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ORIENTATIONAL EFFECTS ON SOILING MEASUREMENTS AT THE SHELDONIAN THEATRE IN CENTRAL OXFORD, UK

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ABSTRACT

A digital camera was used to photograph images around the Sheldonian Theatre, which is a semicircular building located in central Oxford, UK. Close-up images included a color chart for lightness and chromatic calibration across images taken between 10:00 and 13:00 in the spring in order to obtain comparative brightness levels for vertical limestone surfaces around this historical building. A digital light (Lux) meter was also employed in this study to capture variations in incoming sunlight onto building walls at ground-level. The outdoor integrated digital photography and image processing (O-IDIP) method was used, focusing on orientational effects on the lightness and coloration of surfaces. Images in Lab Color were calibrated based on a 3-point (black-white and green-red) procedure. The results convey the brightest surfaces on average to be west-facing. Conversely, the most variation in the means was evident on the east-facing side of the building and lowest on the west wall. These variances convey the effects of piecemeal maintenance of the building, so that on the same wall the lowest and greatest values of calibrated % Mean L *appear. Soiling patterns are affected by microclimatic effects, with wind-driven rain in Oxford coming predominantly from the southwest, affecting buildings differently at the regional to local scale. This means that south- and west-facing walls may be relatively more rainwashed than north- and east-facing walls, which could complicate the results as a confounding variable acting on the degree of soiling and surface brightness. However, Lux meter readings helped to clarify this complication, showing the least illumination on west- and south-facing building walls. The study, hence, contributes to disentangling between and elucidating outdoor lighting conditions and soiling patterns imposed by microclimatic effects on vertical (limestone) surfaces, such as this historical building exterior, where the brightest illuminated surfaces are not west-and south-facing, but rather east- and north-facing. It thereby quantifies the extent of brightness ranges in soiling patterns created by rainwashing (exposure versus sheltering) effects. Finally, the 3-point calibration procedure now integrates chroma as well as brightness and contrast adjustments, allowing for the outdoor measurement of areal chromatic change on building exteriors. The building walls in this study are mainly Slightly Dark and only a minority are actually classifiable as Dark.*

Keywords: Quantitative photography, O-IDIP, Soiling, Chromatic change, Limestone, Historical buildings.

Contribution/ Originality

This study contributions to the quantification of building soiling in polluted (urban) environments. Rather than using point-source measurements, the O-IDIP allows for the areal quantification of color. Its application allows for the differentiation of microclimatic effects on outdoor lighting (orientational effects) and surface brightness and coloration.

1. INTRODUCTION

Buildings are susceptible to stone decay as they are exposed outdoors over time. Earlier research investigated the soiling of buildings, and much work was performed that specifically investigated soiling patterns, such as on Venetian historical buildings [1]. Dark encrustation is known to trigger surface darkening on building exteriors, and this (in combination with granular disintegration) can be produced by a variety of physical (environmental humidity and microclimate, orientation, wind-driven rain, etc.) and chemical (wetting, pollution, etc.) factors. Orientation is one of two (the other being prevailing weather) notable physical factors affecting historical buildings, as found at Salem Abbey in Germany [2]. It is not enough to study soiling, however, as soiling patterns themselves are known to affect the human perception of architecture, and it has been suggested that both the level of soiling and its distribution (or soiling pattern) be examined [3]. Whereas soiling occurs relatively rapidly, the (natural) rainwashing of stone takes much longer (decades), particularly towards the top (at higher elevations) and corners of buildings that face the direction of wind-driven rain, as towards the west (southwest and northwest) at the Cathedral of Learning on the University of Pittsburgh campus [4], and this can establish soiling patterns visible on building exteriors. Modeled results at the Cathedral indicated that sections of the building exterior that received the most rain were "white areas" [5], and this corresponds well to Fassina's [1] "whitewashing" of surfaces. Also affecting these surface soiling patterns are parameters associated with the building fabric, including any treatments (cleaning or surface coatings), and more quantitative research has been encouraged recently to investigate the influencing variables of rainwater runoff [6]. Rainwashing is a competitive process with the soiling of building facades by anthropogenic particles and natural dust [7]. In this study [7], soiling predominated in an atmosphere laden with black dust, and an equilibrium has been attained more recently with improved air quality. Hence, the period of accumulation is an important consideration in the determination of surface soiling. Some authors have already given notable consideration to period, as of karst weathering in London between 1100 and 2100 CE [8].

This study continues to contribute towards the development of the O-IDIP method for the outdoor quantification of lightness and color change. Its anticipated contribution, and the overarching aim of this study, is to quantify the impact of wall orientation on (outdoor) illumination and color quantification (measured surface reflectance or albedo). The specific objectives of the study are: 1) to adopt a calibration procedure for lightness (with adjustments made to brightness and contrast); 2) to add a novel calibration procedure for color (based on measurements of red on a color chart); 3) to measure outdoor lighting using a Lux-meter; 4) to measure orientation and ascertain its impact on the lightness output; and 5) to compare the results with an existing soiling scale in order to link measured and perceived soiling.

2. METHODS

The Sheldonian Theatre, located in central Oxford, was visited between 10:00 and 13:00 on 08 June 2014 in order to conduct a photographic survey under clear-sky conditions. All sides of the building facade were photographed using a tripod-mounted digital camera, specifically a FujiFilm (Finepix) J32 with 12.2 megapixels (M) with flash off and macro on at 3-M image resolution. The camera consistently captured images with dimensions of 2,048 × 1,536 pixels (a total of 3,145,728 pixels), representing roughly 0.80 × 1.20 m of wall. The tripod was set level to the ground surface at 1.06 m each time in front of the building walls and 1.04 m above ground-level.

Photographic sites were selected along the building exterior (Fig. 1), where its walls were relatively flat and devoid of architectural features (where possible). A compass reading was taken of the direction which the building wall faced (for orientation or aspect measurementation) at each site. These were later converted to represent east (45 to 134°), north (315 to 44°), west (225 to 314°), and south (135 to 224°). In this way, Sites 1 to 4 were east-facing; Sites 5 to 20 faced north; Sites 21 to 27 were west-facing; and Sites 28 to 35 faced south. In addition to orientation measurements, a digital light (Lux) meter (LX-1010B) was deployed in the field at a sampling time of 0.4 seconds and Lux ranges of 50,000, with a resolution up to 100 Lux and accuracy at 25°C ±3°C of ±5% + 2d. The instrument was calibrated to standard incandescent lamp at color temperature 2,856 K.

Photographic pairs were taken at each site, one depicting a Gretagmacbeth ColorChecker™ Color Rendition Chart to be employed in the calibration process. For calibration, original JPEG images were first converted to Lab Color in Adobe Photoshop and an uncalibrated histogram output was recorded for the image excluding the color chart. The calibration procedure involved selecting the white and black samples contained in the photographed color chart using the Color Sampler Tool. One sample of each of white (19 on the color chart for white (0.05*)) and black (24 on the color chart for black (1.50*)) were derived for lightness calibration and another of red (15 on the color chart) for chromatic calibration (a maximum of four samples are possible using this tool). Lab Color data needed to reflect lightness (*L*) measurements of 97 for brightness and 20 for contrast (out of 255); for the chromatic calibration procedure, red measurements needed to equal 42/53/28 for *L*/*a*/*b* Color. Error was determined for lightness measurements (of soiling) specifically by recording deviations of *L* data for red. Histogram data were obtained for each photograph (devoid of the color chart) after calibration; these are the calibrated values and include

Mean, Median, and Std Dev. Proportions of these were calculated by dividing the raw data by 255 and multiplying by 100 to obtain a percent for comparison.

3. RESULTS

The appendix at the end of this paper includes both uncalibrated and calibrated results for this study. A total of 35 sites were photographed around the Sheldonian Theatre, including four on the east-facing portion of building wall (between 65 and 84°); 16 facing north (between 5 and 350°); seven facing west (between 245 and 310°); and eight facing south (between 164 and 178°). Lux-meter readings also appear in the appendix for each site; they are depicted in Fig. 2). Least outdoor illumination was measured (on the day of the fieldwork) on the west- and north-facing walls of the building, although there were some high measurements along the north-facing section of wall (at Sites 1 and 2), indicating some variance here; most light was measured on the east- and north- facing walls (see Fig. 2). Both uncalibrated and calibrated measurements of Lab Color are shown (in the appendix) based on a total of 70 digital photographs. Calibration generally improved *L* (both Mean and Median values, which tended to be strongly (positively) correlated in this study, as well as Std Dev). Lightness increased at nearly two-thirds of sites (i.e., at Sites 1, 2, 5, 7, 8, 10, 12, 15 to 27, 29, 30, and 35). Chromatic values showed some tendency towards greening (reduced *a*, as at Sites 4 to 6, 8, 9, 12, 28, 31 to 35) and yellowing of surfaces (increased *b*, as at Sites 2, 3, 9, 10, 12, 13 to 18, 20, 24, 29, 32, and 33). In some cases, there was some bluing (reduced *b*, as at Sites 4 to 6, 30, 31, and 35). There were some instances where there was no significant change produced by the calibration process (e.g., Site 11). Std Dev values remained mostly unchanged for *a*, but were often greatly inflated for *b*.

For *L*, adjustments were mainly in the negative direction (Fig. 3a). East-facing sites required total adjustments (positive minus negative) of 26; north-facing sites were adjusted by -8 in total; west-facing sites by -2; and south-facing by a total of -53 (a grand total of -37, conveying an overall reduction in *L* through calibration). Reductions in the green-red (*a*) color spectrum were -16 for east-facing sites, -108 for north-facing, -39 for west-facing, and -188 for south-facing sites (a grand total of -351 for *a*). This indicates a greening of most sites in the calibration process that is especially pronounced at north- and south-facing sites (Fig. 3b). Along the blue-yellow (*b*) spectrum, 43 increments were made to east-facing sites, 210 for north-facing, 36 for west-facing, and 20 for south-facing sites (for a total of 309), all promoting a yellowing of images, particularly at north-facing sites (see Fig. 3b). Overall Color Balance alterations consisted of 27 changes to east-facing sites, 104 for north-facing, -3 west-facing, and -168 for south-facing sites (a grand total of -40). Total adjustments comprised 53 at east-facing sites, 84 north-facing, -1 west-facing, and -221 at south-facing sites (for a grand total of -85 positive and negative adjustments to lightness and color). This denotes a reduction in lightness (as well as greening and bluing) that is evident particularly at south-facing sites (Fig. 3c). The calibration process had an error margin up to 7% tested on lightness.

The orientational averages of % Mean *L* (Table 1) convey a greater lightness (of 73.36%) on the west-facing wall, where there is the least variance (St Dev = 4.77%). The greatest amount of variance appears, conversely, on the east-facing wall (11.49% on average), and is where the highest (79.01%) and lowest (52.30%) lightness values can be found. The lightness results (for *L*) do not convey a consistent pattern associated with orientation. Some more general trends can be discerned; for instance, calibrated lightness values appear greater on the west-facing portion of the building (Fig. 4b), where lightness values exceed 70%. Lower values (in the 50%s) of *L* are frequently evident on the south-facing side of the building (e.g., Sites 31, 33, and 34); however, this is also the case at some north-facing sites, including Sites 10, 12, and 14 (also in the 50%s; see Fig. 4b). Std Dev *L* values are generally low, but are most inflated at north-facing sites, such as Sites 5 to 7 (where values are between 15 and 20%). Lighting measurements (using a digital Lux-meter) on the day of the fieldwork (see Table 1) convey greater averages on north- and east-facing sides of the building (and are lower at south- and west-facing sites). Variances apparent within these measured averages are highest at south- and east-facing walls.

The chromatic values also convey similar patterns around the building exterior. For instance, lower values of *a* (denoting more greening) appear at Sites 9 and 12 (north-facing). However, Sites 28, 31 to 34 (which are south-facing) are also greener (in the high 40%s) than the rest. The redder sites (in the low 60%s) are visible also along the south-facing portion of the building (at Sites 5 to 8) and on the west-facing side (Sites 25 to 27; Fig. 5b). Yellowing is evident at some north-facing sites, including Sites 5 to 9, where values are in the low 60%s (Fig. 6b). This similarly occurs at Sites 26 to 28 and 33 to 34, which are west- and south-facing, where values are also in the low 60%s. The greatest amount of yellowing is evident at Sites 3 (64.26%) and 33 (64.10%). On the other hand, bluing can be seen on images taken at Sites 1, 11, 33, and 34, where *b* values are as low as 50.59 and 50.98% (see Fig. 6b). This occurs on a variety of orientations, including east-, north-, and south-facing.

4. DISCUSSION

The calibration process seems to have successfully corrected the lighting and color of the images, improving their appearance (as evident in the appendix images). It has not inflated lighting values where more light is shed on walls, as on east- and south-facing walls. Even though some sites where more light is shining also have greater *L* values, for instance at Sites 1 and 11 (both with values in the 70%s), most west-facing sites (with lower light readings) had high *L* values, such as at Sites 21, 25, and 27. The method also picks up on some trends that would be expected, such as greening (with algal colonization on wetter portions of wall [9] on north-facing sections of the building (evident at Sites 9 and 12).

Greening that appears elsewhere (such as at south-facing Sites 28 and 31 to 34) could be due to microclimatic effects associated with sheltering from other buildings surrounding the Sheldonian Theatre (namely, the Bodleian Library), which block light getting to its southern facade. Moreover, since wind-driven rain in Oxford is from the southwest [10], it is expected that more darkening would be observed on east- and north-facing surfaces. This is the case at Sites 2, 10, 12, 14 as well as, however, at Sites 33 and 34, which are south-facing; these sites have L values in the 50%s. The darkening evident at south-facing sites could be attributable to algal colonization (greening due to biological soiling).

It is, hence, necessary to recognize different types of soiling: 1) from encrustation and 2) the development of biofilms. Antill and Viles [11] observed different colors of crusts on the Worcester College boundary wall in central Oxford, including brown crusts that could be evident here through a yellowing of surfaces. Török [12] similarly performed work on the encrustation of limestone walls in Budapest, Hungary and identified different types of crusts (laminar versus framboidal), which could be linked with crust thickness and development. Thornbush and Viles [13] previously also noted the effects of biological colonization on soiling patterns located on stone sensors (with the transformation from speckled to spotted soiling patterns).

This study reveals that it is important to consider multiple variables in an outdoor setting responsible for soiling patterns evident on building facades. It is clear, for instance, that microclimatic effects (such as wind-driven rain from the southwest) alone do not account for the patterns seen here, which could be complicated by local (rather than regional) wind flow patterns produced by sheltering by nearby buildings acting as obstacles to air flow and ventilation (as the Bodleian Library to the south). Research, for instance [14], suggests that moisture is key for the development of biofilms on surfaces, and this could be governed by microclimate. Previous research by Thornbush [15], however, did not find any significant differences in the greening of north- versus south-facing walls in central Oxford, and further research was needed, especially considering work by Arkell [9] that suggested that greening should appear with algal colonization on north walls. Other more recent research [16] has supported this observation by denoting directional changes associated with the appearance of biological colonization (of algae, moss, and lichens) on north- versus south-facing sides of a roadside string course on the High Street in central Oxford. The importance of air pollution, however, cannot be overstated (as for affecting lichen growth), as air-pollution improvements can trigger biological soiling, as evident in this study at south-facing sites, particularly as this building is removed from any busy roadways. This has been conveyed by Thornbush and Viles [14] in their analysis of fungal colonization before versus after a major transport scheme in the Oxford city center, as it promoted the development of biofilm on stone surfaces.

It is difficult to establish connections between quantified levels of soiling and perceived (qualitative) soiling. For instance, people have been known to regard surfaces as visibly soiled when lightness drops below 50% [17]. However, this level of soiling is evident nowhere (for calibration lightness measurements) along the exterior of the Sheldonian Theatre, where the lowest lightness measurement was 52.30% (at Site 2, facing eastward). Nevertheless, some sites do appear to be soiled, such as Sites 2, 10, 12, 14, 18, 31, 33, and 34. So, there is a subjective element to soiling perception, which was addressed recently by Thornbush [18]. According to the Thornbush soiling index (TSI), perhaps 50% is too conservative a cut-off (threshold) measure for soiled surfaces and it should be raised up to 60% of calibrated lightness, which is level 3 in her 5-point scale devised at a west-facing (uncleaned) building facade located at Balliol College in central Oxford. Most of the sites in the current study (except for Sites 2, 10, 12, 14, 18, 31, 33, and 34, which score 2 on the TSI) classify as level 3 on the TSI (greater than 60%) and appear relatively unsoiled. This means that the scales of the TSI can be linked with soiling perception as follows: Black (0 = 0%); Very Dark (1 = 20%); Dark (2 = 40%); Slightly Dark (3 = 60%); Light (4 = 80%); and Very Light/ Bright (5 = 100%). This perceived lightness corresponds well with Thornbush and Viles [13], who recognized Very Dark, Dark, Light, and Very Light (and were missing Black and Slightly Dark) based on % Median L values. This would mean that most of the sites in this photographic survey are classifiable as Slightly Dark (with some (eight of 35, or 23%) of sites as Dark). The brightest of all measured surfaces was 79.01% for calibrated % Mean L at Site 1 (east-facing), which falls just below the level 4 boundary (of 80%). The current study referred to % Mean L values; however, they were quite similar to Median values here (specifically, r = 0.979 for calibrated % Mean versus Median L; r = 0.977 for a; and r = 0.996 for b). For this reason, they can be used interchangeably in this study.

As caveats, this study did not consider the maintenance history of the building, and it should be assumed that blocks have been repaired and replaced piecemeal. Indeed, the exterior of the Sheldonian Theatre is well-maintained and does not appear to be soiled like other buildings that remain uncleaned in central Oxford. The age of individual stone blocks could complicate the findings. Also, stone type could be a further consideration, especially since Bath limestone was replaced by harder stone types in the city center [9], such as Clipsham and other llimestones. The coloration of these limestones would differ and could affect the results. Other influences could be anthropogenic, such as graffiti appearing on the exterior of buildings, as is somewhat apparent along the south-facing façade of this building; see, for instance, sites located along the southern building exterior (in the appendix), which have a reddish stripe through them that is somewhat visible and could indicate previous cleaning of graffiti (e.g., Site 31).

Regardless of such limitations, the research nevertheless makes a contribution towards the development of the O-IDIP method, particularly as concerns chromatic calibration. This was already conducted by Thornbush [19], however, the current study does not consider the impact of outdoor conditions based on overcast versus clear sky conditions, and rather actually measured lighting using a digital Lux-meter. Furthermore, the previous study did not examine different facade orientations, as it focused only on east- versus west-elevations along the southern front (along Beaumont Street) of the Ashmolean. Since the Sheldonian Theatre is set well back from the roadside, traffic flow (along Broad and Catte Streets) was not considered here.

This study has been conducted at the building scale, and this could influence the findings. For instance, Hall [20] examined granite and marble surfaces susceptible to bowing, and discovered that light penetration at the mineral-level depends on surface reflectance (albedo) as well as slope and even latitude. Materials exposed on southern aspects in the Northern Hemisphere may experience greater heat loadings at times other than in the summer, such as early and late in the year. More research is needed to examine more closely the impact of changing light levels on building surfaces throughout the year. This needs to be done in conjunction with consideration of biological weathering, as Hall [20] also noted the effect of light-transmissive minerals on subsurface biotic colonization. Other researchers, such as [21], found that facade orientation at a Portuguese granite historical building, the Third Order of St Francis Church in Porto, on the south facade were cyanobacteria, algae, and lichens associated with surface coloring and detachment. Since wall orientation is a crucial factor in biological colonization, such a quantitative approach as the one adopted in this study represents an important contribution to understanding interactions between light and aspect and microclimatic effects. Finally, this research is completely non-destructive (relevant for built heritage, cf. [22]) and the O-IDIP method can be employed in other studies relatively inexpensively and simply.

5. CONCLUSION

This paper represents another contribution towards the development of the O-IDIP method applied to building exteriors in order to measure soiling extent and patterns. It was possible to effectively conduct a 3-point calibration, correcting for lightness (through brightness and contrast adjustments) as well as chroma (through Color Balance along the green-red and blue-yellow color channels). Calibrated values appeared less bright, with greater Std Dev values; however, the latter did not reflect soiling patterns in this study to the extent that calibrated % Mean and Median *L* values correlated (in a strong positive linear correlation). Most importantly, the study tested for any orientational effects in this semicircular building in combination with outdoor illumination lighting readings derived from a digital Lux-meter. From this, it was evident that less lighting impacted west- and south-facing building walls on the day of the photographic survey. However, lightness results conveyed that surfaces on the south, for instance, were more soiled, so that the outdoor lighting conditions were not having an effect on the lightness results. Nevertheless, it was possible to discern variations in the type of soiling evident, from atmospheric emissions (air pollution) and the development of crusts as well as organics that have led to algal colonization and the greening of some (darker and wetter) sites through the establishment of biofilms on walls and biological soiling. Finally, it was possible to ascertain levels of surface darkening from less than 60% of calibrated lightness as corresponding with Dark (soiled) surfaces. Most sites in the current study were Slightly Dark, with only some Dark building walls that were less than 60% in lightness.

6. ACKNOWLEDGEMENTS

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Captions for Figures

Fig-1. Sites (1 to 35) of the photographic survey performed at the Sheldonian Theatre.

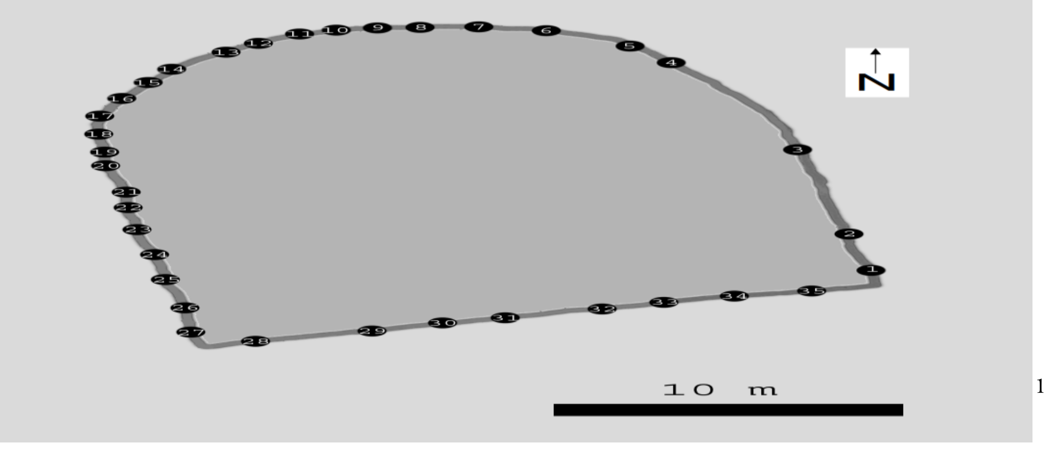
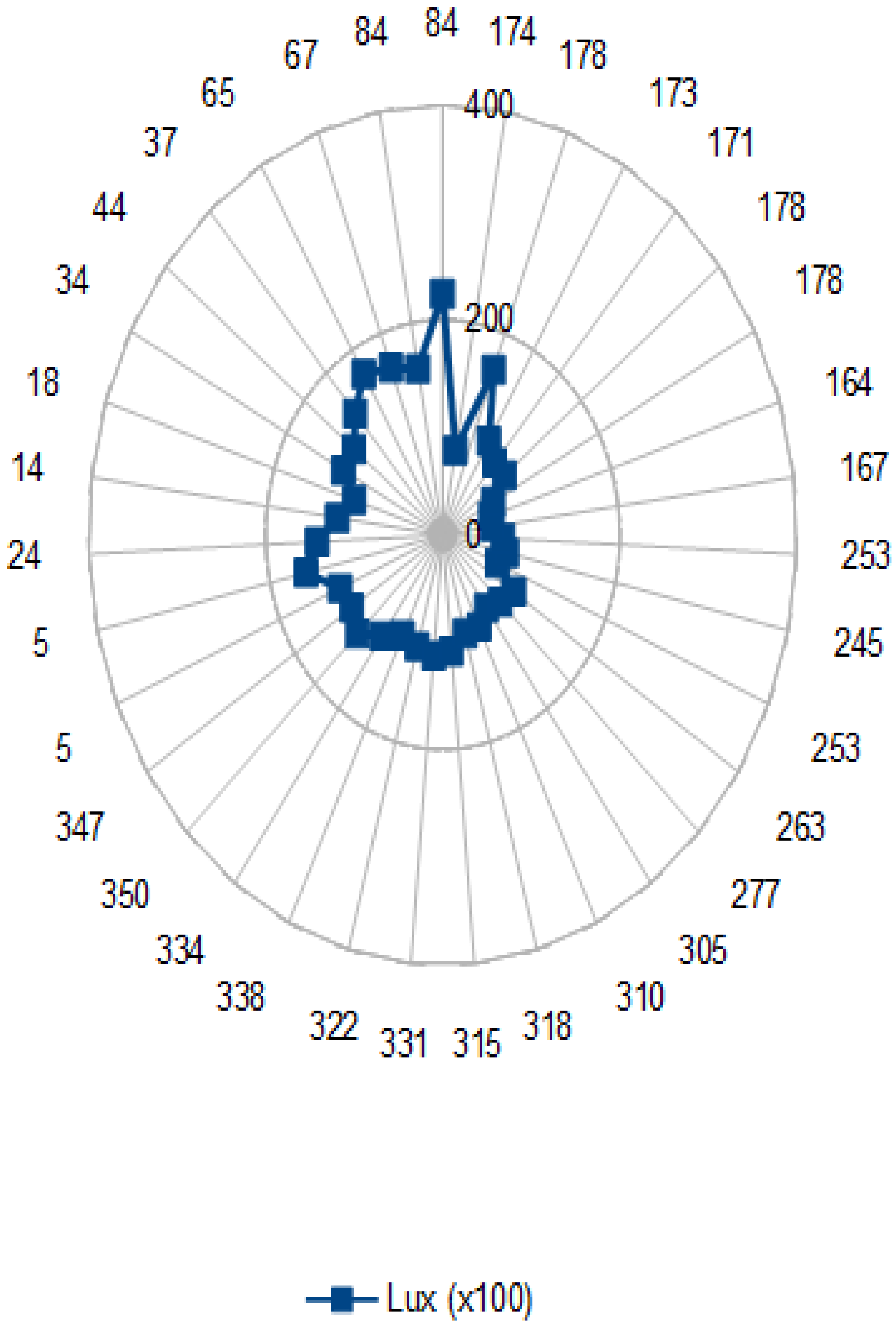
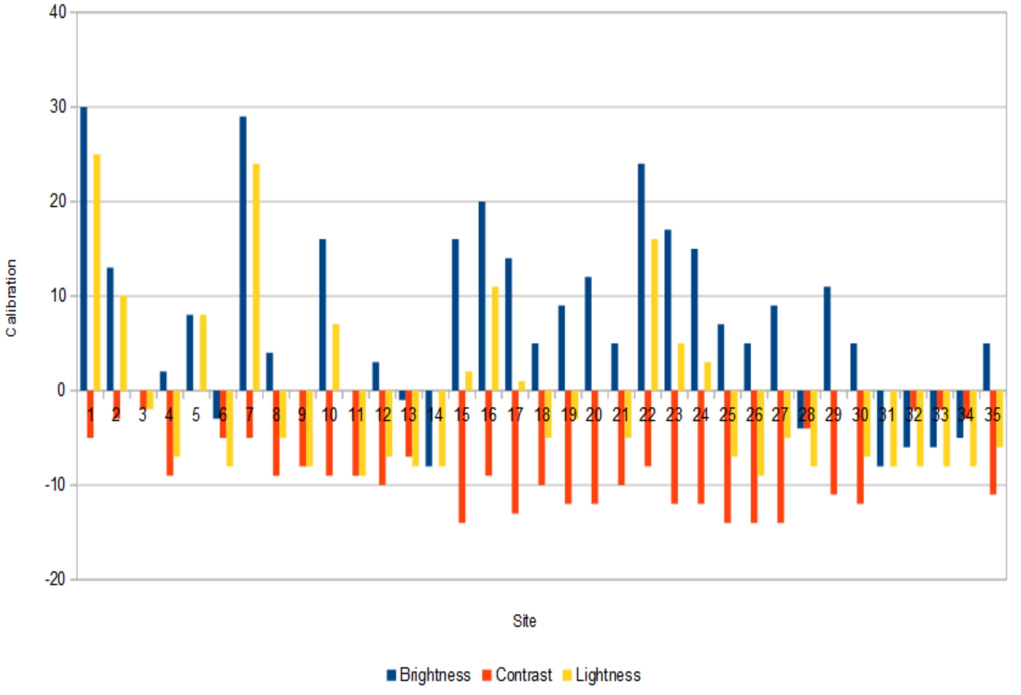


Fig-2. Digital light-meter readings at the different sites of the photographic survey.



(a)


40
30
20
10
0
-10
-20
Calibration
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Site
Brightness
Contrast
Lightness

(b)

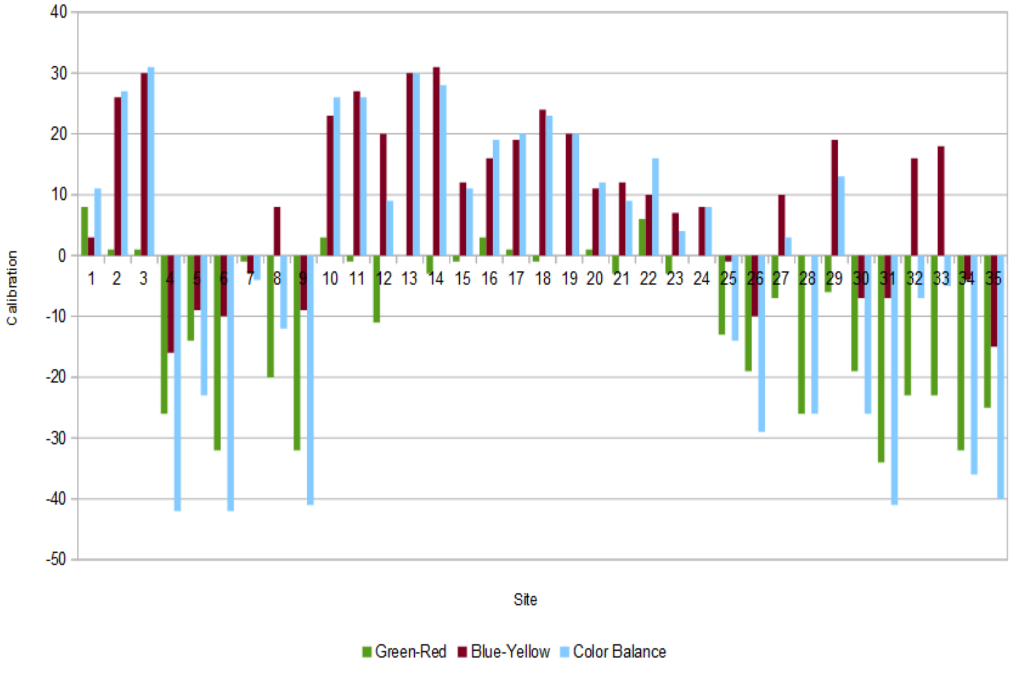
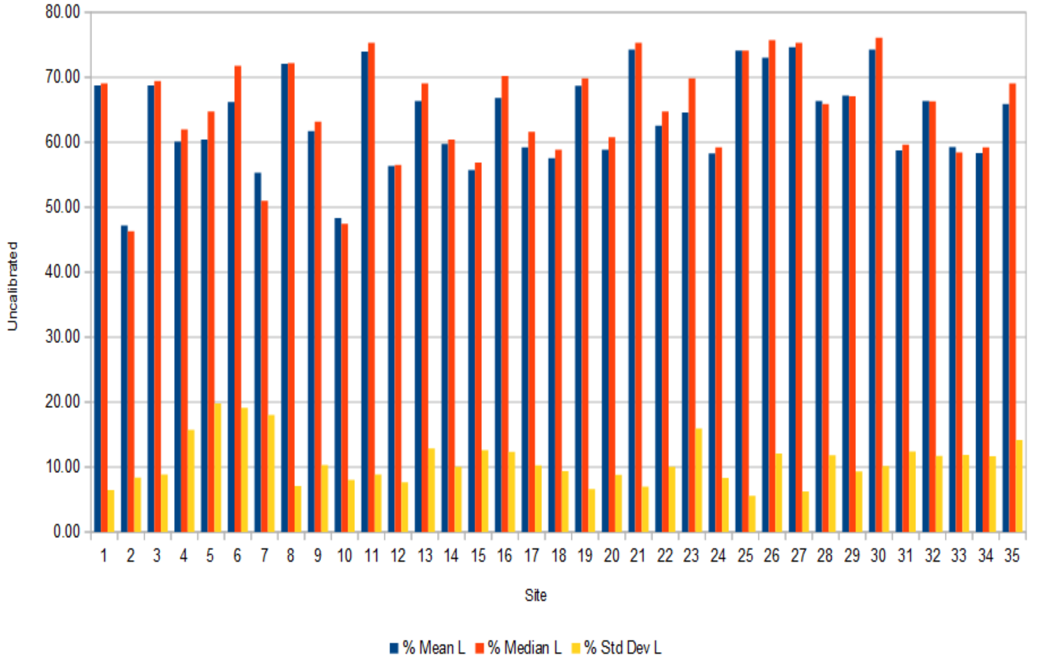

40
30
20
10
0
-10
-20
-30
-40
-50
Calibration
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35
Site
Green-Red
Blue-Yellow
Color Balance

Fig-3. Adjustments in the calibration process for lightness (*L*), including brightness and contrast parameters (*a*), as well as adjustments in Color Balance along the green-red and blue-yellow color channels (*b*).

(a)



(b)

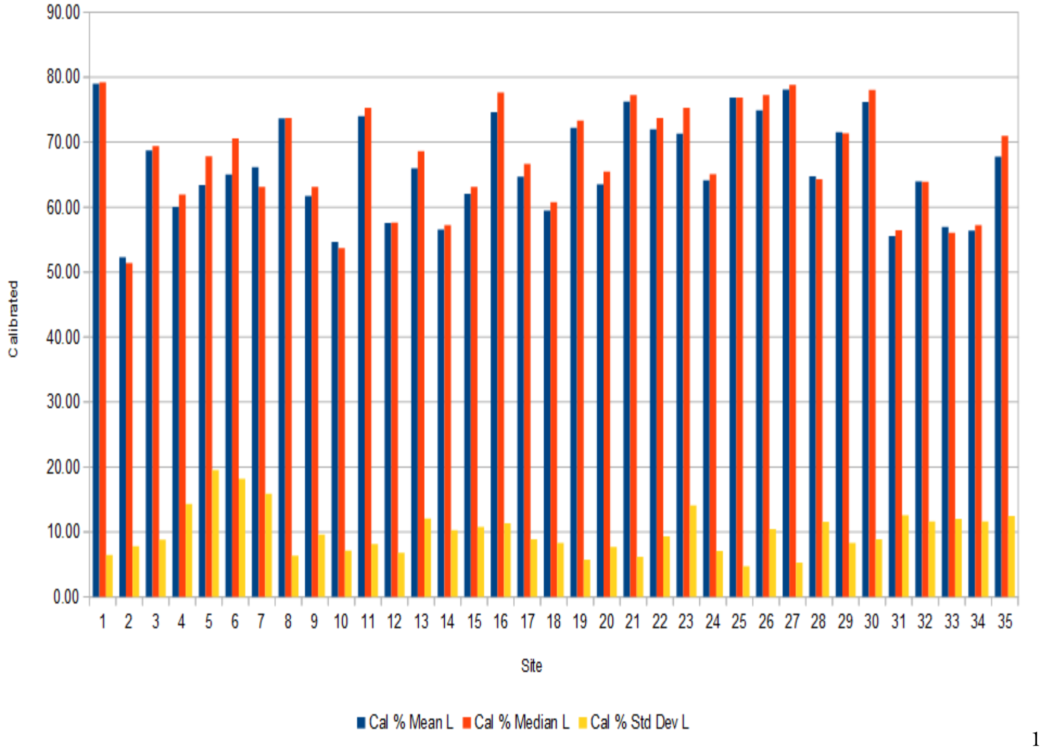
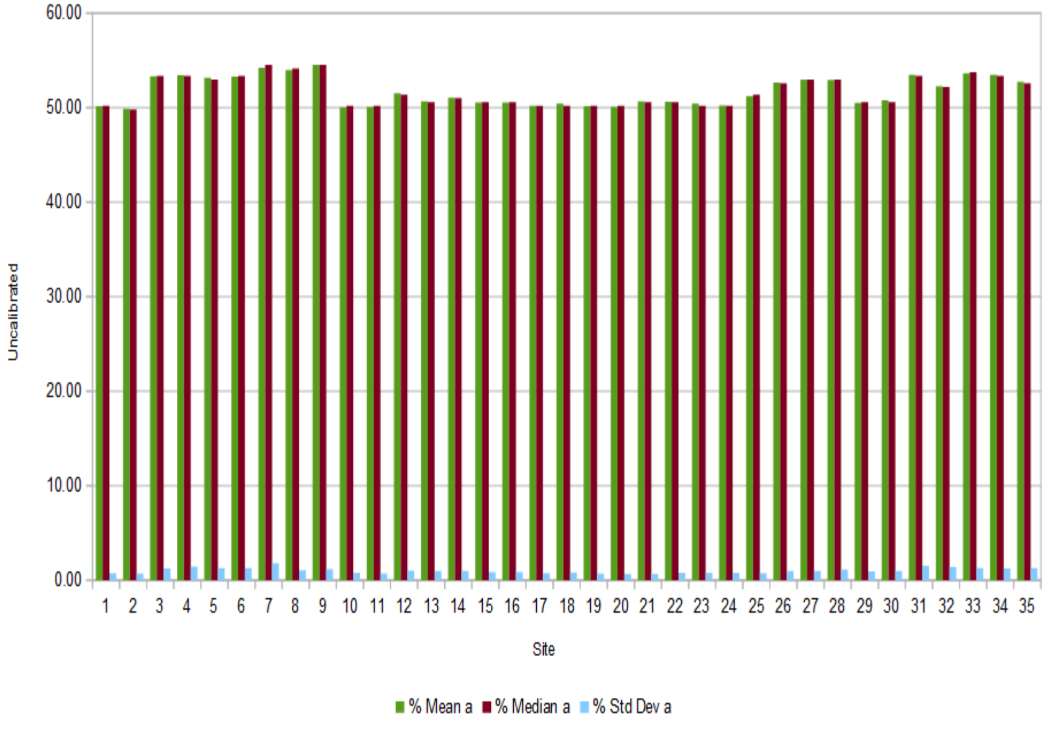


Fig-4. Uncalibrated (a) and calibrated (b) results for lightness (L), including % Mean, Median, and Std Dev values.

(a)



(b)

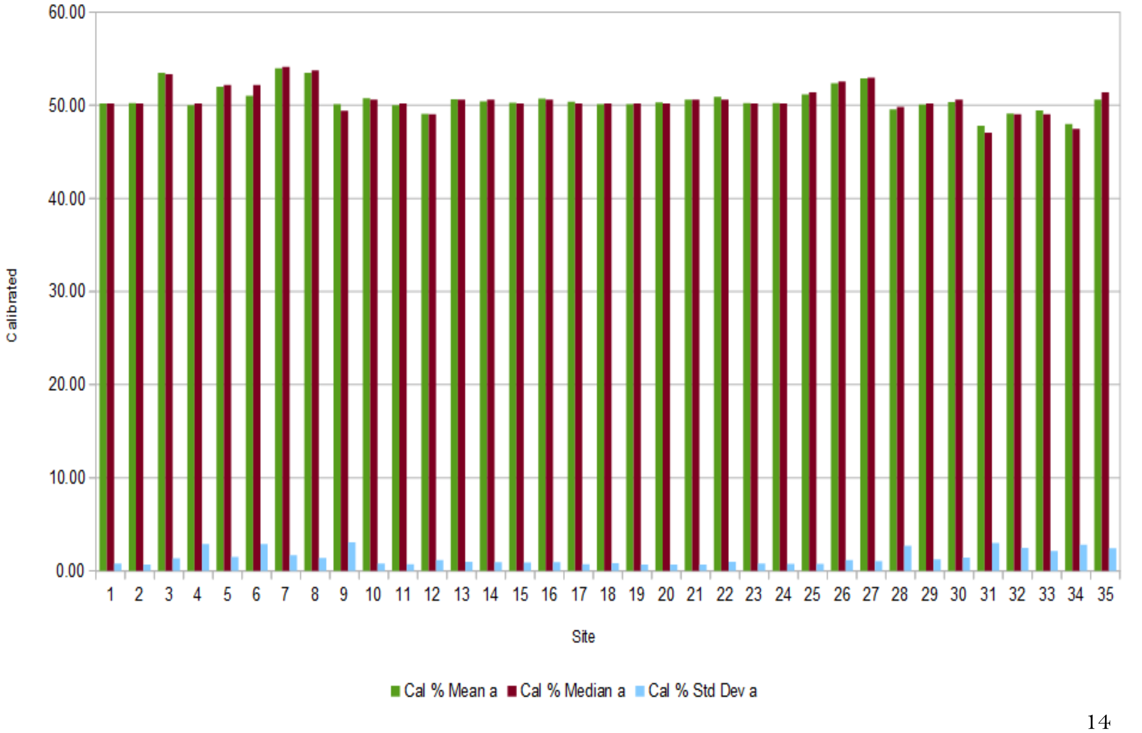
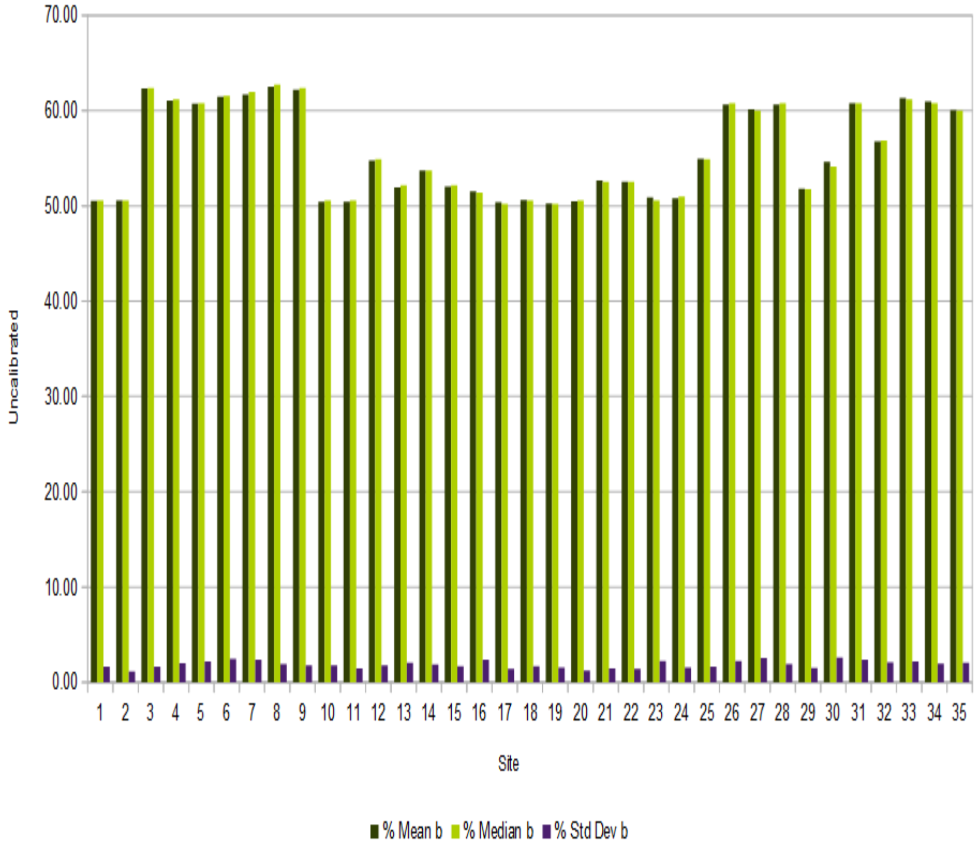


Fig-5. Uncalibrated (a) and calibrated (b) results for the green-red color spectrum (a), including % Mean, Median, and Std Dev values.

(a)



(b)

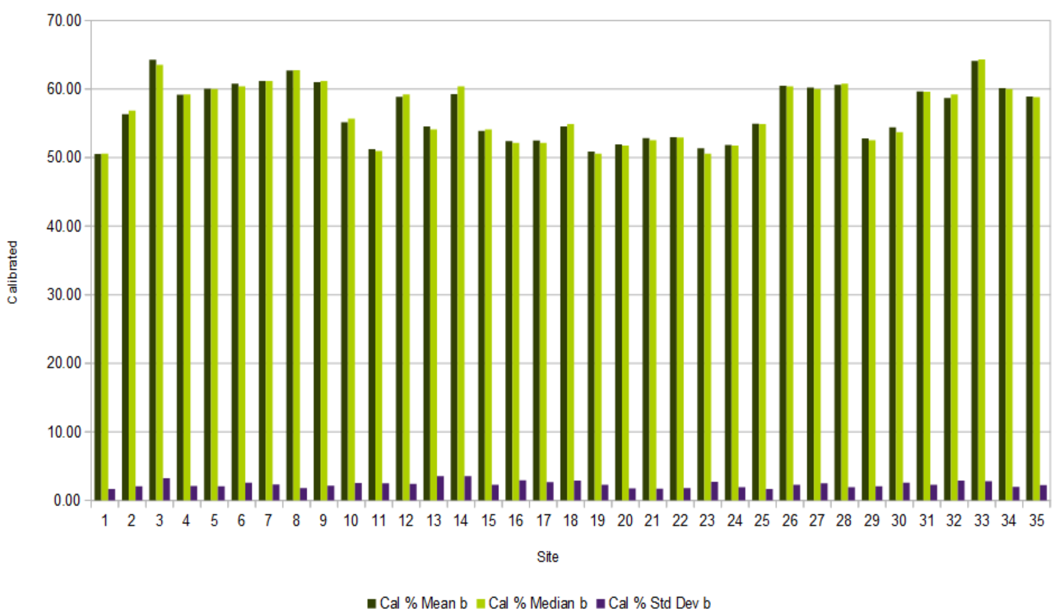


Fig-6. Uncalibrated (a) and calibrated (b) results for the blue-yellow color spectrum (b), including % Mean, Median, and Std Dev values.

Caption for Table

Table-1. Averages of surface lightness versus outdoor lighting conditions.

Wall Orientation (Sites)	**Average Calibrated % Mean *L* (Average St Dev)**	**Average Lux-Meter Readings (Average St Dev)**
East (1-4)	65.01 (11.49)	180 (30)
North (5-20)	64.71 (6.27)	122 (17)
West (21-27)	73.36 (4.77)	82 (12)
South (28-35)	64.14 (7.55)	88 (44)

Caption for Appendix

Appendix. Results of the photographic survey, with a summary of relevant measurements.

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
1: 84° East (224)	 L = 68.73 (69.02) 6.47% a = 50.15 (50.20) 0.74% b = 50.51 (50.59) 1.64%	 L = 79.01 (79.22) 6.45% a = 50.20 (50.20) 0.80% b = 50.53 (50.59) 1.65%
2: 84° East (157)	 L = 47.17 (46.27) 8.36% a = 49.87 (49.80) 0.68% b = 50.57 (50.59) 1.13%	 L = 52.30 (51.37) 7.83% a = 50.24 (50.20) 0.68% b = 56.34 (56.86) 2.07%

Site: Orientation (×100 at 50,000 Lux)	Uncalibrated Image Mean (Median) Std Dev	Calibrated Image Mean (Median) Std Dev
3: 67° East (166)	 L = 68.71 (69.41) 8.86% a = 53.33 (53.33) 1.25% b = 62.35 (62.35) 1.62%	 L = 68.71 (69.41) 8.85% a = 53.47 (53.33) 1.36% b = 64.26 (63.53) 3.25%
4: 65° East (174)	 L = 60.08 (61.96) 15.71% a = 53.41 (53.33) 1.44% b = 61.06 (61.18) 1.99%	 L = 60.03 (61.96) 14.33% a = 50.02 (50.20) 2.88% b = 59.18 (59.22) 2.10%
5: 37° North (150)	 L = 60.40 (64.71) 19.77% a = 53.16 (52.94) 1.28% b = 60.72 (60.78) 2.16%	 L = 63.42 (67.84) 19.56% a = 51.98 (52.16) 1.49% b = 60.06 (60.00) 2.07%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
6: 44° North (128)	 L = 66.16 (71.76) 19.11% a = 53.27 (53.33) 1.28% b = 61.46 (61.57) 2.48%	 L = 65.04 (70.59) 18.21% a = 51.00 (52.16) 2.88% b = 60.77 (60.39) 2.58%
7: 34° North (127)	 L = 55.29 (50.98) 18.02% a = 54.22 (54.51) 1.79% b = 61.69 (61.96) 2.35%	 L = 66.14 (63.14) 15.88% a = 53.97 (54.12) 1.71% b = 61.20 (61.18) 2.32%
8: 18° North (105)	 L = 72.07 (72.16) 7.08% a = 53.95 (54.12) 1.05% b = 62.52 (62.75) 1.90%	 L = 73.65 (73.73) 6.38% a = 53.49 (53.73) 1.41% b = 62.71 (62.75) 1.82%

Site: Orientation (×100 at 50,000 Lux)	Uncalibrated Image Mean (Median) Std Dev	Calibrated Image Mean (Median) Std Dev
9: 14° North (120)	 L = 61.71 (63.14) 10.33% a = 54.52 (54.51) 1.16% b = 62.21 (62.35) 1.80%	 L = 61.71 (63.14) 9.59% a = 50.13 (49.41) 3.07% b = 61.03 (61.18) 2.15%
10: 24° North (142)	 L = 48.33 (47.45) 8.03% a = 50.02 (50.20) 0.77% b = 50.43 (50.59) 1.79%	 L = 54.64 (53.73) 7.16% a = 50.75 (50.59) 0.82% b = 55.14 (55.69) 2.53%
11: 5° North (158)	 L = 73.96 (75.29) 8.84% a = 50.05 (50.20) 0.69% b = 50.42 (50.59) 1.46%	 L = 73.99 (75.29) 8.13% a = 50.00 (50.20) 0.71% b = 51.22 (50.98) 2.48%

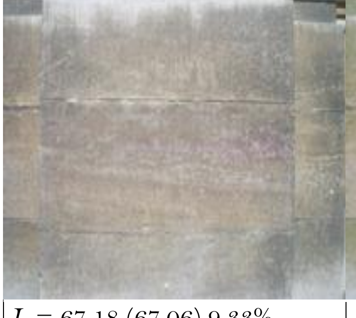
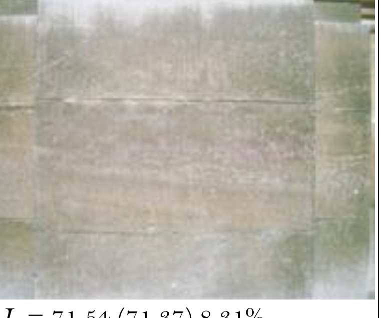
Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
12: 5° North (126)	 L = 56.36 (56.47) 7.64% a = 51.50 (51.37) 1.01% b = 54.78 (54.90) 1.75%	 L = 57.55 (57.65) 6.82% a = 49.07 (49.02) 1.16% b = 58.86 (59.22) 2.43%
13: 347° North (123)	 L = 66.33 (69.02) 12.86% a = 50.65 (50.59) 0.99% b = 51.92 (52.16) 2.04%	 L = 65.99 (68.63) 12.07% a = 50.65 (50.59) 0.99% b = 54.57 (54.12) 3.56%
14: 350° North (133)	 L = 59.71 (60.39) 10.05% a = 51.06 (50.98) 0.95% b = 53.69 (53.73) 1.87%	 L = 56.56 (57.25) 10.27% a = 50.43 (50.59) 0.95% b = 59.27 (60.39) 3.53%

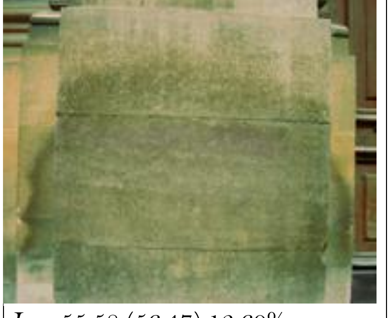
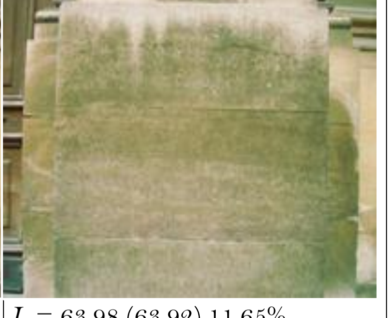
Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
15: 334° North (116)	 L = 55.73 (56.86) 12.57% a = 50.52 (50.59) 0.87% b = 52.03 (52.16) 1.68%	 L = 62.03 (63.14) 10.80% a = 50.27 (50.20) 0.91% b = 53.87 (54.12) 2.28%
16: 338° North (104)	 L = 66.80 (70.20) 12.33% a = 50.54 (50.59) 0.85% b = 51.55 (51.37) 2.38%	 L = 74.64 (77.65) 11.36% a = 50.72 (50.59) 0.95% b = 52.40 (52.16) 2.95%
17: 322° North (108)	 L = 59.21 (61.57) 10.25% a = 50.17 (50.20) 0.73% b = 50.41 (50.20) 1.41%	 L = 64.70 (66.67) 8.86% a = 50.36 (50.20) 0.74% b = 52.49 (52.16) 2.66%

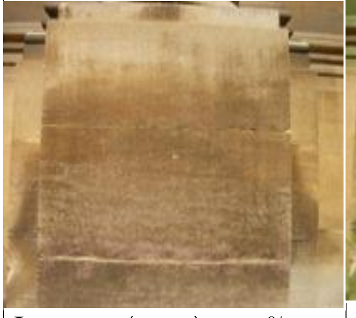
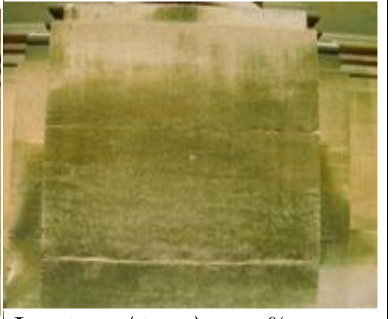
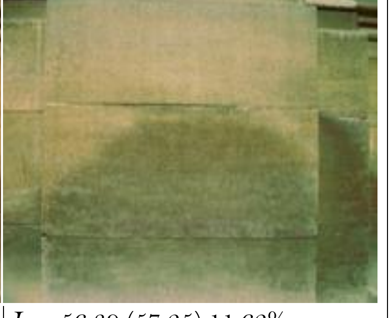
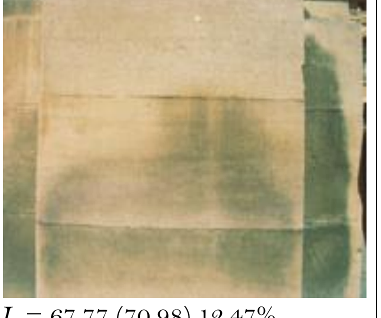
Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
18: 331° North (113)	 L = 57.52 (58.82) 9.35% a = 50.42 (50.20) 0.80% b = 50.62 (50.59) 1.69%	 L = 59.50 (60.78) 8.33% a = 50.11 (50.20) 0.82% b = 54.56 (54.90) 2.89%
19: 315° North (109)	 L = 68.66 (69.80) 6.62% a = 50.13 (50.20) 0.69% b = 50.24 (50.20) 1.56%	 L = 72.19 (73.33) 5.76% a = 50.13 (50.20) 0.69% b = 50.87 (50.59) 2.28%
20: 318° North (95)	 L = 58.86 (60.78) 8.78% a = 50.05 (50.20) 0.66% b = 50.49 (50.59) 1.21%	 L = 63.54 (65.49) 7.73% a = 50.29 (50.20) 0.67% b = 51.92 (51.76) 1.76%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
21: 310° West (95)	 L = 74.27 (75.29) 6.96% a = 50.65 (50.59) 0.67% b = 52.67 (52.55) 1.44%	 L = 76.23 (77.25) 6.19% a = 50.61 (50.59) 0.69% b = 52.84 (52.55) 1.72%
22: 305° West (84)	 L = 62.54 (64.71) 10.06% a = 50.60 (50.59) 0.79% b = 52.54 (52.55) 1.43%	 L = 71.96 (73.73) 9.31% a = 50.89 (50.59) 0.99% b = 52.96 (52.94) 1.80%
23: 277° West (90)	 L = 64.56 (69.80) 15.91% a = 50.41 (50.20) 0.78% b = 50.91 (50.59) 2.24%	 L = 71.32 (75.29) 14.10% a = 50.22 (50.20) 0.80% b = 51.34 (50.59) 2.70%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
24: 263° West (96)	 L = 58.25 (59.22) 8.34% a = 50.21 (50.20) 0.76% b = 50.80 (50.98) 1.53%	 L = 64.14 (65.10) 7.10% a = 50.21 (50.20) 0.76% b = 51.86 (51.76) 1.93%
25: 253° West (67)	 L = 74.09 (74.12) 5.57% a = 51.21 (51.37) 0.73% b = 54.95 (54.90) 1.65%	 L = 76.84 (76.86) 4.70% a = 51.17 (51.37) 0.76% b = 54.94 (54.90) 1.65%
26: 245° West (74)	 L = 72.98 (75.69) 12.05% a = 52.64 (52.55) 0.99% b = 60.63 (60.78) 2.22%	 L = 74.90 (77.25) 10.44% a = 52.35 (52.55) 1.16% b = 60.47 (60.39) 2.30%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
27: 253° West (68)	 L = 74.60 (75.29) 6.24% a = 52.95 (52.94) 0.98% b = 60.15 (60.00) 2.53%	 L = 78.11 (78.82) 5.27% a = 52.89 (52.94) 1.05% b = 60.21 (60.00) 2.48%
28: 167° South (57)	 L = 66.33 (65.88) 11.83% a = 52.92 (52.94) 1.13% b = 60.62 (60.78) 1.93%	 L = 64.76 (64.31) 11.56% a = 49.56 (49.80) 2.71% b = 60.62 (60.78) 1.93%
29: 164° South (57)	 L = 67.18 (67.06) 9.33% a = 50.50 (50.59) 0.92% b = 51.82 (51.76) 1.51%	 L = 71.54 (71.37) 8.31% a = 50.06 (50.20) 1.25% b = 52.81 (52.55) 2.06%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
30: 178° South (65)	 L = 74.25 (76.08) 10.13% a = 50.76 (50.59) 0.96% b = 54.61 (54.12) 2.58%	 L = 76.18 (78.04) 8.85% a = 50.34 (50.59) 1.42% b = 54.43 (53.73) 2.58%
31: 178° South (89)	 L = 58.72 (59.61) 12.37% a = 53.46 (53.33) 1.51% b = 60.80 (60.78) 2.38%	 L = 55.58 (56.47) 12.60% a = 47.79 (47.06) 3.02% b = 59.64 (59.61) 2.28%
32: 171° South (89)	 L = 66.35 (66.27) 11.71% a = 52.26 (52.16) 1.38% b = 56.78 (56.86) 2.10%	 L = 63.98 (63.92) 11.65% a = 49.12 (49.02) 2.48% b = 58.70 (59.22) 2.90%

Site: Orientation (×100 at 50,000 Lux)	**Uncalibrated Image Mean (Median) Std Dev**	**Calibrated Image Mean (Median) Std Dev**
33: 173° South (102)	 *L* = 59.28 (58.43) 11.89% *a* = 53.60 (53.73) 1.29% *b* = 61.31 (61.18) 2.19%	 *L* = 56.92 (56.08) 12.05% *a* = 49.44 (49.02) 2.13% *b* = 64.10 (64.31) 2.81%
34: 178° South (164)	 *L* = 58.34 (59.22) 11.67% *a* = 53.46 (53.33) 1.23% *b* = 60.97 (60.78) 1.95%	 *L* = 56.39 (57.25) 11.62% *a* = 47.97 (47.45) 2.80% *b* = 60.14 (60.00) 1.98%
35: 174° South (80)	 *L* = 65.85 (69.02) 14.18% *a* = 52.71 (52.55) 1.29% *b* = 60.05 (60.00) 2.04%	 *L* = 67.77 (70.98) 12.47% *a* = 50.60 (51.37) 2.44% *b* = 58.93 (58.82) 2.23%