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Article

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High-mast lighting as an adequate way of lighting pedestrian paths in informal settlements?

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ABSTRACT

Lighting of pedestrian paths fulfils crucial needs for informal settlement dwellers. A common technological approach in some countries to address these needs is to provide high-mast luminaires. In this paper it is shown by computer simulation that those luminaires are not able to create adequate consistent lighting conditions in common forms of informal settlements. Illuminance uniformity requirements are not met within the entire pedestrian path network. Furthermore, a significant part of the light is emitted on the dwellings' roof and hence results in light pollution.

1. Introduction

The night-time condition in informal settlements is often characterised by a lack of light on pedestrian path networks. This is mainly caused by the deferred provision of infrastructure by the authorities after an informal architectural structure was built. And even in cases where informal settlements have already been formally supplied with public lighting, a lack of lighting in certain areas can recur because of immigration and expansion of the settlement boundaries (Ravindra Prasad and Malla Reddy, 1994). There are a variety of reasons to support the premise that the lighting of pedestrian paths during night-time is beneficial to the residents of the community – both in formal and informal environments. Lighting can be beneficial, for instance by helping residents of informal settlements to safely find their way to communal toilets after sunset (Musembi, 2015) or by helping them to avoid snakes and stray dogs (Ravindra Prasad and Malla Reddy, *op. cit.*). It also enables people to run their businesses later into the night (UN-Habitat, 2011), thereby supporting economic empowerment, since the informal street is a place of work, shopping and commercial activity (Bhatt and Rybczynski, 2003). Furthermore, informal settlement residents service the formal city, where they may represent up to half of the workforce (Dovey and Kamalipour, 2018); hence, adequate lighting conditions are necessary for their daily commute to work.

Even basic human activities such as walking require an illuminance quantity that natural moonlight can only provide in rare situations. The age-dependent photopic illuminance requirement ranges from 0,22 lx for young people to 0,93 lx for older people to detect a 10 mm obstacle at a distance of 3,4 m (Fotios and Uttley, 2018). However, the highest

natural illuminance under optimal night-sky conditions (i.e. a full moon at 90° altitude) is only 0,27 lux (Kuphal, 2013). This would barely fulfil the lower end of Fotios and Uttley's (2018) required 0,22 lux, which stresses that even for young people with good vision, additional artificial light is required in most night sky conditions to ensure safe walking. Hence, a minimum photopic illuminance of 1,0 lx is regarded as adequate for pedestrians of all ages to safely detect and avoid trip hazards (Ibid.). In addition, Boyce (2019) describes two mechanisms through which lighting can indirectly affect crime. Firstly, lighting enables people on the street during hours of darkness to observe their environment more clearly and recognize the intentions of others; furthermore, it enables surveillance by the authorities and the community in general. Secondly, an investment in improved lighting might affect the level of crime through increasing community confidence and hence the degree of informal social control. Furthermore, according to Boyce (Ibid.), lighting can affect not only actual crime but also the fear of crime by supporting pedestrian reassurance at night. This illustrates the importance of adequate artificial lighting in informal settlements.

Although informal sites can be found that are subdivided “into *uniform lots with conventional street grids*” (Davis, 2007, p. 41), there are also informal settlements that are characterised by a complex non-uniform layout consisting of paths of varying and often inconsistent widths as well as limited linearity: Kamalipour and Dovey (2019) describe the urban morphology of informal settlements in the Global South as dense, small-grain and irregular. Combined with haphazard building structures, this can easily lead to technical challenges when it comes to the provision of lighting. Moreover, those building structures may block out incident light from sources high above such as the moon or street

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Fig. 1–4. Example of high-mast lighting in Johannesburg, South Africa (David M. Kretzer, 2017).

luminaires: [Brillembourg and Klumpner \(2005\)](#) have for example reported cases in Caracas where the daylight penetration to the ground is only 7%. Hence, a similar ratio can be expected from the relationship of a building and light sources that are located above the same building structure. A possible technological strategy to cope with the lighting of complex structures such as informal settlements is the installation of high-mast luminaires - column and luminaire assemblies that are 20–40 m high ([CIE, 1996](#)) - as can be found, for instance, in South Africa and Kenya (see for example [Fig. 1–4](#)).

Previous publications have addressed the potential effect of stigmatisation caused by high-mast lighting in informal settlements, attributing the creation of a military ([Mayekiso, 1996](#)) or prison camp ([Hornberger, 2008](#)) feeling to it. In addition, [Uhrig \(2015\)](#) points out the importance of considering human perception for the specification of a public luminaire's height and design. Specifically, he argues that the luminaire geometry should take into account the proportionality between road width, roof height and the empty space in between. Hansen defines “human scale” as an important urban design quality, referring to “physical elements that match the proportions and size of humans” ([2014, p. 153](#)). [Ewing \(2013\)](#) argues that the definition of *human scale* would be a debatable point; however, he states with respect to buildings that experts would set a range of three to six storeys. In addition, he suggests that street trees can moderate the scale of wide streets and tall buildings.

Furthermore, an improvement of the night-time conditions created by high-mast lighting (compared to no public lighting) in informal settlements have been reported via subjective ratings ([The Steadman Group, 2006](#)). However, the technical lighting implications of applying high-mast lighting technology in informal settlements have been understudied. Lighting literature points out the risk of deep shadows cast by objects lit by high-mast luminaires ([Tulla, op. cit.](#)). Therefore, the goal of this paper is to quantitatively evaluate the lighting quality created by high-mast luminaires in an informal urban fabric, addressing the research question to *what extent do high-mast luminaires constitute an adequate technological solution to light informal settlements with regards to the lighting conditions created?*

2. Material and methods

To address this question, a computer-based simulation research strategy was conducted. The software used for the calculation was Dialux 4.13. The *CIE Technical Report 180:2007* was selected as the evaluation criterion for this calculation,¹ serving as the definition of an ‘adequate’ lighting condition.

In order to evaluate the lighting conditions created by high-mast lighting, a ‘best case model’ of an informal settlement was created, and lighting calculations of the illuminance distribution in this

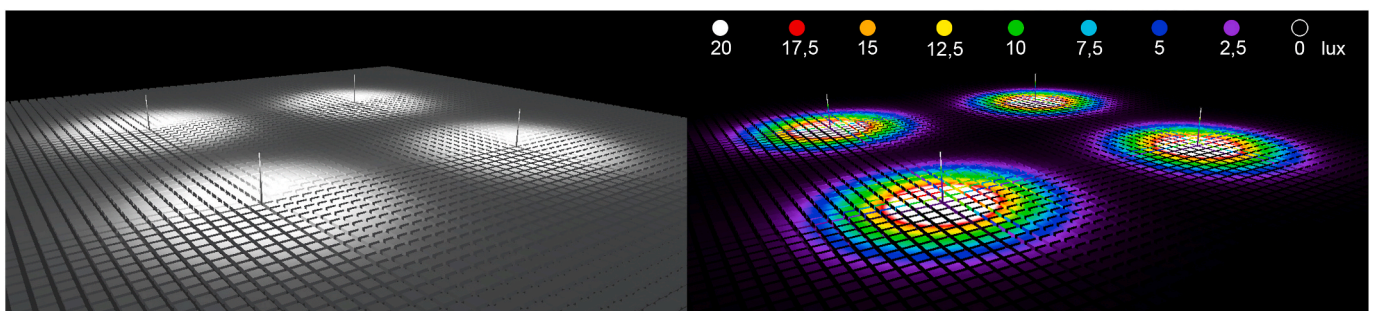


Fig. 5. Illuminance distribution in the hypothetical model of 5625 dwellings (rendering and pseudo colours).

In contrast, installing high-mast lighting in informal settlements is creating the opposite effect: Within narrow streets and low dwellings, a physical element is placed that is multiple times higher than its surroundings. In this regards, [Tulla \(2016, p. 10\)](#) states that “[i]n residential areas, columns should be no higher than the eaves of the adjacent buildings”.

¹ This lighting standard defines rather low requirements (see section 4.1) compared to many national standards (for example, there are no vertical illuminance requirements defined). This results in evaluation conditions in favour of high-mast lighting.

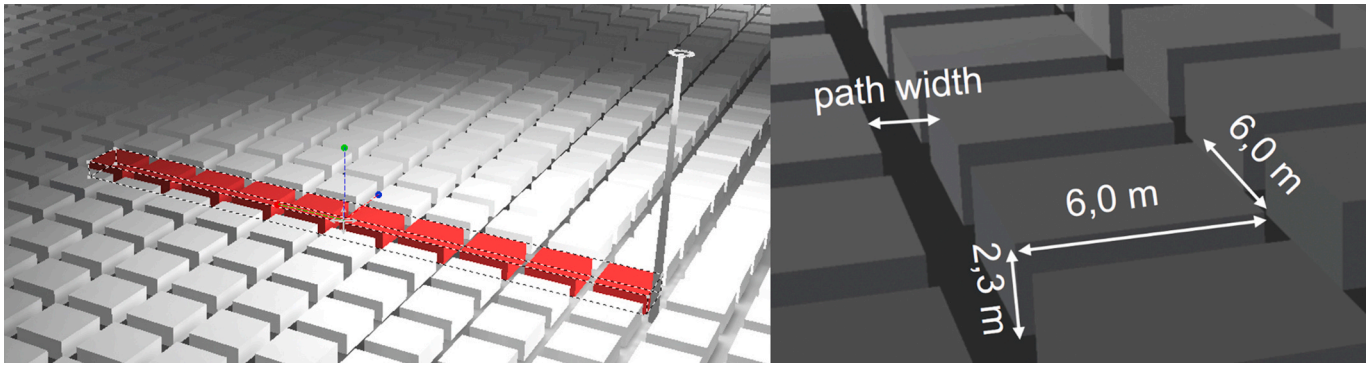


Fig. 6-7. A row of 10 dwellings was closer analysed (see also Fig. 10); the dwelling and path dimensions.

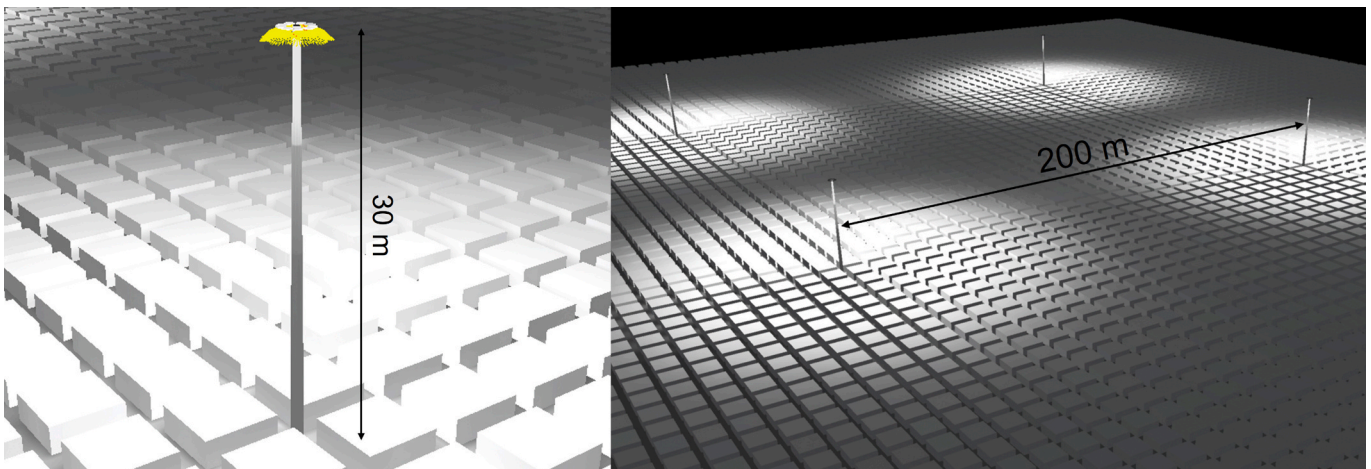


Fig. 8-9. High-mast luminaires' height and spacing.

hypothetical model were conducted. 5625 informal dwellings (each having the dimensions of $6 \times 6 \times 2,3$ m (length \times width \times height)) were placed in a regular array and lit by four high-mast luminaires (see Figs. 5-7). Bearing in mind that a precise and universally valid definition of dwelling dimensions is not possible due to local differences and non-enforcement of building regulations, these dwelling dimensions were specified based on a review of the extant literature, combined with informal field observations. The dwelling footprint specification was based on the findings of Kamalipour and Dovey (2018), who analysed the morphology of informal settlements in Bangkok, Medellín and Pune. The lot size in Bangkok ranged from 20 m^2 to 60 m^2 (100% site coverage) and in Medellín from 30 m^2 to 70 m^2 (without mentioning the site coverage). Regarding the settlement in Pune, the dwelling footprints (instead of the lot size) ranged between 15 m^2 to 45 m^2 . Hence, the dwelling footprint used for this model ($6 \times 6 = 36 \text{ m}^2$) was chosen to lay within their research results, while also corresponding with informal observations and estimates in the field. The dwellings' height of 2,3 m, on the other hand, was based solely on estimates reached during informal settlement site visits (see, for example, Fig. 1-4).

Each dwelling had matt surfaces with a reflectance of 0,5, and the floor's matt surface a reflectance of 0,3. The intention of creating a 'best case model' (i.e. model conditions in favour of the application of high-mast lighting) was to illustrate that in case the lighting conditions would not even be adequate under a 'best case condition' (i.e. a regular array of dwellings, single-storey dwellings, a medium dwelling reflectance, a medium path widths), they would certainly not be adequate when applied in a complex non-regular array with narrower path widths, low dwelling reflectance values and multiple-storey dwellings.

The dwellings' reflectance, for example, was assumed to be 0,5 for the 'best case' calculation (resulting in 50% absorption of light); however, the reflectance values of certain building materials can also be expected to be significantly lower: raw bricks, for example, have a reflectance of around 0,1 to 0,15 (Ulmann, 2015) which means that more light would be absorbed by a dwelling and hence less light would be reflected from the dwelling façades onto the paths. Furthermore, calculation results coming from a regular dwelling array allow a better transferability (in order to predict lighting conditions in other informal environments) compared to results that are derived from a random array.

For the model, each high-mast light incorporated 9 single luminaire heads arranged in a circle. Each of these 9 luminaire heads had a power consumption of 322 W, resulting in a luminous flux of 35 624 lm. Consequently, each of the 4 high-mast luminaires had a total power consumption of 2898 W resulting in a total luminous flux of 320 616 lm. These data as well as the related photometric files were derived from a luminaire manufacturer, who recommends using a high-mast luminaire spacing of 300 m and a high-mast luminaire height of 30 m for this type of luminaire when applied in informal settlements (see Fig. 8-9). Furthermore, 30 m also represents the mid-point of the CIE's high-mast luminaire height definition (i.e. 20-40 m (see above)).

3. Calculation

To approach the research question, three different conditions (see Table 1) of the urban fabric and the location of the high-mast luminaires were simulated and calculated:

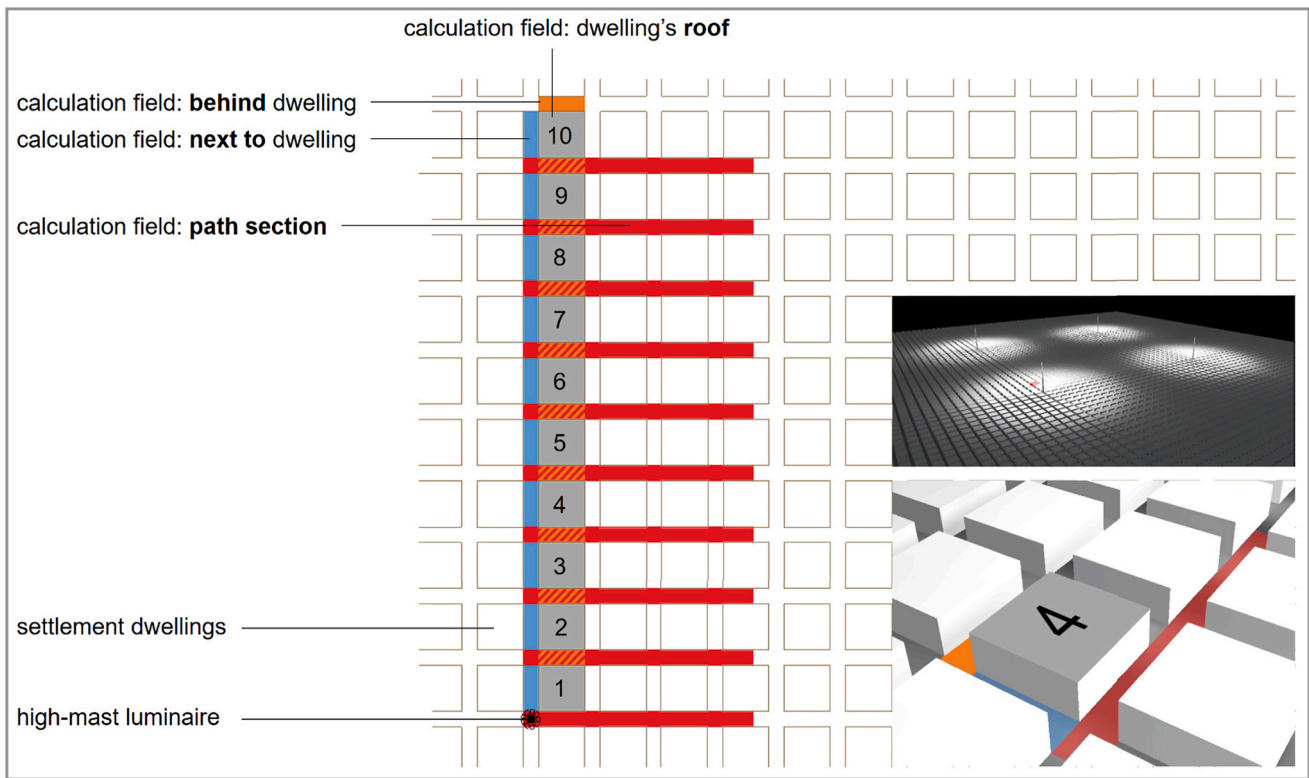


Fig. 10. Plan view (cutout) illustrating the position of calculation fields, and a three-dimensional illustration of dwelling no. 4 as example (the location of dwelling no. 4 is indicated red in the model).

Table 1
Calculation conditions.

	Luminaire spacing (m)	Path width (m)	Dwelling height (m)
Condition no. 1	200	2,0	2,3
Condition no. 2a	200	1,2 to 2,0	2,3
Condition no. 2b	200	2,0	1,5 to 2,3
Condition no. 3	100	2,0	2,3

3.1. Condition no. 1

The spacing of the luminaires was determined to be 200 m (see Fig. 9). This spacing was 100 m shorter than recommended by the luminaire manufacturer to prevent calculations close to a possible threshold range (by doing so, a condition in favour of high-mast luminaires was created); a closer spacing increases the amount of light that reaches the centre of the installation. The distance between two dwellings (and hence the width of each pedestrian path) was 2 m.

A row of 10 dwellings (starting next to a high-mast luminaire (see Fig. 6)) was selected for the evaluation of the lighting conditions by placing three calculation fields around each dwelling: 1 calculation field placed next to the dwelling; 1 calculation field placed behind the dwelling; and 1 calculation field placed on-top of the dwelling (see Fig. 10). This analysis was done in order to analyse average illuminance values within certain areas around the same dwelling in relation to their distance to a high-mast luminaire.

So as to analyse not only the average illuminance of certain areas but also the uniformity² within area, 10 path sections adjacent to the 10 selected dwellings were also evaluated. According to the CIE Technical Report 140–2000 (CIE, 2000) a calculation field of 2 × 30 m with 3 rows,

² Uniformity (U_0) is defined as the minimum illuminance (E_{min}) divided by the average illuminance (E_{av}).

each consisting of 10 calculation points (resulting in 30 calculation points for each path section) was placed on each path section (see Fig. 15). The calculation point spacing in the longitudinal direction was 3,0 m, and the spacing in the transverse direction was 0,67 m. This direct application of the CIE calculation point spacing metric³ was chosen to avoid the possible suspicion of a spacing selection in favour of certain intended outcomes.

3.2. Condition no. 2a

The width of one of the 10 path sections analysed in condition no. 1 was selected for a case analysis and reduced from 2,0 m in 0,05 m increments. Each time it was re-calculated in order to analyse the impact of different path widths on the lighting distribution (see Fig. 11). The path section selected for this calculation was the path section in front of dwelling # 2 (see Fig. 10). The calculations of condition no. 1 showed that only 1 out of the 3 calculation point rows was directly obstructed from incident light by the adjacent dwellings (see Figs. 16–18). The purpose of the calculations of condition no. 2a was to determine at what path width the second calculation point row would also be obstructed.

³ 'Calculation field width' divided by 3 and 'calculation field length' divided by 10, for calculation fields ≤ 30 m.

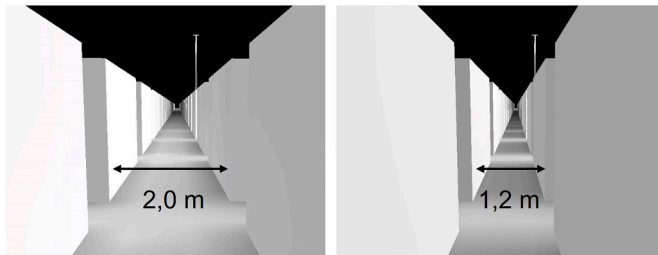


Fig. 11. Illustration of different path widths.

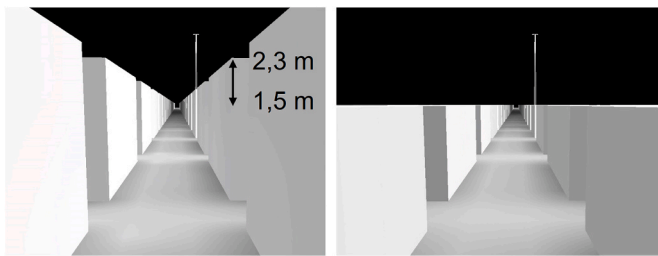


Fig. 12. Illustration of different dwelling heights.

3.3. Condition no. 2b

The dwellings' height of the same path section as in condition no. 2a (dwelling # 2, see Fig. 10) was selected for a second case analysis and reduced from 2,3 m in 0,05 m increments. Each time it was re-calculated in order to analyse the impact of different dwelling heights on the lighting distribution (see Fig. 12). The calculations of condition no. 1 showed for 2,3 m high dwellings a uniformity value of $U_0 = 0,06$ would be achieved. The purpose of the calculations for condition no. 2b were to determine at what dwelling height the uniformity U_0 would improve to 0,2 (which is the standard defined in the *CIE Technical Report 180:2007* (see section 4 'Results' below)).

3.4. Condition no. 3

The path width of condition no. 1 (i.e. 2,0 m) was maintained for this calculation. However, the high-mast luminaire spacing was changed from 200 m to 100 m (see Fig. 13) to analyse whether the findings of condition no. 1 were caused by a spacing that had been designed too

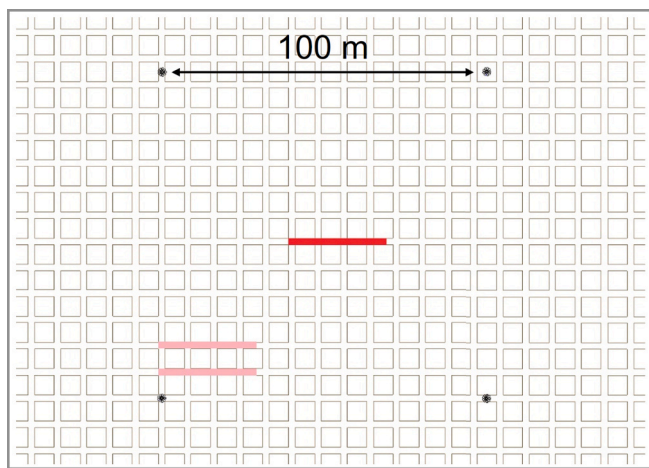


Fig. 13. Reduced luminaire spacing (condition no. 3) with the red calculation field located at the furthest distance from the 4 luminaires, and the 2 pink calculation fields representing the re-calculated path section #2 and #3 of condition no. 1 (plan view).

distant. The same CIE 140–2000 calculation field of 2×30 m (as used in 10 areas for condition no. 1) was placed at the most distant area from each of the four high-mast luminaires, namely in the centre of all 4 luminaires. Moreover, two critical calculation fields of condition no. 1 (path section #2 and path section #3 (see results of condition no. 1)) were re-calculated. By placing the high-mast luminaires closer to each other, the chance was increased that calculation points that are obstructed by adjacent dwellings (see Fig. 15b) might instead receive light from the other high-mast luminaires that are placed in other (maybe unobstructed) angles.

4. Results

The calculation results of the 3 different conditions are presented below:

4.1. Condition no. 1

The outcome of the calculation of the average illuminances next to (see blue calculation fields on Fig. 10), behind (see orange calculation fields on Fig. 10) and on the dwellings' roof (see grey calculation fields on Fig. 10) shows that the illuminance values vary significantly throughout the pedestrian path network: in extreme cases, a pedestrian might experience average illuminance ratios of up to about 1:11 around the same dwelling (see Fig. 14).

It can be assumed that this ratio derived from a regular array of dwellings is likely to be even higher in an irregular path array, as can be found in several informal settlements. Furthermore, the results show that the highest illuminance values are generally found on the dwellings' roofs, which is a questionable situation regarding its ecological implications. Energy efficiency and light pollution need to be carefully considered in this case. Light being emitted on roofs does not support residents travelling through an informal settlement. In addition, such lighting might result in negative effects such as sleep disturbance for residents inside the dwellings (if a dwelling were light-transmissive due to substandard construction quality). Furthermore, the light will be partly reflected from a dwelling's roof in the direction of the firmament so that it is likely to cause light pollution. Light pollution influences the environment in several ways: for instance, birds, insects and humans might be affected by it (Goronczy, 2018).

For the detailed analysis of the illuminance uniformity within the 10 selected path sections (see red calculation fields on Fig. 10), the illuminance values on 3 rows of 10 calculation points (see Fig. 15) are presented in Figs. 16–18. Depending on the path section, significantly different illuminance values can be found. Within a row of calculation points, the values are rather similar. However, the values of one row of calculation points compared to the values of a parallel row of calculation points (0,67 m next to it) vary significantly. The section of the path in front of dwelling 2 (path #2) illustrates this situation well: most of the calculation points in row 1 are below 5 lx. In contrast, most of the calculation points from row 2 and row 3 are above 25 lx. In that case it means that row 1 is obscured by the adjacent dwelling that casts a 'shadow' (little light still reaching the calculation points due to light reflected by the dwelling façades), whereas the high-mast luminaires' light directly reaches row 2 and row 3. The results show that the more distant a path is from the high-mast luminaire, the higher the chance that further rows are obscured by the adjacent dwelling. From path #4 onwards all 3 rows of each path (path #4–10) are obscured. Only at the path intersections are the illuminance values in some cases higher (since there is no adjacent dwelling that obscures the light at an intersection).

In order to interpret the results, the lighting requirements stated in the *CIE Technical Report 180:2007 "Road transport for lighting for developing countries"* for residential areas, pedestrians and many non-

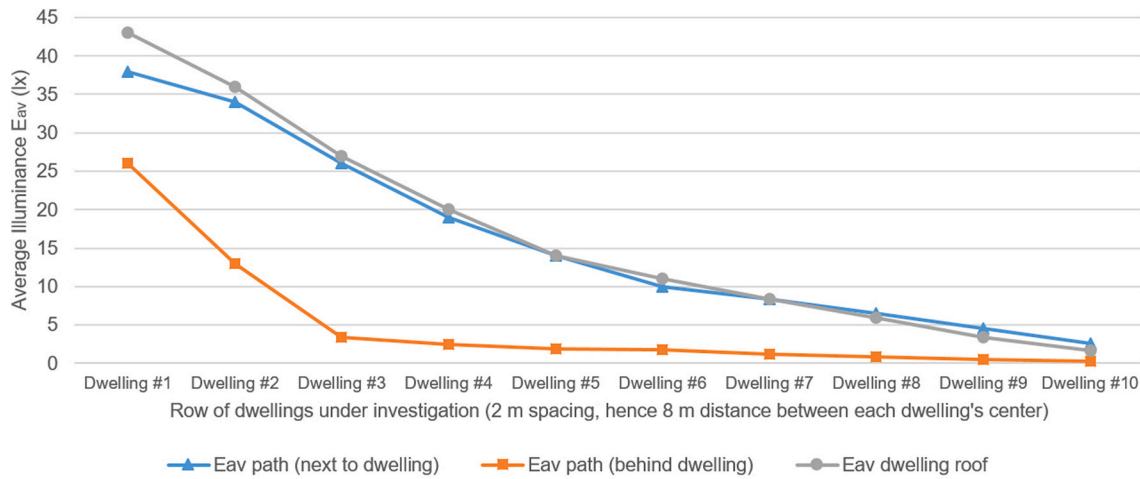


Fig. 14. Average illuminance (E_{av}) decline over distance: The average illuminance values (measured in lux) of three surfaces around a dwelling (calculation field #1 (2 × 6 m; 0 m above ground) placed next to the dwelling, calculation field #2 (6 × 2 m; 0 m above ground) placed behind the dwelling, and calculation field #3 (6 × 6 m; 2,3 m above ground) placed on the dwelling’s roof) were calculated for 10 dwellings (see Fig. 6–7 and Fig. 10) respectively with a dwelling centre-to-centre spacing of 8 m.

Table 2

Average illuminance (E_{av}), minimum illum. (E_{min}) and illum. uniformity (U_0) values of path sections #1-10.

	Path #1	Path #2	Path #3	Path #4	Path #5	Path #6	Path #7	Path #8	Path #9	Path #10
E_{av} (lx)	30,00	22,00	13,00	5,37	3,80	2,72	2,38	1,71	1,24	0,77
E_{min} (lx)	19,00	1,27	1,59	1,54	1,26	0,99	0,88	0,61	0,41	0,23
U_0	0,65	0,06	0,12	0,29	0,33	0,36	0,37	0,36	0,33	0,30

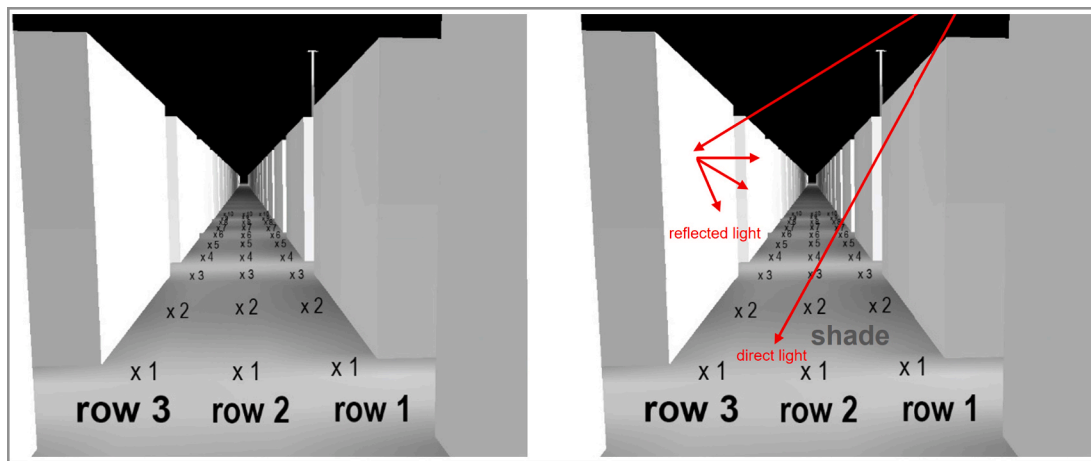


Fig. 15. Calculation point positions: each path section is measured by a field consisting of 3 rows, each having 10 calculation points (30 calculation points for each path section); the calculation results showed that some calculation point rows receive direct light coming from the high-mast luminaire, whereas adjacent row(s) only receive light reflected by the opposite walls.

motorised vehicles are referred to, namely an average illuminance (E_{av}) of 1–2 lx and a illuminance uniformity (U_0 ⁴) of 0,2 (CIE, 2007, p. 26). Except for path section #10, the average illuminance within all other 9 path sections is above 1 lx (see Table 2). Admittedly, a closer high-mast luminaire spacing can be expected to raise the average illuminance within path #10 also to 1 lx or higher.

⁴ U_0 is defined as the minimum illuminance divided by the average illuminance.

However, difficulties arise regarding the illuminance uniformity: within path section #2 and path section #3, U_0 is below 0,2. The low degree of uniformity is caused by the fact that some calculation points are directly exposed to the high-mast luminaires, whereas others only receive light through reflection as shown above (see Fig. 15). A closer high-mast luminaire spacing would unlikely solve this uniformity shortcoming (see calculation results of condition no. 3).

The results of condition no. 1 show that the lighting levels around the same informal dwelling may vary significantly when high-mast lighting is applied. Hence, a person walking between two rows of informal

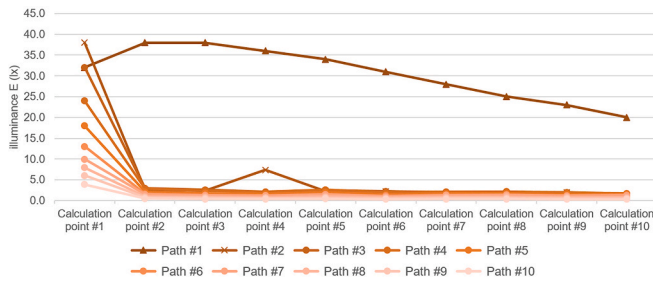


Fig. 16. Illuminance (E) value for each calculation point of row #1 of path section #1 to path section #10 (see also Fig. 15); it is shown that only within row #1 of path section #1 every calculation point receives direct light from the nearby high-mast luminaire – this is because the luminaire is located in the same axis as the luminaire (see Fig. 10) and hence not obstructed by any dwelling; the spacing between each calculation point is 3,0 m.

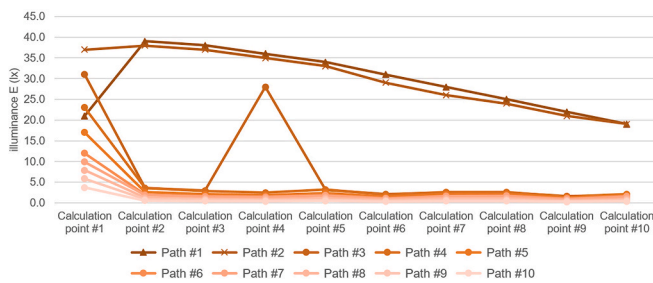


Fig. 17. Illuminance (E) value for each calculation point of row #2 of path section #1 to path section #10 (see Fig. 15).

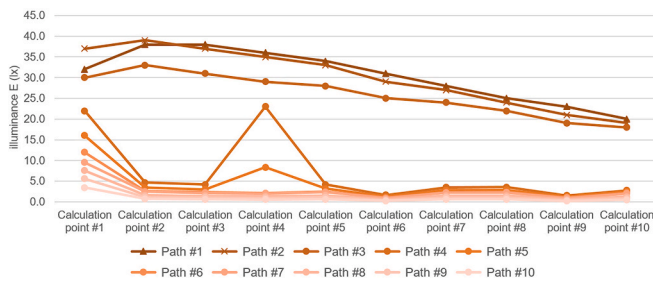


Fig. 18. Illuminance (E) value for each calculation point of row #3 of path section #1 to path section #10 (see Fig. 15).

dwelling and then turning left or right into an upcoming path might suddenly face areas of darkness. Furthermore, even within a path the lighting levels may vary significantly, which might result in areas of shade. This is likely to increase residents’ fear of crime, considering that criminals may use shaded areas as hiding places (Boyce, 2019). Moreover, some calculation point values are below 1,0 lx, which does not allow for adequate obstacle detection (Fotios and Uttley, op. cit.).

4.2. Condition no. 2a

The reduction of the path width in 0,05 m increments revealed for the selected path section (having initially a width of 2,0 m resulting in only one obstructed calculation point row #1) that at a path width of 1,2 m (see Fig. 11), calculation point row #2 (see Fig. 15) would also be obstructed. Hence, more than half of the path would be in ‘shade’ at a 1,2 m path width and an adjacent wall height of 2,3 m (at this position within the hypothetical model). This corresponds to a path width to dwelling height ratio of 0,5 under the given angles of incident light.

The results of condition no. 2a show that the density of the urban fabric, especially the path-width-to-dwelling-height ratio, impacts the degree of uniformity created by high-mast luminaires. Such results become challenging in light of informal settlements’ constant physical adaptation to what Hernández-García (2013, p. 172) terms the state of “permanent transformation”, of “change as the main characteristic of informal settlements”. Even if a high-mast lighting installation provides adequate lighting results during a certain moment in a settlement’s history, ongoing densification resulting in a change of path-width-to-dwelling-height ratios might later result in inadequate lighting conditions.

4.3. Condition no. 2b

The reduction of the dwelling height in 0,05 m increments revealed that for the selected path section (with an initial dwelling height of 2,3 m, resulting a uniformity $U_0 = 0,06$) only dwelling heights of 1,5 m or less (see Fig. 12) would raise the uniformity in calculation point row #2 to the necessary $U_0 = 0,2$. As described above, informal dwellings tend not to be bound by building standards. As such, dwelling heights might in reality be lower (or higher) than the specified 2,3 m. However, these calculations of condition no. 2b demonstrate that even informal dwellings with a significantly lower height would still negatively affect the lighting uniformity.

4.4. Condition no. 3

The average illuminance (E_{av}) within the calculation field evaluating the path section in the centre of the high-mast luminaire installation (see red rectangle on Fig. 13) was 2,25 lx and the illuminance uniformity (U_0) was 0,72, complying with the requirements of the CIE. It can be concluded that the too low illuminance values of path section #10 in conditions no. 1 were caused by a too wide luminaire spacing. However, the uniformity shortcomings of path section #2 and path section #3 (see pink rectangles on Fig. 13) in conditions no.1 could not be solved by a closer spacing, remaining below $0,2 U_0$ ($0,07 U_0$ for path section #2 and $0,13 U_0$ for path section #3).

These results show that the location of a luminaire plays a major role when it comes to informal settlements lighting. If a luminaire is not located directly above a path, non-uniform lighting conditions can be expected. Increasing the amount of light emitted onto a path (either by decreasing the luminaire spacing or by increasing the luminaire’s luminous flux) cannot compensate for a luminaire location that is offside.

5. Summary

The following overall conclusions can be drawn from the different case simulation conditions:

- 1.) High-mast lighting creates the highest illuminance values on the dwellings’ roof and hence contributes significantly to light pollution. Such light is partly reflected by the roofs into the sky, which influences the night-time fauna in a negative way: For example, migrating birds may be disoriented (Goronczy, op. cit.). Furthermore, residents’ circadian rhythms may be affected by light entering the dwellings through windows or skylights (Ibid.).
- 2.) High-mast lighting is likely to result in low illuminance uniformity. This low degree of uniformity can happen within a certain path section, but also when it comes to larger areas adjacent to each other (such as the area next to a dwelling compared to the area behind a dwelling). Low illuminance uniformity increases the perceived contrast between ‘bright’ and ‘gloomy’ areas, and in so doing decreases the degree of night-time reassurance (Boyce, 2019).

- 3.) Lower degrees of illuminance uniformity can be expected within a path section the closer they are located to the high-mast luminaire.
- 4.) The density of the urban fabric, especially the path-width-to-dwelling-height ratio, impacts the degree of uniformity created by high-mast luminaires. Hence, a high-mast installation should not be planned without prior and highly accurate consideration of the urban fabric, ideally also taking into account possible physical change in the future.

6. Discussion and conclusion

Different arguments for and against the application of high-mast lighting in informal settlements have been published in the past. However, it seems that nobody has ever tried to assess the resulting lighting conditions in a systematic and quantitative way. By doing so, this paper has shown that the application of high-mast luminaires in informal settlements has several limitations.

The calculations have been conducted under 'best case conditions'. Hence it is important to emphasise that the unfavourable results presented in this paper would most likely be even more negative if the calculations would be conducted using models consisting of more complex dwelling structures, non-regular dwelling arrays and less reflective building materials. Such calculations have purposely not been conducted as part of this research in order to maintain transferability, yet further potential lighting shortcomings of high-mast lighting in informal environments still need to be considered.

Further research is required to determine what alternative lighting approach would be adequate for lighting pedestrian paths in informal settlements. The following thoughts seem to be promising entry points to approach this question: In order to tackle the low degree of illuminance uniformity caused by high-mast luminaires, "better lighting usually involves the use of more light sources (...) more closely spaced" (Boyce, 2014, p. 485). Moreover, this paper has shown that these light sources need to be installed directly above the paths. If complex building structures do not allow for pole-mounted luminaires, the dwellings themselves might be considered for luminaire mounting options (see, for example, Lynch and Hack, 1984).

Recent lighting technology component developments relating to grid-independent energy supply (e.g. solar PV panels), occupancy- and photo-sensors, LED light sources and communication technology hold promise for the development of luminaires that can be adapted to the challenging lighting design conditions of an informal urban fabric. For instance, solar-run luminaires could be installed instantly in a settlement, regardless of existing electricity connections, while photo-sensors could switch the luminaires on automatically once the sun has set. On top of this, occupancy sensors could allow the luminaire to switch-on only when people's movements are detected nearby, thereby reducing the amount of energy required as well as the required solar PV panel and battery size. Furthermore, LEDs are characterised by a size that differs from lamp technologies one was traditionally familiar with (Uhrig, op. cit.). Their smaller size would make it possible to 'break' a rather big light source into several smaller ones, allowing for more detailed lighting installations. In addition, LEDs have a high luminous efficacy, which again would be beneficial for the solar PV panel and battery size. A final example comes from Schneck (2015), who illustrates the advantages of bidirectional communication (possibly wireless) between a luminaire and lighting operators, which allows for, among other things, automatic detection of lamp and electrical failures. This could facilitate maintenance in areas that are difficult to access frequently by the authorities.

Further research would also be required to address the question of the role policies play when it comes to the provision of formal public lighting in informal environments. In light of the specific legal situation of informal settlements, it appears advisable to consider not only the lighting technology as such, but also informal-settlement-specific

lighting policy requirements. Even the best technology might fail in the application phase, if there is no political will to support its implementation.

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