement the light protection by the awnings. Some of the exhibition cases were built up with deep, dark inner boxes for providing additional protection to the more sensitive objects and a group of original items were repositioned in darker exhibition areas.

## Light risk table

<table>
<thead>
<tr>
<th>Light risk table</th>
<th>Ultraviolet (UV)</th>
<th>Photo</th>
<th>Summer (16h/day)</th>
<th>Autumn (14h/day)</th>
<th>Winter (12h/day)</th>
<th>Spring (14h/day)</th>
<th>Autumn (14h/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond C</td>
<td>106,000 J/Nh</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diamond B</td>
<td>840</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Helm C</td>
<td>10,000</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Helm B</td>
<td>500</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The numbers indicate days of display until just noticeable colour change may occur. **Red:** less than 3 weeks. **Yellow:** less than 3 month. **Green:** more than 3 month.

### Extremely light sensitive materials

Most plan extracts, hence most historic bright dyes and lake pigments in all media: yellow, oranges, greens, purples, many reds, blues. Insect extracts, such as lac dye and cochineal (e.g. carmine) in all media. Many cheap synthetic colorants in all media. A few historic plant extracts, particularly madder-type reds containing primarily alizarin, as a dye on wool or as a lake pigment in all media. It varies throughout the range of media and can reach into the low category, depending on concentration, substrate and mordant. Most colour photographs with “chrome” in the name, e.g. Cibachrome, Kodachrome. Rag paper and sulphate pulp paper.

### Highly light sensitive materials

Most plan extracts, hence most historic bright dyes and lake pigments in all media: yellow, oranges, greens, purples, many reds, blues. Insect extracts, such as lac dye and cochineal (e.g. carmine) in all media. Many cheap synthetic colorants in all media. Most felt tip pens including blacks. Most red and blue ball point inks. Most dyes used for tinting watercolours, gouaches, coloured prints. Bistre, sepia, complex black inks. Wood pulp paper.

### Medium light sensitive materials

Most plan extracts, hence most historic bright dyes and lake pigments in all media: yellow, oranges, greens, purples, many reds, blues. Insect extracts, such as lac dye and cochineal (e.g. carmine) in all media. Many cheap synthetic colorants in all media. Most felt tip pens including blacks. Most red and blue ball point inks. Most dyes used for tinting watercolours, gouaches, coloured prints. Bistre, sepia, complex black inks. Wood pulp paper.

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7 A representative part of the full light table. The red markings indicate that exhibition is only possible less than 3 weeks. The yellow marking allows less than 3 months (21-90 days) while the green marks more than 3 months.

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museum professionals. The light risk map is taken as neutral information based on research and is encouraging the discussion between curators, conservators and the exhibition staff at a very early stage of the exhibition planning phase. Conflicts are avoided and better relations are developed between management and conservation. Preliminary experience has shown that curators are more aware of the necessary exhibition restrictions when they are confronted with the consequences of exhibition of individual objects.

The light risk map provides an adequate tool for exhibition planners helping them to lower illumination levels, choose the less vulnerable objects, show sensitive objects only during the opening of an exhibition, turning the pages according to a scheduled plan, target the sensitive objects for seasons with lower light levels or ultimately produce a copy for exhibition purposes.
Light sensitive objects could also be exhibited on specially announced days, as part of a collection highlight event. This limitation leads into a creative process where a variety of new solutions are enforced through discussions between the different professional groups.

The map is a simple tool which can be further employed by conservators taking into account the specific vulnerabilities and risk of loss in the case of previously faded or changed colours, objects exhibiting low contrast etc.

To use the light risk map in a responsible way it is, as a rule of thumb, suggested to work with a maximum exposure allowance of 20% of the indicated amount of days in the light risk map for one exhibition. The light map will be periodically updated as new and more qualified data will be obtained by year-long light logging. It should also be taken into account that different objects have varying significance value. Some objects are more important as historic objects than others and therefore the balance between short term access in an exhibition might be less important than long-term preservation with emphasis on future generation’s access to an undamaged object of outstanding national significance. Therefore the risk map should never stand alone.

The light mapping of the exhibitions areas was quickly done to get an idea of the order of light levels and the consequent risk in different areas. Since then we have installed light data loggers in different areas to qualify the estimated light doses. In general light levels below the estimated ones used in the light risk map are expected because worst case scenarios consistently were chosen. It is not an accurate tool but in spite of common uncertainties regarding the light sensitivity of specific materials and the light dose to be exposed to, it highlights the risk and gives an idea of the order of magnitude of the light risk in different areas. Implementation of the light risk map effectively reduces the light doses for items going into exhibition and several vulnerable objects have been spared from exhibition in the day-lit areas.

Focusing on the risk from light has derived creation of a new tool (part of the conservation documentation system) to log
exposure to very vulnerable and significant objects and a more extensive and systematic colour measurement programme during long-term or highly lit exhibitions. Also, new exhibition cases with special protection from light have been developed. The library provides digital access to an increasing amount of the collections and this trend will keep the physical objects on more or less permanent storage. As a consequence the conservators will be faced more frequently with semi-permanent exhibitions of the written heritage which are becoming museum objects. Admittedly in rooms with well controlled low light levels, but like exhibiting in the day-lit areas, this also results in significant risk regarding fading of ink and other colours because of long-term exposure. The knowledge gained from working with the risk light map has also facilitated the work with this new challenge.

Endnotes
* This contribution was first presented as a talk during the XII IADA Congress at Berne in August/September 2011 and has been revised for publication.

References


Suppliers
Preservation Equipment Ltd, Vincents Road, Diss, Norfolk, IP22 4HJ, United Kingdom, Tel +44-1379-647400, www.preservationequipment.com (Elsec Environmnetal Monitor 765 with data logger [RH Temp UV & LUX]).

Tempcon Instrumentation, Unit 19 Ford Lane Business Park, Ford Lane, Ford, Nr. Arundel, West Sussex, BN18 0UZ, United Kingdom, Tel +44-1243-558270, www.tempcon.co.uk (Hanwell ML4703 Light [LUX] and Ultraviolet [UV]).

German Title and Abstract
Räumliche Kartierung zur Lichtbelastung: Ein Planungswerkzeug zur Begrenzung von Lichtschäden in Ausstellungsfächern mit Tageslicht

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