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Conceptualising Object Lighting Across Multiple Scales and Media

Introduction

This paper presents findings in conceptualising object lighting across multiple scales, developed for a workshop, experimenting with directed LED spotlights in full scale 1:1 as well as in 1:10 and 1:20 scale models. The experiment set out to test whether conceptualised directed LED spotlight is perceived similarly at different scales in physical models with special interest in the smaller scale 1:20. Our focus was the perceived qualities of light distribution, shadows, light temperature (colour), balance, and intensity.

We combined analogue and digital representation, using photographed 360° panoramas of the architectural scale models for evaluation in virtual reality (VR). The didactive method used was based on hands-on experiments applying and evaluating object lighting for exhibitions. The method is qualitative and focus on human perception of light and light qualities.

The aim was to introduce fast and iterative workflows for experimenting with scaled directed lighting in spatial design with (often existing) scale models to supplement digital design tools.

Background

Light is a prerequisite for visual perception. Architects and designers are focused on the atmosphere and experience of space and objects in space and therefore light quality is an important aspect of spatial design (Garnslandt & Hofmann, 1992). In our teaching we consider both light source, object and context, and perceiver including evaluation medium.

Object lighting for retail, exhibition fairs and museums require a broad range of lighting knowledge including legislation and regulations (Olsson, 2019). Often museum exhibits are fragile and sensitive towards light exposure and require light protection limiting intensity, ultraviolet radiation and infrared radiation. This can be achieved with LED luminaires with low-damage spectrums ensuring long-term, conservation-compliant art displays. In this study we only considered the perceived qualities of light as a starting point for conceptualising object lighting for exhibitions using scale models.

Our spatial design master students have different backgrounds including various international architecture and design educations. Many students have not previously received dedicated lighting training. The presented didactive method for conceptualising object lighting for exhibitions require basic lighting knowledge, therefore we propose a three-part workshop setup where each part can be taught independently (Kreutzberg & Mose, 2021b).

First an initial general introduction to lighting through lectures and observations and experiments in 1:1, then specific exercises with LED lighting in scale models (Kreutzberg & Mose, 2021a) and finally digital modelling with IES lighting files.

In this paper we present the experiments and findings that defined some of the exercises included in the second workshop, working with directed LED spotlights in 1:1, as well as in 1:10 and 1:20 scale models and their representations.

Methods

An exhibition scenario was established with four lighting variations in three different scales. The smaller scale model scenarios were qualitatively evaluated and directly compared to the 1:1 physical reference by viewing series of perspective photographs or 360° panoramas captured inside the scale models as well as in the 1:1 setting and displayed on smartphones/tablets or in VR head mounted displays (HMD) to balance contrast and compensate for brightness eye adaption, (Fig. 05).

Exhibition scenario

The illuminated object in this experiment was a 43 cm white gypsum replicate of a Venus torso (see weblinks). The human body is a well-known object we can understand without explanation and is well suited for lighting studies. The torso was centered on a podium placed 12,5 cm from a wall as backdrop and 110 cm left from a floor-to-ceiling window (100 cm with curtains drawn) reaching a total hight of 145 cm (Fig. 01). In this study the colour of light was evaluated on white surfaces only.

Fig. 01. A. Exhibition object. B. Daylight setting, C. Mixed LED light setting.
Source: Authors.

Lighting scenarios

Both daylight and general lighting can contribute towards the illumination of displayed objects, as can light from directed spotlights. Sculptures generally require directed light in combination with diffuse light to best reveal three-dimensional quality, materiality, and surface structure.

We are aware of cultural and geographic differences in perception of light colour qualities and the use of cold, neutral and warm white light (Durmus, 2022). We define warm white with a colour temperature of less than 3500 K, neutral white with a colour temperature between 3500 K and 5000 K and cold white with a colour temperature of more than 5000 K. In the Nordic region neutral white light is often perceived as cold.

For this study we recreated four representative lighting scenarios in 1:1, from a larger series of scenarios used in teaching fundamental lighting design (Fig. 02):

A Diffuse cold daylight
B Warm white spot and diffuse cold daylight
C Warm white spot and neutral white wall wash (vertical lighting)
D Warm white spot and neutral white spot and neutral white wall wash

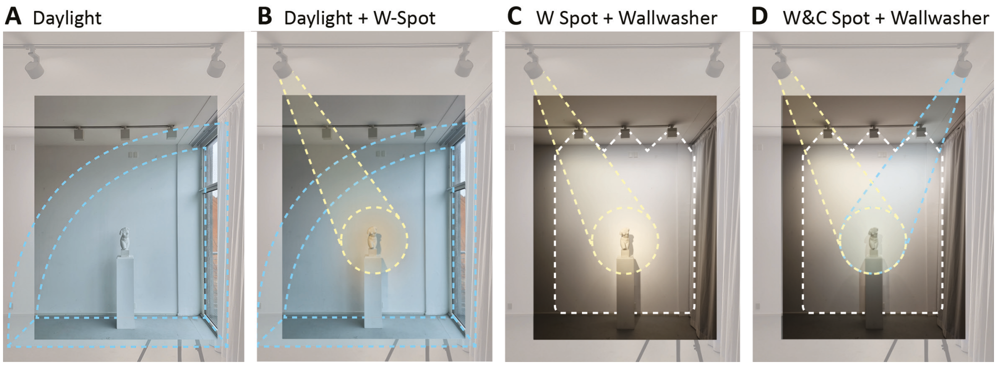

Fig. 02. Lighting scenarios A, B, C & D
Source: Authors

Three different LED light luminaires were used in combination with and without daylight (Table 01)[1,2] (see weblinks). ERCO spotlights use high quality LEDs and are widely used in museum lighting.

Table 01. Light sources 1:1

1:1	Luminous flux	CCT	Manufacturer part number
ERCO Parscan Spotlight (Warm white)	1042 lm	2700K	25999.000
ERCO Parscan Spotlight (Neutral white)	1042 lm	4000K	25999.000
ERCO Pantrac Lens Wallwash (Warm white)	694 lm	3000K	77766.000

Source: Authors.

1 Luminous flux is the total amount of light emitted from a light source and is meassured in the unit lumen (lm).
2 Correlated color temperature (CCT) is a one-dimensional metric that aims to quantify the perceived visual quality of nominal white light sources.

The two ERCO Parscan spotlights of different colour temperatures defined an illuminated oval of 110 cm width on the back wall in scenario B, C and D. The ERCO Pantrac wall washer used in scenario C and D created reflected vertical back light to tone down shadows for a less dramatic scenario (Fig. 03).

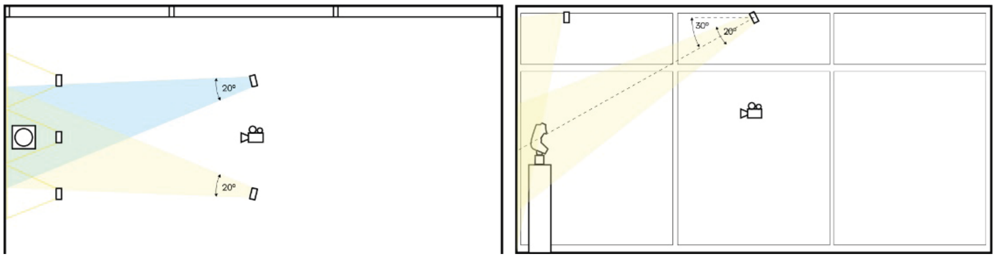

Fig. 03. Lighting setup. Plan left, Section right
Source: Authors

Shadow shapes and intensity were photographic registered and approximate colour temperatures were measured with a Sekonic C7000 spectrometer in front of the exhibition object and in the shadows in all four lighting scenarios to indicate the effect of light mixing (see weblinks) (Fig. 04).

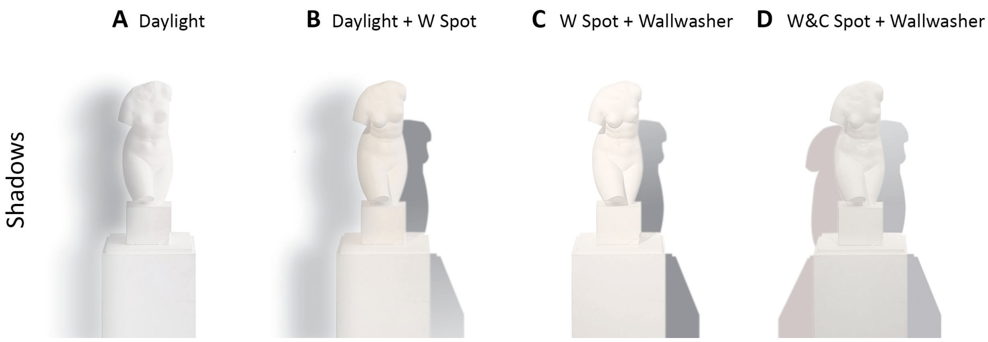

Fig. 04. Shadows
Source: Authors

Scales

There is a long tradition of using physical scale models for dayligt and shadow studies, since daylight is perceived precise at any scale without having a reference for size. And the scale models are still legitimate in evaluating the perceived qualities of day light compared to digital simulations (Bertram, 2012). Artificial light on the other hand is not perceived as scale less and vary in intensity depending on the distance to the illuminated object or area. In this study we experimented with and compared scaled LED lights.

The four lighting scenarios were established in three scales: A 1:1 studio equipped with ERCO luminaires for reference, a 1:10 detailed scale model and a 1:20 rough scale model both equipped with scaled LED lights.

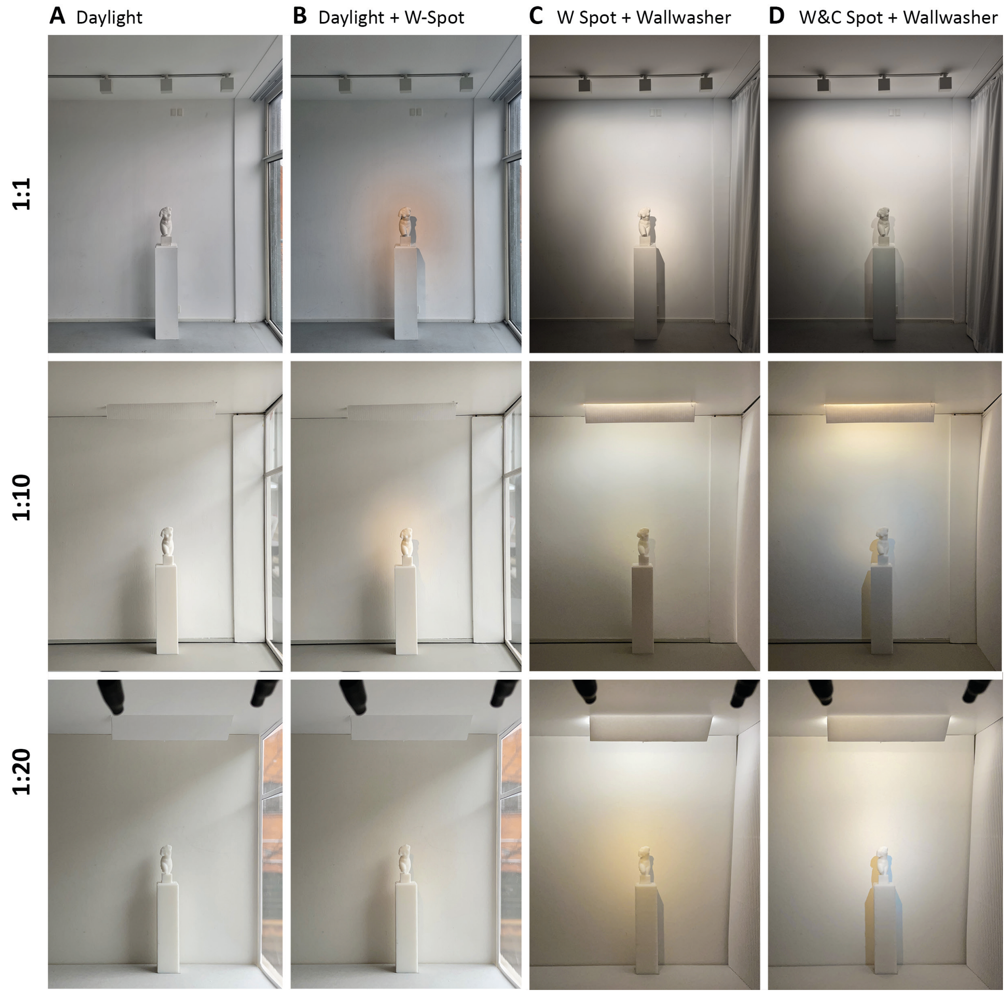

Fig. 05. Lighting scenarios A, B, C & D.
Source: Authors.

The 1:20 scale model size is widely used by students for daylight assessment and final presentations but has not to our knowledge been tested for sketching conceptual interior LED lighting design.

For the scale models we constructed spotlights by assembling round 5mm UHB LEDs with convex fronts and wires with heat shrink tubes and power glue. The LEDs were powered with CR2032 Lithium coin cell batteries. T5 LED tube lights were used as wallwashers and mounted on top of configurable cardboard ceilings with slits for vertical reflected lighting in the 1:20 as well as the 1:10 scale model (Fig.05-06) (Table 02) (see weblinks).

Fig. 06. Lighting parts
Source: Authors.

Table 02. Light sources 1:10 & 1:20

1:10 & 1:20 model	Luminous flux	CCT	Manufacturer part number
5mm UHB LED (Warm white)	1,61 lm*	3000K	OSM54K5111A
5mm UHB LED (Neutral white)	1,61 lm*	5500K	LRR5UW5C200G
LED T5 (Neutral white)	340 lm	4200K	LST5442
* Converted from mcd			

Source: Authors.

The gypsum Venus torso was scanned with an Artec Space Spider 3D scanner and the 3D mesh was refined and prepared for 3D printing in Rhino v6. The 1:10 and 1:20 models were printed with warm white 1,75 mm PLA filament on a Prusa i3 MK3S 3D printer (see weblinks).

Representation media

We photographed 360° panoramas of all four scenarios from a visitor's point of view in scales 1:1, 1:10 and 1:20 as well as supplemental perspective photography with smartphones. The Theta Z1 360 camera (see weblinks) used to capture 360° panoramas was placed on stands in different heights to achieve a correct scaled eye height eqivalent to 160 cm at the lens centre (Leyrer et al., 2011). The stands were designed to leave minimal visible footprint in the 360° panorama after the automatic stitching (Kreutzberg & Bülow, 2019). The 1:10 stand was crafted in wood and the 1:20 stand was 3D printed (Fig. 07).

Fig. 07. ThetaZ1 camera stands 1:10 – 1:20 and 360° panorama from 1:1 exhibition scenario.
Source: Authors.

The Theta Z1 camera is small and easily fit into scale models of sizes 1:10 and 1:20. The camera was operated remotely by a wifi connected smartphone.

For capturing the mixed light scenarios with optimal colour balance, test series with White Balance settings from 2700K to 4000K in steps of 100K was shot at all scales.

Perception methods

The perception of space is bodily grounded, we estimate heights and lengths as well as the distribution of light in space from our own body height and eye height, standing as well as seated (Corujeira & Oakley, 2013).

We used the photographed 360° panoramas of all four scenarios in all scales and compared the perception of the lighting scenarios from their equivalent position in all scales in VR and on screen in VR single view.

We specifically evaluated the perceived quality of light distribution, shadows, light temperature (colour), balance, and intensity.

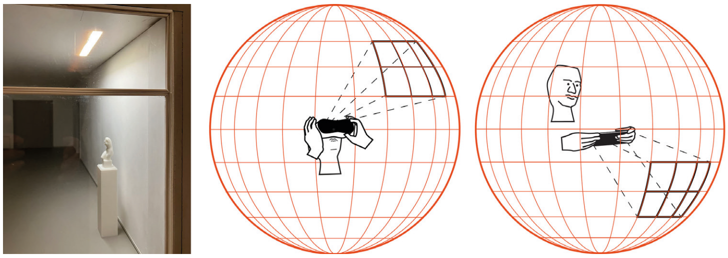

Fig. 08 Direct view, VR view and VR single view.

Source: Authors.

We evaluated direct view through windows of the scale models when possible. Perspective photographs were evaluated on smartphone and computer screen, and 360° panoramas were evaluated with smartphone VR with or without optional Homido Clip-on HMD (Fig. 08) (see weblinks).

Findings and Discussion

The experiment set out to test whether conceptualised directed LED spotlights are perceived identically at different scales in physical models with special interest in the smaller scale 1:20. The aim was to introduce fast and iterative workflows for experimenting with scaled directed lighting in spatial design with (often existing) scale models to supplement digital design tools.

Our focus was the perceived qualities of light distribution, shadows, light temperature (colour), balance, and intensity.We did not consider glare from a glass exhibition case since it was not part of the set up.

Light distribution

Several experiments with different approaches were made to create the scaled LED spotlights. 3D printed casings and soldering wires was the initial setup but using heat-shrink tubing in combination with power glue was easier to manage and much quicker to adjust in an iterative test process. Varying the ⌀ size of spotlight cones was achieved with either adjusting the length of the tube by moving the UHB LED further in or out of the tube or heat-shrinking the tube edge to a smaller ⌀ size (Fig.09).

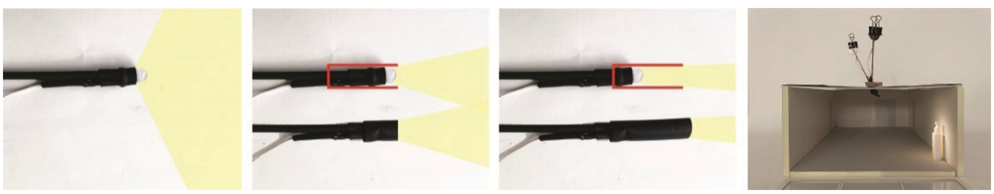

Fig. 09. Adjusting light distribution

Source: Authors.

Adjusting the direction of the ceiling mounted spotlights inside both scale models were managed by rotating the heavy copper wire, but proved to be difficult to evaluate due to limited visual access through the windows in the scenarios with occluded daylight. A solution was to connect a live broadcast from a smartphone or the Theta camera.

Shadows

Fig.10 Shadows in three scales.
Source: Authors

In scenario A the shadow from the diffuse daylight was very soft and subtle and was scaled to 1:10 and 1:20 with no perceived difference (Fig. 10).

In scenario B combining daylight with a warm white spotlight the daylight shadow was colored by the warm spotlight. The spotlight shadow was crisp and distinct and slightly colored by the cooler daylight. In the scale models the daylight dimmed the spotlight shadows more than in the 1:1 setup.

In scenario C combining a warm white spotlight with a neutral white wall washer the spotlight shadow was also crisp and distinct and was slightly dimmed by the wall washer. In the 1:10 scale model the wall washer dimmed the spotlight shadow more than in the1:20 scale model and in the 1:1 setup.

In scenario D the shadow from the warm white spot occluded from the warm white light is lit by the neutral white spot and therefore shifts the perceived shadow colour towards a cooler blue & purple whereas the shadow from the neutral white spot occluded from the neutral white light is lit by the warm white spot shifting the perceived shadow colour towards a warmer orange and red (Baxandall, 1995). The neutral white wall washer contributed to dimming of shadows as in scenario C.

Light temperature/colour

The light temperatures and colours of the Warm White and Neutral White ERCO Parscan LED spotlights (2700 K & 4000 K) used in the 1:1 lighting scenario were visually matched within acceptable range with the UHB LEDs (3000 K & 5500 K).

The T5 LED tube lights with a colour temperature of 4200 K used in the scale models were perceived as cold compared to the ERCO Pantrac wall washer with a warm white 3000 K colour temperature. The light colour was adjusted by mounting colored filtering paper over the cut ceiling slids.

Intensity

Contrast is a very important factor in perceiving brightness and balance of lighting. The eyes can adapt to different light levels as can the camera with exposure value settings (Reeves, 2009). It is in the contrast we perceive the difference of varying light intensities. The UHB LEDs used as spotlights only have a Luminous flux of 1,61 lm which made it necessary to establish relatively dim lighting scenarios.

Balance

Working with the mixed lighting scenario B including daylight was challenging because of the big difference in brightness between daylight compared to the UHB LEDs. Several dimming and shading solutions were therefore tested and evaluated, most effective was moving the scale model further into the room and away from the daylight contributing window to lower the daylight intensity.

The mixed lighting scenarios C & D simulating spotlights and wall washer were challenged with very different luminance levels of the LEDs (Table 02). The T5 tube LED representing the wall washer having a luminance of 340 lm, more than 200 times the 1,61 lm of the UHB spotlights. Dimming was achieved by placing the T5 tube at varying distances next to the cutaway in the ceiling only allowing reflected light from a mounted reflector flap. Stacking layers of paper or cloth over the cutaway also contributed to dimming as well as to color correction of the light.

Perception

Initial assessments as well as iterative changes of light distribution and light balance in the 1:10 and 1:20 scale models were done in real-time from the smart phone 360 display when connected to the Theta Z1 camera placed inside the models. Connecting a tablet to the camera instead of a smart phone provided a larger screen for monitoring alowing more people to view and evaluate at the same time. The captured 360 panoramas were viewed with clip-on VR glasses for a more spatial experience of the scenarios. When comparing the lighting scenarios for evaluating their resemblance in this experiment perspective images were used captured with a remotely controlled smartphone (Fig.04 & 09).

Conclusion

Comparing the 1:1 exhibition lighting scenario with the scale models showed slight differences in perceived qualities of all parameters evaluated; light distribution, shadows, light temperature/colour, intensity and balance, but taking into account the quick and iterative workflow with often existing scale models we found the perceived qualities of directed LED light in both the 1:10 and the 1:20 scale model to be adequate as a starting point for conceptualising object lighting design.

The smaller 1:20 scale model proved to perform very well with the relatively dim UHB LEDs because of the short distances between emitting lights and lit objects. In the mixed light scenarios dimming of diffuse daylight and wallwasher were easily manageable whereas the larger 1:10 model required more dimming of diffuse daylight and wallwasher to achieve a balanced lighting.

It is crucial to note the importance of having balanced lighting when evaluating the perceived quality of light distribution and intensity in scale models, especially when combining several light sources with different luminous flux. For this a 1:1 reference mock-up is ideal support in choosing and modifying the scaled light sources, although not always accessible for students.

The proposed lighting parts can easily be introduced and fabricated during a workshop as starting point for individual student projects with object lighting.

Demonstrating a larger variety of mixed lighting experiments in scale models for students would didacticly benefit from flexible adjustment of light intensity, temperature and colour achievable when connected with a programmable electronic prototyping platform like Arduino (see weblinks), this could also inspire to work with more advanced dynamic lighting designs.

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