technical transactions

No. 2024/012

environmental engineering

sciendo

The outdoor lighting of the Wawel Royal Castle and its contribution to the occurrence of light pollution

Jakub Łygan

jakub.lygan@doktorant.pk.edu.pl | https://orcid.org/0009-0005-2028-8982

Anna Czaplicka

anna.czaplicka@pk.edu.pl | https://orcid.org/0000-0002-2063-9034

Faculty of Environmental Engineering and Energy,
Cracow University of Technology

Scientific Editor: Michał Zielina,
Cracow University of Technology
Technical Editor: Aleksandra Urzędowska,
Cracow University of Technology Press
Typesetting: Anna Pawlik,
Cracow University of Technology Press

Received: June 29, 2024
Accepted: November 6, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing interests: The authors have declared that no competing interests exist.

Citation: Łygan, J., Czaplicka, A. (2024). The outdoor lighting of the Wawel Royal Castle and its contribution to the occurrence of light pollution. *Technical Transactions, e2024012*. https://doi.org/10.37705/TechTrans/e2024012

Abstract

This paper concerns the phenomenon of light pollution. Its goal is to identify light sources in the Wawel Royal Castle that influence this phenomenon. The term of the discussed phenomenon is given, with emphasis on its categories. Then, the impact of light pollution on the environment was discussed. During the research, light sources were identified and divided according to their type. Then it was determined how individual light sources affect the occurrence of light pollution. The results contain information about the location of light sources, their type, colour and direction of light beam. The authors present them in photographic documentation and a map of Wawel Hill. Additionally, changes were proposed in the external lighting of the Wawel Royal Castle, aimed at reducing the occurrence of light pollution. A total of 294 light sources were inventoried, of which 82 were classified as abnormal, 59 as normal, and 63 as partially correct. The rest were unavailable or unused.

Keywords: Glare, Illumination, Light pollution, Sky glow, The Wawel Royal Castle

1. Introduction

Since Thomas Edison patented the light bulb in 1879 and its mass production began, outdoor lighting has become an integral part of human life. Artificial lighting improves human activity after dark, gives a sense of security and allows you to display the most beautiful elements of the urban landscape. With advances in technology, lighting that was initially used sparingly is now often overused. This is due to the wide availability of light sources and the low costs of their production and operation. The widespread use of light bulbs has made it possible to illuminate even entire agglomerations at relatively low costs. Although the use of artificial light to illuminate cities is not a problem in itself, the incorrect selection and arrangement of light sources, excess light and its scattering in many directions cause a phenomenon called light pollution. It is common for large, bright billboards or LED signs to blind drivers or pedestrians, posing a risk to road safety. It is worth noting that light pollution also affects illuminated buildings of high historical or cultural value. In the past, researchers conducted an inventory of the external lighting of many historical monuments in Kraków, identifying issues in the lighting of sites such as the Main Square, the Juliusz Słowacki Theatre, and the St. Joseph's Church (Wiehle, Czaplicka & Ściężor, 2022; Esmund, Kotra, Ściężor & Czaplicka, 2020; Bylinowska, Czaplicka & Ściężor, 2019). However, the impact of external lighting on light pollution at the Wawel Royal Castle had not been previously analysed. Therefore, the aim of this study is to identify the light sources of Wawel Royal Castle that contribute to light pollution. The harmful effects of light not only affect cities but also the natural environment, disturbing the biological clock of animals and plants. In addition, light pollution affects the quality of astronomical observations, often making them impossible.

2. Term of light pollution

The first mention of the brightened sky appeared already in the 19th century, while in the 1970s astronomers formulated the term of light pollution. It was defined as the brightening of the night sky due to artificial lighting (Berry, 1976; Walker, 1973). Then in 1985, Dutch ecologist Verheijen introduced the notion of photopollution as the "artificial light having adverse effects on wildlife" (Verheijen, 1985). Light pollution is an interdisciplinary field of science and nowadays it is defined as the negative impact of artificial lighting. As part of the described phenomena following categories can be distinguished (Ściężor, 2020; Ściężor, 2015):

- glare – very strong direct effect on the sense of sight causing glare;
- trespass – lighting of the area, which is not intentional;
- skyglow – brightening night sky by the artificial light scattering in the atmosphere;
- clutter – excessive grouping of light sources;
- excessive lighting – use of artificial lighting when it is not necessary;
- wasting electricity.

3. Legal regulations on light pollution

Light pollution is a global issue affecting both rural and urban areas. Despite this, the European Union has not established a unified legal framework to address this phenomenon. However, many countries, such as Italy, Slovenia, and Spain have implemented regional laws against light pollution. A model regional law is considered to be the legislation passed on the 27 of March 2010, by the parliament of Lombardy, which is recognized as one of the most light--polluted regions in the world (Kubala, 2017). In contrast, Polish law does not

https://doi.org/10.37705/TechTrans/e2024012

offer comprehensive solutions regarding light pollution (Szlachetko, 2022). Existing legal acts do not directly address this issue, covering it only indirectly. A particularly significant gap is the lack of explicit recognition of light pollution as a category of pollution in the Environmental Protection Law (Dz.U. 2024, p. 54).

4. The impact of light pollution on the environment

Research conducted by scientists indicates that light pollution can have adverse effects on both human health and the natural environment. One of the primary consequences of the harmful impact of artificial light is the disruption of the day-night rhythm, associated with irregularities in melatonin secretion. Studies carried out with volunteers in the Rocky Mountains (USA) have shown that artificial light delays the evening synthesis of melatonin, leading to increased brain activity and contributing to sleep disruptions (Kostecka, 2017). A decrease in melatonin levels also increases the risk of depression, cardiovascular diseases, diabetes, and obesity (Sala, 2020). Short-term effects of light on human health include headaches, increased stress, and fatigue (Uniwersytet Wrocławski, 2008).

Excessive illumination poses a threat to the biodiversity of animals by disrupting their biological rhythms and behaviour (Dobiesz & Ziółkowska, 2015). Biological rhythm disruptions force animals to adjust their activities and change their orientational, feeding and reproductive behaviours (Kaleta, 2007). Birds are especially vulnerable to the impacts of light pollution. Artificial light impedes their ability to navigate by the positions of the Moon and stars during night migrations (Dobiesz & Ziółkowska, 2015). A common phenomenon are birds colliding with illuminated buildings. They also become trapped in brightly lit areas from which they cannot escape, circling light sources until they lose strength. In the case of insects, artificial light disturbs the communication among fireflies, which relies on visual signals (Williams, 2023).

A group threatened by light pollution also includes plants, which adjust their growth and development to natural light conditions (Tałanda, 2015). Light determines the course and efficiency of photochemical processes, which are integral to photosynthesis. It also provides plants with information about the season and surrounding environment allowing them to adapt to the current conditions (Kostecka, 2017). Light pollution may disrupt flowering, bud development, dormancy, repair processes, and resource allocation in roots and stems. Additionally, it has been observed that in light-polluted areas, plants conduct photosynthesis at night. This weakens their resilience and exposes them to various diseases (Wojciechowska, 2019).

5. Research site

The Wawel Royal Castle is located in the district of the Old Town in the centre of Cracow, on the Wawel Hill, on the left bank of the Vistula River. There are two historic complexes on a hill site: the Royal Archcathedral Basilica of Saints Stanislaus and Wenceslaus and the Wawel Royal Castle. Entrance to the complex is possible through the Arms Gate or Bernardine Gate. The history of the first royal residence on Wawel Hill dates back to the turn of the 10th and 11th centuries. At that time, during the reign of the Piast dynasty, Wawel remained a timber-earth castle (Wawel Royal Castle, n.d.). Over the years Castle has undergone many changes and is now described as a Renaissance-Baroque building (Fig. 1).

The primary lighting of the Wawel Royal Castle was provided by oil lamps (Drabik, 2014). In 1857, the first gas lamps were lit in the Main Square. And then in 1893, the replacement of oil lamps with gas lighting was completed. Due to the appearance of lighting powered by electricity, gas lighting became obsolete

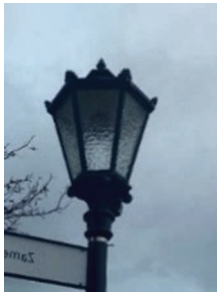
and in 1912 its replacement began. In 1939 there were already 5279 electric lamps in Cracow and in 1936 the most important monuments in the city were illuminated. The current illumination of the Wawel Royal Castle dates from 2009 when 510 light sources were mounted.

Fig. 1. View of the Wawel Royal Castle from the western side (by Jakub Łygan)

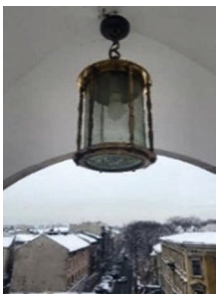
6. Methodology of research conducted in the Wawel Royal Castle

During the research sources of light were identified and divided according to their type (Tab. 1). Information on the location of the light sources, their type, colour, and direction of light beams was also collected.

Table 1. The classification of light sources present in the area of the Wawel Royal Castle

Type of light source	Photo	Definition
Park lamps		These lamps are located along the traffic routes leading to Wawel Castle. The light source is placed on a green pole, whose approximate height is 4.30 metres. The luminaire is made of metal and the cover is made of frosted glass.
Old-fashioned lamps		The lamps located in the Wawel Castle area, are made in a retro style. The cover is made of frosted glass, while the pole is made of metal painted black. The height of the pole on which light sources are placed is approximately 2.80 metres.

https://doi.org/10.37705/TechTrans/e2024012

Facade lamps		Any kind of external lighting mounted on the walls of buildings. They have a cover made of frosted glass and a luminaire made of metal. They are usually hung on the façade with a hook and a chain.
Suspended lamps		The lamps are suspended under the vaults of gates, passages, and buildings. Their cover is made of transparent or semi-transparent glass and the luminaire is made of metal.
Wall lamps		Light sources built in the walls surrounding the Wawel Castle and all walls within its area. They are mounted in a metal enclosure and designed to illuminate traffic routes.
Pavement lamps		Any kind of light source placed in the ground of traffic routes, lawns and paved surfaces around buildings.
Floodlights		The lamps emitting beam of light in the designated direction. Their purpose is to illuminate monuments located in the Wawel Castle area.
Illuminator lamps		Floodlights used to illuminate plants. They are located in the external courtyard of the Wawel Castle.

Based on collected data and taking into account environmental, economic and technical aspects, the performance of outdoor lighting was assessed by dividing it into four categories:

- correct lighting – no change is required; lighting does not contribute to occurrence of light pollution;
- partially correct lighting – a change is required; lighting contributes to occurrence of light pollution with little impact;
- incorrect lighting – a change or removal is required; lighting contributes to the occurrence of a light pollution with large impact;
- lighting excluded from use.

It is also worth explaining the following terms used in this paper:

- cover – a transparent or semi-transparent part of the lamp, which protects the filament;
- luminaire - a non-transparent part of the lamp which protects the light source from both mechanical damage and the chaotic scatter of light;
- pole – a mast, where luminaire and cover are mounted;
- reflector – a non-transparent structure placed inside the cover to restrict or direct light in the desired direction.

7. The assessment of the functioning external lighting in the Wawel Royal Castle

7.1. Park lamps

At first, the park lamps were taken into consideration. These are light sources located along routes leading to the area of Wawel Hill. They emit white light with a low correlated colour temperature and a wide spatial distribution (Fig. 2). Although lamps fulfil their role of illuminating the pavement, the light emitted is scattered. This phenomenon is intensified by the high pole height. What is more, lamps can cause glare due to the high light intensity. Therefore, the park lamps were classified as partially correct lighting.

In order to improve their functioning, it is proposed to decrease the height of poles where light sources are mounted. It is also worth moving filament at a maximum height in a cover to reduce light scattering. In addition, it is suggested to use a reflector inside the cover to reflect light through the ground direction.

Fig. 2. Example of a park lamp at night (by Jakub Łygan)

Fig. 3. Example of an old-fashioned lamp at night (by Jakub Łygan)

https://doi.org/10.37705/TechTrans/e2024012

7.2. Old-fashioned lamps

The old-fashioned lamps are another group being discussed. This kind of lamp appears in the area of Wawel Hill in a number of 4. They emit light with a bit lower correlated colour temperature than the park lamps (Fig. 3). Although the old-fashioned lamps are shielded from above, the filament in a luminaire is placed not high enough. This leads to light emission in all directions, including upwards. They were classified as partially correct lighting. Their performance may cause glare and make a small contribution to the formation of skyglow.

As in the case of the park lamps, it is proposed to move the filament to a maximum height in a cover to reduce light scattering and use a reflector inside the cover. Furthermore, an increase in correlated colour temperature and an increase in light intensity would reduce the occurrence of glare.

7.3. Façade lamps

The façade lamps are present almost all over Wawel Hill. They emit light with a warm colour, which, as in the case of lamps discussed above, is scattered, and makes a contribution to the presence of light pollution. Some of the façade lamps illuminate the adjacent wall instead of the ground which makes them incorrect lighting (Fig. 4). It should be noted that lamps mounted on the walls of the conference centre have reflectors inside their cover (Fig. 5). These lamps and mounted along the way to the castle were classified as correct lighting. The remaining façade lamps due to the lack of reflectors were categorized as partially correct lighting.

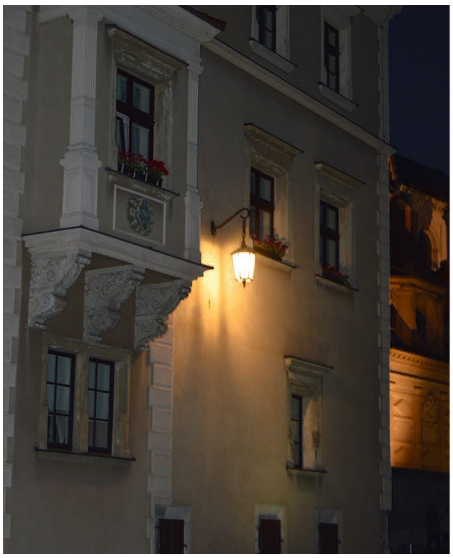


Fig. 4. Façade lamp illuminating improperly (by Jakub Łygan)

Fig. 5. Façade lamps as the correct lighting (by Jakub Łygan)

Incorrect lighting should be removed or adjusted by decreasing its height above the ground to make it possible to illuminate traffic roads. For all other lamps, it is suggested to use reflectors like in these façade lamps mounted on the walls of the conference centre.

7.4. Suspended Lamps

Suspended lamps are one of the smallest groups of light sources present in the area of the Wawel Royal Castle. There are two lamps that cause glare located close to Arms Gate and they are an example of incorrect lighting (Fig. 6). All the other suspended lamps were classified as correct lighting.

To improve performance of incorrect lighting the cover should be changed to a semi-transparent one with a reflector inside.

Fig. 6. Glare caused by suspended lamp (by Jakub Łygan)

7.5. Wall lights

A further light source to be assessed are wall lights. They emit a beam of low-intensity light downwards at angle of approximately 45° (Fig. 7) and are designed to illuminate the pavement. These light sources do not influence the occurrence of light pollution.

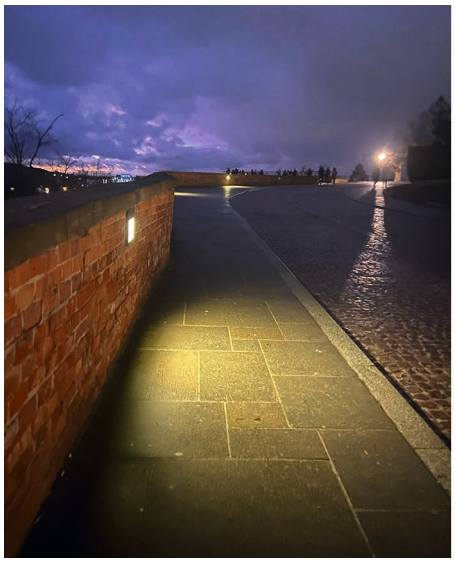


Fig. 7. Example of wall light at night (by Jakub Łygan)

Fig. 8. Wall light excluded from use (by Jakub Łygan)

Wall lights mounted at the level of Cathedral Museum and Seminary are excluded from use. Lamps look neglected and it has not been possible to verify their working condition (Fig. 8). Due to their appearance, it is suggested to replace them with wall lights similar to these mounted in the other parts of the wall.

https://doi.org/10.37705/TechTrans/e2024012

7.6. Pavement lights

Lamps with circular (Fig. 9) or rectangular (Fig. 10) luminaries made of stainless steel and cover of semi-transparent tempered glass or frosted tempered glass in the case of lamps mounted in lawn (Fig. 11) fell into this category.

Fig. 9. Circular pavement light (by Jakub Łygan)

Fig. 10. Rectangular pavement light (by Jakub Łygan)

Fig. 11. Circular lamp mounted in the pawn (by Jakub Łygan)

Lamps with circular luminaries placed nearby Arms Gate, Vasa Gate, Danish Tower, Thieves Tower and the Statue of John Paul II are examples of incorrect lighting (Fig. 12). The light beam is emitted at an angle of 90° to the ground, so it does not illuminate the targeted object. Thus, it results in intensification of the sky glow. Moreover, pavements lights cause glare and in bad weather condition they may be dangerous due to risk of slipping.

Pavement lights installed in the recesses of Hen's Foot are an example of correct lighting (Fig. 13). Due to the positioning of the lamps in the recesses, close enough to the walls, the light beam is limited by the arcades. Next to the Hen's Foot is the Danish Tower, where the lamps are installed in a similar way, but the light beams have no limited way out and increase the phenomenon of artificial sky glow.

Fig. 12. Pavement lights located next to the Vase Gate (by Jakub Łygan)

Fig. 13. Illumination of the Hen's foot (by Jakub Łygan)

Lamps with rectangular luminaries are placed along the wall at the level of Cathedral Museum and Seminary. During the research phase all these lamps expect the one were out of use. The lamp in operation is an example of incorrect lighting as emitted light goes above the horizontal plane.

Both rectangular and circular pavement lights installed in the ground are example of incorrect outdoor lighting (Fig. 14). They inefficiently illuminate the space, wasting electricity and can contribute to the brightening of Cracow's night sky by directing light beams into the sky.

It is suggested to remove all pavement light with the exception of lighting located in the recesses of Hen's foot. Where lighting is necessary, it is proposed to use lamps emitting light towards the object. The light emitted by the lamps should be directed from top to bottom, directly at the object, so as not to contribute light pollution.

Fig. 14. Pavement lights installed in the pawn at night (by Jakub Łygan)

7.7. Floodlights

The first floodlights to be analysed are those used to illuminate the Sandomierz Tower (Fig. 15). In total, ten floodlights illuminate the tower, however three of them are out of use. One of the other floodlights illuminating the tower from its western wall is an example of an incorrect light source It emits high-intensity light beam that is scattered and, apart from Sandomierz Tower, illuminates the conference centre and the road (Fig. 16). This results in formation of artificial sky glow and cause glare and trespassing. Remaining floodlights have been assessed as partially correct lighting. They can cause glare and their light colour temperature could be higher. For the same reason floodlights illuminating Thieves Tower from western and eastern side were classified as partially correct lighting (Fig. 17).

Floodlights used to illuminate the back wall of administration building do not contribute to formation sky glow, but their installation is incorrect (Fig. 18). Light sources are embedded in the wall too high or at too large angle, so that part of the light beam is reflected from the edge of the wall. Thus, it results in loss of energy.

Fig. 15. Illumination of the Sandomierz Tower (by Jakub Łygan)

Fig. 16. Set of floodlights at night (by Jakub Łygan)

https://doi.org/10.37705/TechTrans/e2024012

Fig. 17. Illumination of the Thieves Tower (by Jakub Łygan)

Fig. 18. Incorrectly mounted floodlight (by Jakub Łygan)

Floodlights placed on the south-west part of Presbytery's roof exemplify incorrect lighting (Fig. 19). They emit light to the upper parts of the administration building and conference centre (Fig. 20). Lighting leads to trespassing and waste of electricity. It is pointless to illuminate these buildings as it does not serve to emphasis their architectural qualities and it is possible to emit light into the space if the light beam is directed close to the roof.

Fig. 19. Floodlights located on the Presbytery's roof (by Jakub Łygan)

Fig. 20. Illumination of the administration building (by Jakub Łygan)

Subsequently flood lights from the opposite side of Presbytery's roof were taken into consideration. They are used to illuminate Clock Tower (Fig. 21), Silver Bell Tower (Fig. 22) and façade of the Wawel Cathedral.

Floodlights illuminating the Clock Tower and façade of the cathedral were assessed as partially correct light sources. The beam of light is directed at the boundary between the dome and the tower walls. The floodlights are mounted high enough that the risk of flare to pedestrians is negligible. The intensity of the light emitted is not high, but the colour seems too cold. Whereas, floodlights illuminating the Silver Bell Tower were classified as incorrect lighting. Light beam is directed at the roof of the tower, which results in emission of light into space and consequently formation of artificial sky glow.

On the roof of the Royal Kitchens nine floodlights are installed, which are responsible for illuminating the south façade of the cathedral and the Silver Bell Tower (Fig. 23). The light emitted by these floodlights directed towards the façade is characterized by low intensity and white colour. Meanwhile, the two floodlights illuminating the Silver Bell Tower are similar to the others illuminating this tower (Fig. 24). Thus, they were assessed as incorrect light sources, while the remaining, due to clutter phenomena, were classified as partially correct light sources.

Close to the Arms gate, there are floodlights classified as incorrect lighting. They make a contribution to the formation of the sky glow and cause glare.

Fig. 21. Illumination of the Clock Tower (by Jakub Łygan)
Fig. 22. Illumination of the Silver Bell Tower (by Jakub Łygan)

Fig. 23. Example of clutter phenomenon (by Jakub Łygan)
Fig. 24. Illumination of the Silver Bell Tower and façade of cathedral (by Jakub Łygan)

Fig. 25. Illumination the Sigismund Tower and Kosciuszko monument (by Jakub Łygan)

https://doi.org/10.37705/TechTrans/e2024012

Light sources are used to illuminate the Kosciuszko monument, the Sigismund Tower and the Clock Tower (Fig. 25). A part of the light beam directed at the Sigismund Tower is emitted above the horizontal plane. This light is characterised by its high intensity and cool colour. The same applies to the beam of light directed at the Clock Tower. In the case of the Kosciuszko monument, the beam of light directed towards it also illuminates the buildings behind.

The Senator Tower is illuminated by three floodlights. Its western wall is illuminated by floodlight 65 metres away, which is incorrect light source (Fig. 26). Shaft of light is directed into the area between the edge of the roof and walls, so that the roof is also illuminated. This may result in the phenomenon of brightening night sky, by emission of light into the environment (Fig. 27). Eastern wall is illuminated by two floodlights 10 metres away, Due to the excessive presence of other light sources they were classified as partially correct lighting. Next to them there is a set of three floodlights illuminating the south wall of the Royal Palace which are an example of incorrect light sources (Fig. 28). The light beam emitted by them is sent out at an incorrect angle, which results in its emission into a space, contributing the formation of night sky glow.

Fig. 26. Light beam emitted by headlight directed into Senator Tower (by Jakub Łygan)

Fig. 27. Illumination of Senator Tower (by Jakub Łygan)

Fig. 28. Illumination of southern façade of the Royal Palace (by Jakub Łygan)

The eastern facade of the Royal Castle, including the towers there, is illuminated by 27 floodlights in total. Floodlights located in the wall of the upper terrace of Royal Gardens were identified as partially correct lighting (Fig. 29). They emit white light with a high colour temperature, which is directed at façade at an angle that prevents the light from emitting into half-space. However, some of emitted light falls on the plants in the Garden. Floodlights standing along the wall in the lower terrace of the Royal Garden are incorrect light sources (Fig. 30). Due to their excess, they cause a clutter phenomenon.

Fig. 29. Example of lighting located in the upper terrace of Royal Gardens (by Jakub Łygan)

Fig. 30. Example of glare caused by headlights located in the lower terrace of Royal Gardens (by Jakub Łygan)

They emit white light characterised by high intensity, which can cause a glare effect. Part of the light is directed to the roof of the Royal Palace and on the domes of the towers, unintentionally illuminating the chimneys (Fig. 31). This means that light is emitted above the horizontal plane, increasing the brightness of night skyglow. Some of the emitted light also falls on the plants. Two floodlights located in the south-east corner of the wall were identified as incorrect light sources. Due to their incorrect mounting and the angle of the emitted light, the beam is not properly directed.

Fig. 31. Illumination of the eastern façade of the Royal Wawel Castle (by Jakub Łygan)

To reduce the impact of floodlights on the formation of light pollution, these installed on the south-west part of Presbytery's should be removed. Then due to the clutter it is suggested to remove some of floodlights installed on the roof of the Royal Kitchens and on the lower terrace of Royal Garden. For light sources located in the wall of the upper terrace of Royal Gardens it is proposed to reduce the angle of the floodlights in relation to the ground. In addition, it is proposed to remove one of the floodlights illuminating the western wall of the Sandomierz Tower. Floodlights illuminating towers, facades should be fitted with cover panel, allowing the light emitted to be directed towards the object and limiting the emission of light above the horizontal plane. It is also suggested that the angle of the floodlights, which illuminate the back wall of the administration building, should be reduced in relation to the ground. It can be also possible to change their reposition by bringing them forward so that the light emitted is not reflected off the top edge of the wall.

7.8. Illuminators

Illuminators were classified as incorrect lighting. They are used to illuminate plants that should be free from artificial light (Fig. 32). What is more, illuminators emit high-intensity light beam with high colour temperature. They can also cause glare.

Due to the negative impact that artificial light has on plants, it is proposed to remove these light sources.

Fig. 32. Light pollution phenomenon caused by illuminators (by Jakub Łygan)

https://doi.org/10.37705/TechTrans/e2024012

8. Summary

A total of 294 light sources (Fig. 33) were inventoried. 82 of them were classified as incorrect light sources, 59 as correct light sources, 63 as partially correct light sources and others were not available or there were out of use. To summarize gathered information two maps were created. The first one shows the spatial distribution of categorized light sources with information on their location (Fig. 34). While the second map presents assessment of inventoried light sources (Fig. 35). Following phenomena were identified during the research: wasting electricity, glare, clutter, excessive lighting and increasing brightness of night sky glow. There are also a number of light sources on the Wawel Hill that exemplify wasting electricity. In an era of high electricity charges, unnecessary lighting generates additional costs that burden to the Castle manager's budget. Additionally, artificial light may lead to a variety of adverse effects on humans, wildlife and vegetation present on the Hill. However, potential changes proposed in this paper will reduce the formation of light pollution and will also have a positive impact on enhancing the historical and architectural features of the buildings on the Wawel Hill. There are plans to continue research on the contribution of the outdoor lighting of the Wawel Royal Castle to the occurrence of light pollution. This will involve conducting measurement studies using a Sky Quality Meter (SQM) to assess the quality of the night sky. Additionally, an inventory of the external lighting of the castle will be carried out at different times of the year to observe the seasonal operation of the lighting system. Finally, the research will include assessing the impact of light sources that were previously inaccessible.

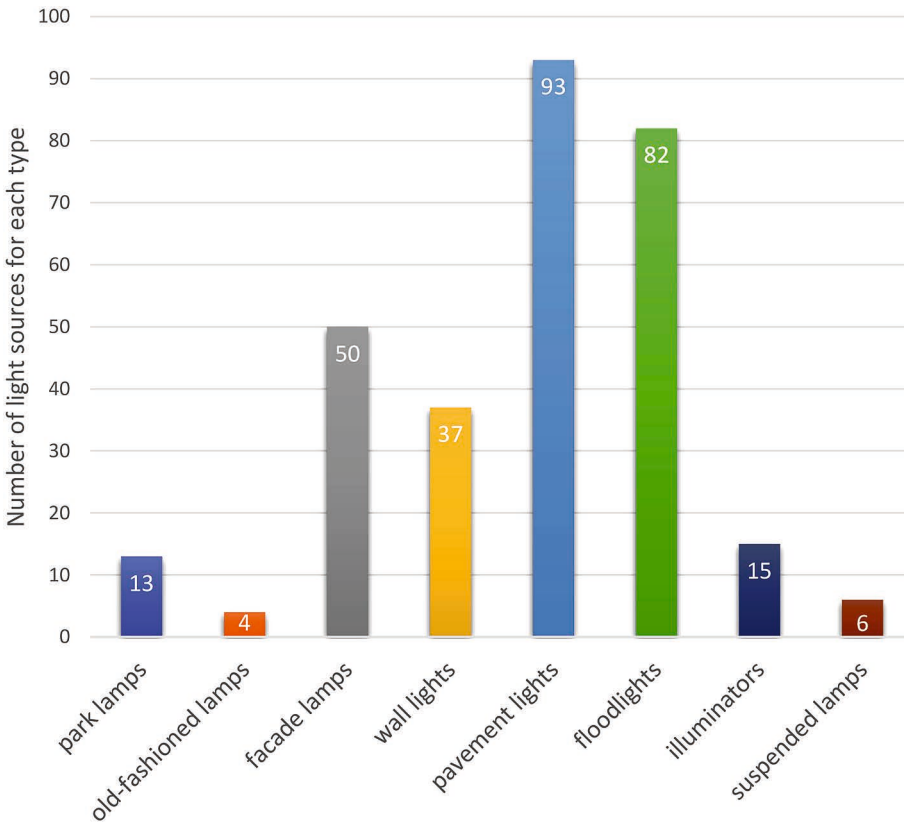


Fig. 33. The number of inventoried light sources for each type (by Jakub Łygan)

Fig. 34. Map of spatial distribution of categorized light sources (based on: © authors Open Street Map)

Fig. 35. Map of light sources assessment (based on: © authors Open Street Map)

https://doi.org/10.37705/TechTrans/e2024012

References:

Berry, R.L. (1976). Light Pollution in Southern Ontario. *Journal of the Royal Astronomical Society of Canada 70*, 97–115.

Bylinowska, U., Czaplicka, A., & Ściężor, T. (2019). Oświetlenie zabytków w Krakowie na przykładzie kościoła Świętego Józefa w Podgórzu. *Aura*, 14–17.

Dobiesz, M., Ziółkowska, A. (2015). *Wpływ zanieczyszczenia światłem na wędrówki ptaków*. III Ogólnopolska Konferencja na temat Zanieczyszczenia Światłem, Kraków.

Drabik, P. (2014). Od latarni umarłych po iluminację Sukiennic, Dziennik Polski. Retrieved from https://dziennikpolski24.pl/od-latarni-umarlych-po-iluminacje-sukiennic/ar/3580393 (access: 25.04.2024).

Esmund, I., Kotra, A., Ściężor, T., & Czaplicka, A. (2020). Oświetlenie Rynku Głównego w Krakowie jako źródło zanieczyszczenia świetlnego. *Aura*, 3–6.

Kaleta, T. (2007). Wpływ niektórych antropogenicznych zmian środowiskowych na zachowanie się zwierząt. *Życie Weterynaryjne 82*(5), 375–379.

Kostecka, J. (2017). Zanieczyszczenie sztucznym światłem a świadczenia ekosystemów i zdrowie człowieka. cz. 2. *Polish Journal for Sustainable Development 21*, 59–69.

Kubala, M. (2017). „Prawo lombardzkie" jako przykład wzorcowego podejścia do walki z zanieczyszczeniem świetlnym. *Aura*, 11–13.

Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 7 grudnia 2023 r. w sprawie ogłoszenia jednolitego tekstu ustawy – Prawo ochrony środowiska (Dz.U. 2024 p. 54).

Sala, K. (2020). Zanieczyszczenie świetlne. *Zagrożenia i sposoby jego ograniczania 6*, 254–266.

Ściężor, T. (2015). *Light Pollution Monitoring Laboratory*. Retrieved from http://lightpollution.pk.edu.pl/ (access: 25.04.2024).

Ściężor, T. (2020). Light pollution as an environmental hazard. *Technical Transactions 116*, 129– 142.

Szlachetko, K. (2022). *Memorandum w sprawie ustanowienia prawnych podstaw zrównoważonej polityki oświetlenia zewnętrznego*. Instytut Metropolitalny.

Tałanda, J. (2015). Ekologiczne zanieczyszczenie światłem, czyli kiedy sztuczne światło w nocy zaburza cykl światła i ciemności w ekosystemie. *Kosmos 64*(4), 611–616.

Uniwersytet Wrocławski. (2008). *Zanieczyszczenie światłem*. Retrieved from http://www.astro.uni.wroc.pl/ciemna-strona-swiatla/css2/css2.html (access: 25.04.2024).

Verheijen, F.J. (1985). Photopollution: artificial light optic spatial control systems fail to cope with. Incidents, causation, remedies. *Experimental Biology 44*(1), 1–18.

Walker, M.F. (1973). Light Pollution in California and Arizona. *Publications of the Astronomical Society of the Pacific 85*(507), 508–519.

Wawel Royal Castle. (*n.d.*). *The History of the Royal Palace* Retrieved from https://wawel.krakow.pl/en/the-history-of-the-royal-palace (access: 25.04.2024).

Wiehle, K., Czaplicka, A., & Ściężor, T. (2022). Oświetlenie budynków Teatru im. Juliusza Słowackiego w Krakowie jako źródło zanieczyszczenia świetlnego. *Kosmos 71*, 165–172.

Williams, T. (2023). *A Summer Light Show Dims: Why Are Fireflies Disappearing?* Retrieved from https://e360.yale.edu/features/fireflies-glow-worms-lightning-bugs-decline (access: 25.04.2024).

Wojciechowska, R. (2019). Czy oświetlenie nocne może zaburzać funkcjonowanie roślin? In A.Z. Kotarba (Ed.) *Zanieczyszczenie światłem. Źródła, obserwacje, skutki* (pp. 39–54).