COMPARISON BETWEEN LUX METER APPS AND ILLUMINATION MEASURING DEVICES

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Abstract: *The focus of our study was to compare the accuracy of illuminance measurements using a smartphone and a traditional lux meter. The measurements were performed with cell phones with two different operating systems (Android and iOS), for which we presented characteristic differences and compared and evaluated them in relation to the reference measuring device Testo 435. The paper presents the results on what the accuracy of illuminance measurements depends. It can be argued that smartphones are unreliable for illuminance measurement when high measurement accuracy is required. However, it is a matter of time and interest when we will be able to accurately measure illuminance with smartphones under various conditions.*

Key words: *illumination, smartphone, mobile application, light measurement*

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1. Introduction

The right illumination of workplace is of vital importance for the efficiency and well-being of a company's employees. It improves the quality and productivity of work while preventing the employees from injuries. To ensure the right illumination for a specific workplace a number of standards have to be followed, like EN 12464-1 (2021), ISO 8995-1 (2002) and ISO 8995-2 (2005). This is possible only with accurate measurements of the on-site illumination. Devices for light measurements are called lux meters and the most accurate professional devices can be expensive and are therefore not widely used. Smartphones present a compelling alternative. Everybody owns them and they are regularly improved with better hardware, processors, sensors, and cameras. New software applications are developed at a fast pace and offer a broad use for smartphones including useful light measurements.

Despite all this progress, the available literature on smartphone light sensors is surprisingly modest. In the recent years only a handful of studies (Gutierrez-Martinez *et al.*, 2017; Messalam & Abdoli-Eramaki, 2018; Goldschmidt, 2016; Odenwald, 2020) addressed the comparison between standard lux meters and smartphone illumination measurements. The authors of these studies concluded that it is impossible with a smartphone to achieve the repeatability and accuracy of measurements on a professional device, so they ruled out the possibility of replacing the lux meter with a smartphone. Approximate results could be obtained with calibration (Cerqueira *et al.*, 2018; Odenwald, 2020), but they are not good enough for measuring illuminance in the workplace. Given the fast development of the smartphones and sensor technology, even the new studies become quickly out of date. So further research in this area is vital to keep track of the development in the field of light measurements.

In this paper we present the current status in this area. We tested the improvement of smartphones and their applications for illumination measurements since the time the above studies were published. We start with summarizing the previous work, then introduce our methodology and measurements. For this, a number of different smartphones, applications and operation systems were tested and compared to a calibrated professional lux meter. The obtained results are analysed and an evaluation of the measurements for the use in a workplace is made.

2. Previous Research

Since the reliability of illuminance measurement using smartphone has not been confirmed so far and previous researches did not provide satisfactory results, a review of various researches was conducted. Three major studies comparing lux meter apps and metres are presented. The authors hypothesised the following:

- with a lux meter and a smartphone, we can measure illuminance without major deviations.
- the sensors built into smartphones are good enough to measure the quality of illuminance.

All authors followed these specific guidelines:

- a lux meter (model 106e, PCE-174) was used as a reference
- the measurements took place in a room without external influences
- the illuminance was measured vertically under the light source

Comparative measurements performed in 2016 in an accredited laboratory, proceeded as follows (Goldschmidt, 2016): 7 different cell phones were used for the measurements, including 3 iPhones with iOS operating system, 2 Sony phones and 1 Samsung with Android operating system and Nokia with Windows operating system. Then, the applications were selected based on the operating systems, since the same applications are not supported on different operating systems. So, 3 applications for iOS, 3 for Android and 1 for Windows Phones were selected. A paid application was also tested, but it did not provide more accurate results. After analysing the data, they found that the measurements were very different, even up to 113% from the reference value. With iPhones, the data measured was on average 60% below the reference value, while the other phones showed results above the reference value, also on average 60%. It was also found that the measurements with phones that have a light sensor (Android, Windows) are independent of the different applications. Only with iPhones that use a camera for the measurements there is a difference. They also tested 4 identical iPhone 5 models, but they had different luminance values for the same application. Even with a different reference luminance, they were unable to get a consistent deviation that could be used to calibrate the application.

Comparative measurements conducted at the University of Alcala, Spain, showed the following (Gutierrez-Martinez *et al.*, 2017): Unlike the other two studies, they used an external sensor to measure the illumination, which they developed themselves. A large part of the research was dedicated to calibration, since the deviations from the reference value were very large, 60%. With calibration, they managed to reduce the error to as low as 10%, and by calibrating with segments 0-100; 101-500 and 501-700, they managed to reduce the error to a maximum deviation of 2%.

Comparative measurements from 2018, conducted at Ryerson University, Canada, were determined as follows (Messalam & Abdoli-Eramaki, 2018): 70 smartphones were used, including 21 different models, 7 with the IOS system and 14 with the Android system. Measurements were made with each phone using three different applications. They found that the measurements were approximate and unpredictable for the same smartphone models and differed greatly depending on the operating system, as shown in Fig. 1. The conclusion was that Android phones provided more accurate data measurements than the phones from IOS.

Research conducted by Cerqueira *et al.* (Cerqueira *et al.*, 2017; Melo *et al.*, 2018) focused on smartphones for the use in the occupational health industry as general illuminance monitors to check workplace compliance with safety regulations. It included nine smartphones and 14 applications that were tested against a lux meter. Their study extended over four illuminance levels (300 lx, 500 lx, 750 lx and 1000 lx) and three correlated colour temperatures (2700 K, 4000 K and 6500 K). They reported statistical significant differences between the values displayed by the mobile phones and the ones on the lux meter.

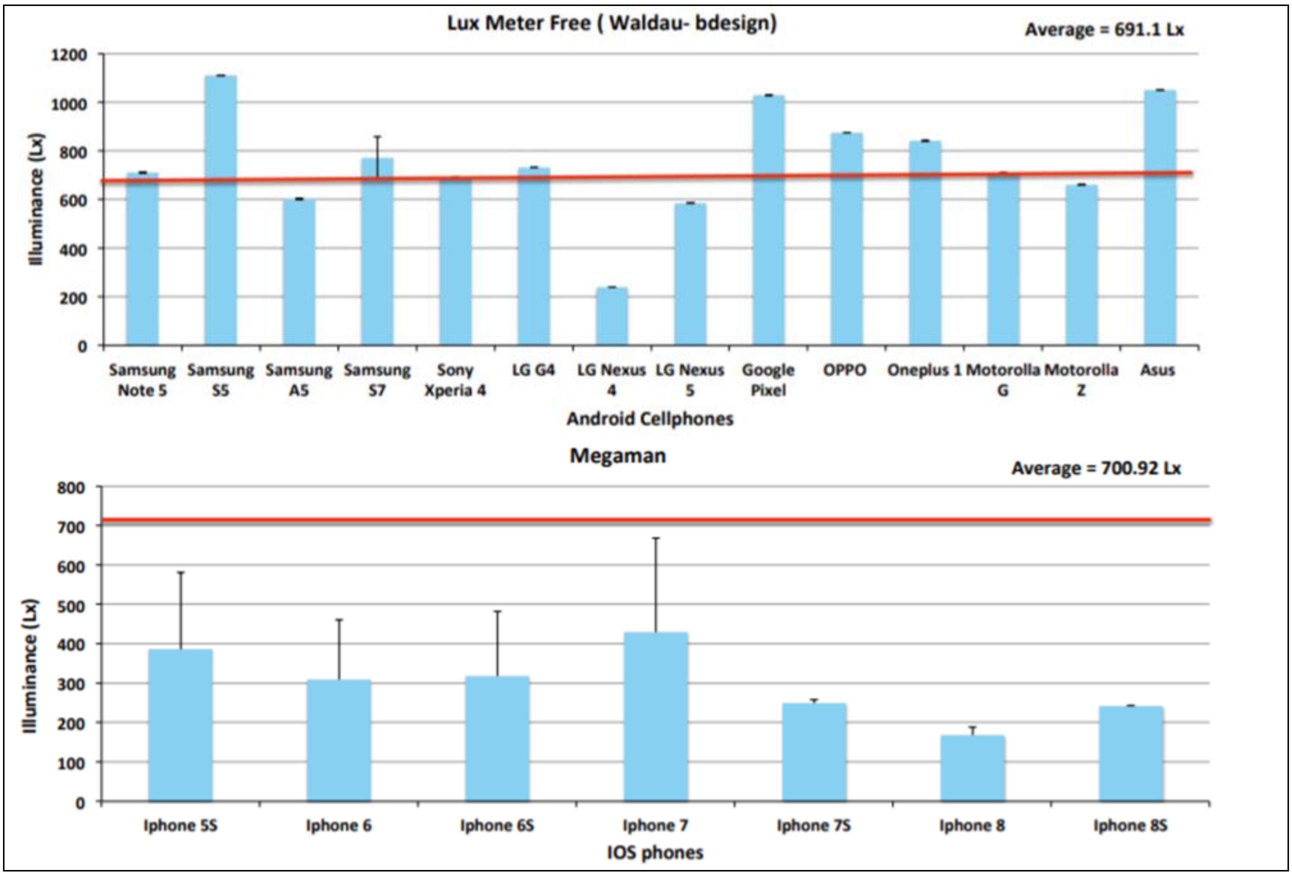

Fig. 1. Comparative measurements conducted at Ryerson University (Messalam & Abdoli-Eramaki, 2018).

Based on those findings smartphones were decided to be unsuitable for measuring illuminance and determine the adequacy of lightning in occupational settings.

In a more recent paper Odenwald (Odenwald, 2020) critically assessed light and sound sensor systems in modern smartphones and their use in citizen science projects. Such projects require on-the-spot measurements of a variety of parameters, illuminance being one of them, and smartphones are very useful as low-cost mini physical labs. Odenwald calibrated the light sensors on a variety of apps (Lux Light Meter, Light Meter, Galactica) and on three platforms (Samsung Note 5, Galaxy S8, iPhone 6S) using professional-grade instruments. With adjustments to the recorded data he made a set of calibration curves that notably improved the usefulness of smartphones sensor light systems. The light intensity measurements for illuminance above 3000 lx could be made with a 12% accuracy compared to calibrated values but there is a significantly worse performance below 3000 lx. Interestingly, Odenwald reported a lack of light-metering apps that were able to save the measurements in exportable file formats for later analysis and argued that this greatly limits their usefulness for non-photographic applications. The author would have benefited from more general physical applications like Phyphox that include practical export options of data.

The authors of these studies, who measured illuminance with a smartphone and a lux meter, concluded that it is impossible to achieve the repeatability and accuracy of measurements with a smartphone, so they ruled out the possibility of replacing the lux meter with a smartphone. Approximate results can be obtained with calibration, but they are not good enough for measuring illuminance in the workplace.

In conclusion, everyone noted the need for the development of applications for illuminance measurement and further research in this area.

3. Methodology

For the present problem, different smartphone types were selected and tested in different measurement environments (indoors/outdoors at the faculty, with natural and artificial light). The measurements were compared and evaluated with respect to the reference measuring device Testo 435.

3.1 Reference measuring instrument

A precise multifunctional meter, Testo 435, was used to measure the reference illuminance in the selected environments (Fig. 2). The meter was manufactured in Testo SE & Co, Germany. It has different sensors and probes to measure different values such as temperature, air velocity, illuminance and others. We used a probe to measure illuminations with the following specifications:

- measurement of all types of illuminations from another source (K < 5,000),
- accuracy according to DIN EN 13032-1 and class C according to DIN 5032-7,
- measuring range: 0 to 100000 lux with a resolution of 1 lux.

Fig. 2. Multifunctional measuring device Testo 435 (Testo SE & Co, Germany).

3.2 Selection of different smartphones

Different types of smartphones were used for this problem analysis, ranging from cheap to expensive, newer to older versions, and phones with different operating systems (Tab.1). Due to the inconsistent applications and the type of illuminance measurement, a major difference quickly became apparent. Smartphones with iOS systems measure illuminance using the phone's camera, while other smartphones use light sensors that are mostly used to adjust screen brightness to the environment.

Smartphone	Operational System	Illumination sensor /camera	Resolution (lux)	Arrival on the market
iPhone 5	iOS	1,2 MP	/	2012
Huawei P10 lite	Android	light-ltr578	1	2017
Xiaomi Redmi Note 4	Android	LTR579 ALSPS	0,015	2017
Samsung Galaxy A5	Android	TMD3725 Light	1	2017
Huawei Mate 20 lite	Android	light-ltr578	1	2018
Huawei P20 lite	Android	light-ltr578	1	2018
Samsung Galaxy A51	Android	TCS3701 Light	1	2019
iPhone 11 Pro Max	iOS	12 MP	/	2019
Huawei P40 Pro	Android	als-stk3638	1E-12	2020
Xiaomi Redmi Note 10	Android	rohm_bu27030	0,0001	2021

Tab. 1. List of used smartphones and their specifications.

3.3 Illumination meter applications

A variety of illumination meter applications are available in the online cell phone store (reviewed by Ciricillo, 2022; Adams, 2021). The advantage over the lux meter is the wide range of free apps or apps with a minimal co-payment that also offer advanced features, such as: calibration, different measurement methods for specific professions like photography, greenhouses, photovoltaics, export of measurement data and others (Kumar, 2017; Deruvo, 2022). The biggest difference is between phones with iOS and Android operating systems. Android phones use a brightness sensor to measure light, while iPhones use a camera to measure illuminance. Therefore, it is impossible to measure illuminance on iPhones with applications that require a light sensor for their measurements.

Applications for the Android operating system

Illuminance measurement applications are installed on Android phones via the Google Store, which comes pre-installed on every phone. However, since the results of illuminance measurements using smartphones with Android operating system did not depend on different applications, we will describe only 2 applications that we used most often in the comparative measurements with a lux meter.

The Lux Meter (Light Meter, 2019) application was developed by My Mobile Tools Device (Figure 3, left part of the figure). It is basically similar in structure to other applications for measuring illuminance. The applications mostly differ in the form of user interface, all of them allow output of data (analog or digital), output of minimum, maximum and average illuminance values, and some of them also allow calibration.

The Lux Meter (illumination meter) application offers:

- free installation
- calibration of illuminance
- output of minimum, maximum and average illuminance values
- name of the sensor integrated in the cell phone

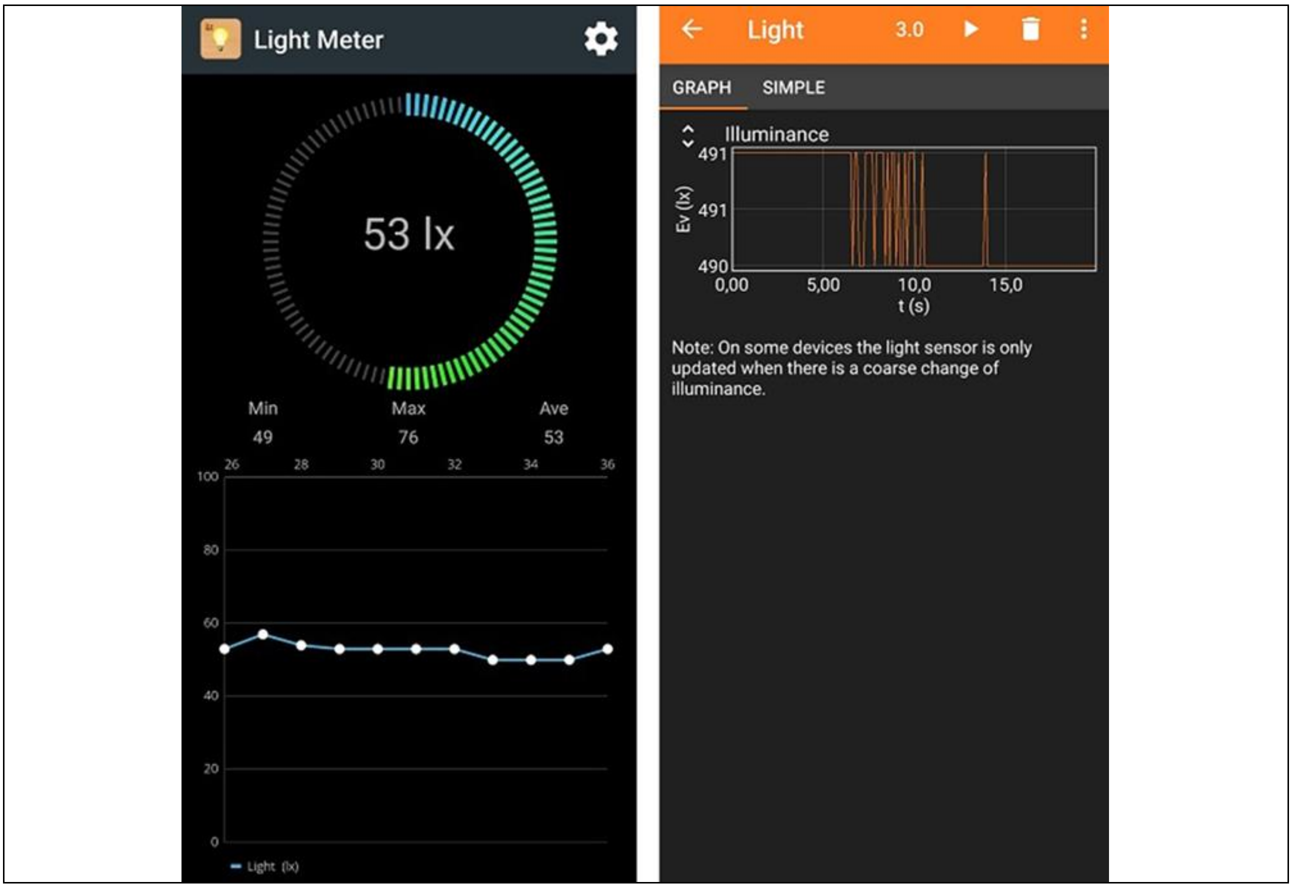

Fig. 3. Applications Lux Meter (left) and Phyphox (right).

The Phyphox application, developed by RWTH Aachen University (phyphox) the possibility to measure other physical quantities in addition to lighting. It also draws a graph of changing illuminance as a function of time, Figure 3 (right part of the figure). The advantage of this application over others is that we can determine the duration of the illuminance measurements and the delay in the start of the measurement. It allows us to move away from the phone so that we do not disturb the measurements with our presence. Also, we can export the data in various formats (Excel, csv), which can then be analysed in any data analysis program. This feature is missing in some of the applications merely focused on light measurements. An interesting option is also the management of the measurements through the computer, with which we control our connected smartphone, which is in the same network as the computer. In general, Phyphox proved to be the most universally useful application.

Applications for the iOS operating system

On cell phones with iOS operating systems, it is possible to install various applications through the App Store. It is possible to access both free and paid applications. Since we were interested in low-cost applications, we selected only free applications. iPhones do not have a built-in light sensor. They measure light through the camera, so we were forced to find applications other than those for Android phones. It was interesting that the brightness measurement on Android phones was independent of the application, while on iOS operating systems each app displays a different value.

For more accurate measurements, some apps require a diffuser for exposure measurement, which can be purchased or homemade. We made it ourselves according to the instructions. Below we present the last updated application, which also gave the most accurate results. During the measurements, we used 2 applications from the same developer, both of which gave solid results. We will describe one of them in more detail below, as they work on a very similar principle.

The Photone application, developed by Lightray Innovation GmbH (Photone, 2022), allows the measurement of illuminance with digital display of the results on the user interface. The application already requires a diffuser at the beginning of the measurement, which anyone can make at home from white paper by following the application's instructions. It is also possible to buy online a diffuser, which corresponds to the measuring probes of lux meters. We made our diffuser from a white sheet of A4 paper, from which we cut a 1.5 cm wide strip and glued it to the front and rear cameras of the iPhone (Figure 4). The resolution at which the illuminance can be measured is 10 lux. The developers state these characteristics:

- measurement accuracy on all iPhones (calibration to class A reference lux meter).
- no light sensor required
- performing measurements with different units

There are far fewer free and paid measurement apps in the App Store than in Google Play. In the App Store, we found apps whose last update was a few years ago and which are not suitable for newer phones. The problem also occurs when we want to access the latest app on an old phone because we cannot open it, but we did not encounter such problems on Android phones. The disadvantage is also that we need a diffuser for the measurement, while with Android phones we can start measuring immediately without any tools. For the iOS operating system, we have not found an application that allows measuring the illuminance at a specific time and offers data export to Excel, as is possible with the Phyphox application.

Fig. 4. iPhone with a self-made diffuser.

4. Measurements

4.1 Research environment and measuring procedure

The research was conducted in the physics laboratory at the Faculty of Mechanical Engineering, University of Maribor. In this environment there is natural light and artificial lighting. For comparison with indoor measurements, the illuminance was also measured outside the faculty, on the benches near the faculty building.

According to the Slovenian Occupational Safety and Health Act and SIST EN 12464-1:2011 standard (Lighting of workplaces - Part 1: Indoor workplaces, Part 2: Outdoor workplaces), the minimum illumination value for visual comfort in the workplace is 200 lx. The recommended values are similar to European Standard NEN 12464-1, which specifies lighting requirements for people at indoor workplaces that meet the visual comfort and performance requirements of people with normal vision. This European Standard specifies the requirements for lighting solutions for most indoor workplaces and associated areas in terms of quantity and quality of lighting.

It also provides recommendations for good lighting practise (Harari, 2017; Vujica Herzog, 2019). The optimal value for visual comfort is around 2000 lx, but for some workers this value is too high and for others too low. The fewest complaints have been recorded at a value of 1000 lx, at which no glare occurs and the workplace is uniformly illuminated. Some examples of recommended illuminance levels are listed in Table 1.

Type of activity	**Ranges of illuminances [lx]**
Public spaces	20 to 50
Simple orientation for short temporary visits	50 to 100
Working spaces where visual tasks are occasionally performed	100 to 200
Performance of visual tasks of high contrast or large size (office, laboratory)	200 to 500
Performance of visual tasks of low contrast or very small size	500 to 1000
Performance of visual tasks of low contrast and very small size over a prolonged period (quality control)	1000 to 2000
Performance of very special visual tasks (surgery room)	> 2000

Tab. 2. Examples of recommended illuminance values (Kroemer *at al*., 2003)

In practice, illuminance is measured with a calibrated meter. With our research, we would like to investigate whether illuminance can also be measured appropriately with a smartphone and a selected application. Illumination measurements should be performed in different situations:

- to verify the appropriateness of the calculated value in a new work environment,
- to verify compliance with specifications and recommendations,
- to check if maintenance, modification or replacement is required,
- to compare the quality and economy of lighting.

4.2 Measurements of illumination withought daily lighting

To ensure repeatability of measurements, we created the environment without outdoor light. A darkroom closed with curtains was chosen, where the conditions were the same for all smartphones. Since the illumination changes on the illuminated area, a place for the smartphone was marked with a template (Fig. 5).

The measurement process began with setting up the reference illumination, which was measured with the Testo 435 multimeter. Since the measurement probe has a cable, we were able to place it in the closed cabinet and read the illumination value outside. This was followed by the measurement with different smartphones. For the measurement with Android systems, we used the Phyphox application, where a time delay can be set so that we can close the curtains. With this application we can also set the measurement time and the data can be exported to an Excel file. The time delay was set to 5 seconds before and 30 seconds after the illuminance measurement. The end of the measurement was announced with a sound signal.

On smartphones with iOs system, the Phyphox application cannot be used, so the measurement process was slightly different. To perform the measurement, we had to go into the closed room, close the curtains and read the measurement value.

As a light source we used a table lamp LED, which allows a function of continuous light change, height and angle of illumination and has the following characteristics:

- Power: 5 W
- Luminous flux: 200 lx
- Colour brightness: neutral, 4000K

The table lamp was 27.5 cm from the floor and was perpendicular to the floor to ensure maximum illuminance.

4.3 Measurements of illumination with daily lighting

To compare how well smartphones and applications can measure illuminance in daylight and combinations of daylight and artificial light, we also made measurements in the classroom and outside the faculty building, in the classroom and at the bench outside (Fig. 6). As before, a place for the smartphone was labelled with the template.

Fig. 5. Measuring point – darkroom.

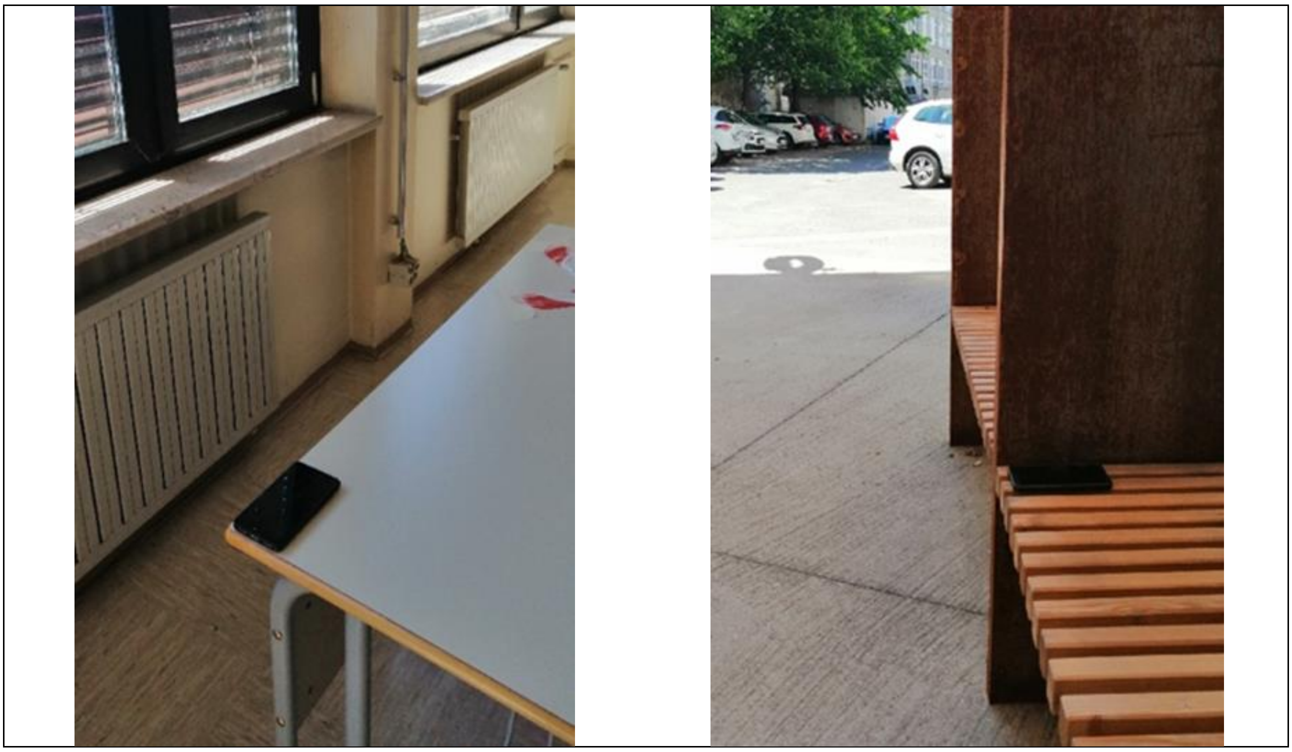

Fig. 6. Measuring points: left – classroom, right – bench outside.

5. Results and discussion

Table 3 shows the results of the illumination measurements depending on the different applications used. We found that smartphones with Android system, Huawei Mate 20 lite, Huawei P40 Pro, Xiaomi Redmi Note 4, all measured more or less the same illumination level, regardless of the application used. The biggest deviation was 1 lx and is practically negligible.

The smartphone with iOS system 11 Pro Max shows different results obtained with different applications. Only the applications of the same developer, Light Meter LM -3000 in Photone, show the same illumination level, all others show larger deviations from the previously mentioned applications.

According to the obtained results, testing of different applications was abandoned and further research was focused on different smartphones. Among all tested applications, Phyphox application was chosen because it offers the possibility of exporting data to Excel and the easiest way for further data processing.

For smartphones with iOS system, i.e. iPhone, the result depends on the different applications. The measurements performed in our faculty laboratory show that the value closest to the Testo 435 metre was obtained with the Photone application (Lightray Innovation GmbH) and this application was later used for comparable measurements.

5.1 Comparison of illumination measurements with different smartphones

The illumination measurements for ten different smartphones were performed in a cabinet to avoid mixing with outdoor light. A LED lamp with a colour brightness of 4000 K was used as the light source.

Phone	**Application**	**Illumination [lx]**
Huawei Mate 20 lite	Lux Light Meter Free (Doggo Apps)	787
	Lux Meter (My Mobile Tools Dev)	787
	Smart Lux meter (Smart Tools co.)	787
	Light Meter (Trajkovski Labs)	787
	Lux Light Meter (waldau-webdesign.de)	787
	Lux Light Meter (Batusoft)	787
	Lux Light Meter Free (waldau-webdesign.de)	787
	Lux Light Meter (Micro Inc)	787
	Photometer PRO (Przemek Pardel)	787
	Phyphox (RWTH Aachen University)	787
	Physics (Vierya Software)	787
Huawei P40 Pro	Photometer PRO (Przemek Pardel)	626
	Phyphox (RWTH Aachen University)	626
	Lux Meter (My Mobile Tools Dev)	625
	Light Meter (Trajkovski Labs)	625
Xiaomi Redmi Note 4	Photometer PRO (Przemek Pardel)	522
	Phyphox (RWTH Aachen University)	522
	Lux Light Meter (waldau-webdesign.de)	522
	Lux Meter (My Mobile Tools Dev)	522
	Lux Light Meter Free (Doggo Apps)	522
	Physics (Vierya Software)	522
Iphone 11 Pro Max	Galactica Lux meter (Flint Soft Ltd.)	290
	Light Meter LM-3000 (Lightray Innovation GmbH)	400
	Photone (Lightray Innovation GmbH)	400
	Lux Light Meter Pro (Marina Polyanskaya)	141
	Light Meter Free (Nipakul Buttua)	136

Tab. 3. Results of the measurements depending on the different applications used.

Figure 7 shows the reference measured value obtained with the Testo 435 at 400 lx. The results of the different cell phone manufacturers are marked with different colours: Huawei - blue, Samsung - red, Xiaomi - purple and IPhone - green. The results achieved with the Samsung Galaxy A51 came closest to the reference value with a deviation of 1%. Deviations of up to 10% were found for Xiaomi Redmi Note 10, iPhone 5 and iPhone 11 Pro Max. The Huawei Mate 20 Lite had the biggest deviation of 99%.

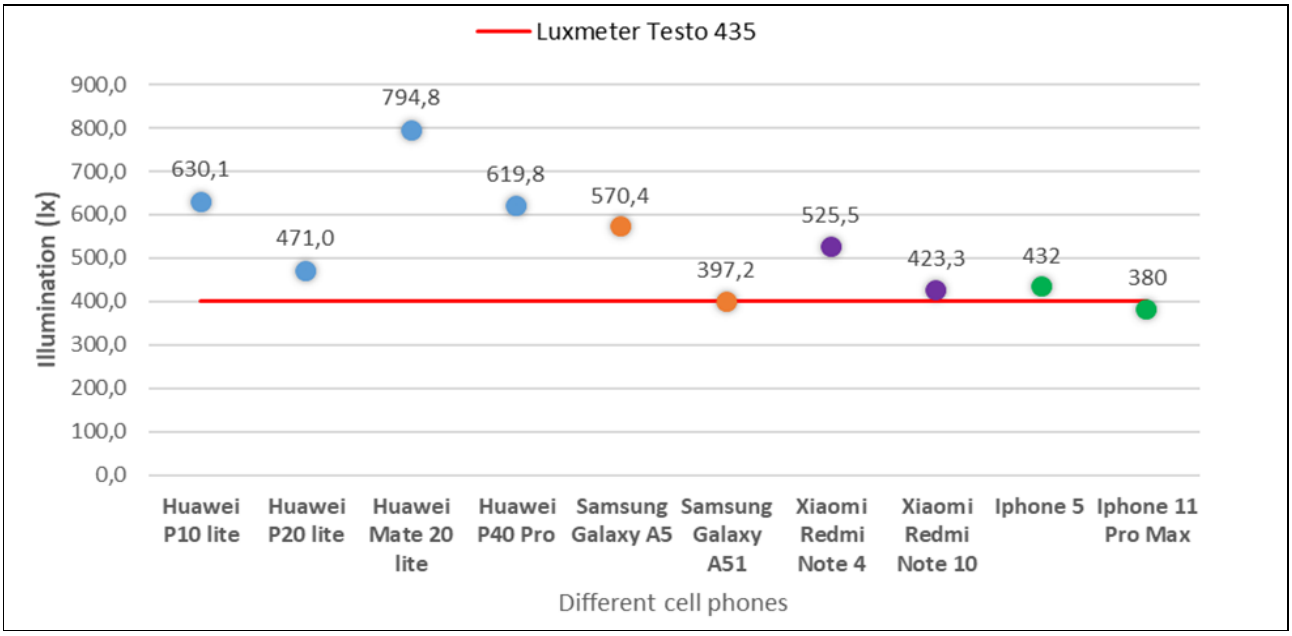

Fig. 7. Illumination measurements with different smartphones used in this study.

Cell phones from the manufacturer Huawei had the biggest deviation from the reference value on average. The most accurate results were achieved with iPhones. Since the measurement results are randomly unpredictable, it is not possible to relate the deviation to the phone brand. It also cannot be concluded that more accurate results can be obtained with more expensive and newer phones. It is also interesting that the measurements with Huawei P10 lite, Mate 20 lite and P20 lite, which use the same sensor, gave different results. The resolution of the sensor did not affect the accuracy of the results in our case.

The standard deviation of the illumination measurement with the smartphone in 30 seconds is too small to show in the chart because the measurement error is smaller than the character size in the figure. This means that our black closed environment created a controlled environment for the measurements.

To check repeatability, measurements were also performed with changing reference illumination (Tab. 4). The measurements were performed in the darkroom, without external light and with the lamp LED with the possibility to change the brightness.

Phone	**Percentage of deviation from reference**				
Reference illumination (lx)	**204**	**400**	**758**	**1080**	**1567**
Huawei P10 lite	60 %	58 %	56 %	58 %	53 %
Huawei P20 lite	19 %	18 %	19 %	27 %	13 %
Huawei Mate 20 lite	100 %	99 %	97 %	99 %	98 %
Huawei P40 Pro	54 %	55 %	52 %	48 %	53 %
Xiaomi Redmi Note 4	31 %	31 %	28 %	31 %	29 %
Xiaomi Redmi Note 10	10 %	6 %	14 %	7 %	7 %
iPhone 11 Pro Max	-7 %	-5 %	2 %	6 %	8 %

Tab. 4. Percentage of deviation from the reference value depending on the model of the smartphone.

The results show that the deviations from the reference value are fairly constant. For smartphones with Android system, where all deviations from the reference value are higher, it can be assumed that it could be a system error. The deviations at different illumination values only differ by a few percent, which means that we could accurately approach the reference value with the help of the calibration process.

The IPhone 11 Pro Max shows the highest deviation from the reference value of 8% with five different illumination values, which is the best result achieved without the calibration process. For a meaningful value, we can conclude that this deviation is acceptable.

5.2 Comparison of illumination measurements taken with different light sources

We also compared the percentage deviation of illuminance from the reference value obtained with the Testo 435 metre. The measurements were taken at three different locations. The results referred to as artificial lighting are measurements made with the light source LED (4000 K). For natural lighting, the light source was the sun, and for the combination of artificial and natural lighting, the measurements were taken in daylight and with the overhead lighting on.

Since the results measured in the closed room with LED show constant deviations from the reference value, we wanted to know if this deviation remains the same when another light source is used. The graph shows that the deviations from the reference value are different for different lighting combinations and cannot be compared with each other. The smartphone with the biggest deviation is the Huawei Mate 20 lite. Phones with the best results are Huawei P20 lite and Xiaomi Redmi Note 10. If we exclude measurements in natural light, very good results were achieved with the Iphone 11 Pro Max, comparable to the lux meter in the Testo 435.

In terms of all the measurements performed, we can conclude that the results of the illumination measurements with the smartphone are not as reliable as the measurements with the lux meter, even when using the smartphone calibration procedure. The smartphone calibration procedure can only reduce the deviations and therefore provides more precise measurements.

6. Conclusions

Our measurements show that smartphones are not reliable enough for high-precision illumination measurements without proper calibration. Most smartphones provide good, meaningful data for illumination measurements that can be used at home, for photography, or for plant growth. However, professional lux meters are still needed for more accurate measurements.

We have found that for smartphones with Android operating systems, measurements do not depend on the application, while for phones with iOS, illumination readings depend on the application. If Android smartphones are used for measurements under always the same light source, then very accurate results can be obtained with calibration. The best results were obtained with the Photone app from Lightray Innovation GmbH, which is regularly updated in the App Store and can only be installed on newer iPhone models.

The higher accuracy of the illumination measurements could not be related to the age of the mobile device, the manufacturer of the device, its price and the quality of the sensor. Problems occur when multiple light sources are present and the same smartphone can show unexplained deviations from the reference. If these deviations were all in the same direction under all tested conditions, the phone's calibration would result in accurate measurements comparable to those of a standard lux meter.

In conclusion, we can say that smartphones are not yet useful enough for lighting quality measurements because the light sensor cannot detect indirect light. More work needs to be done with the new phones coming to the market. More attention should also be paid to the correct calibration offered by some applications that even use artificial intelligence to detect the light sources.

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