Wagdy, Ayman, Fathy, Fatma, Elhenawy, Mohammed, Masoud, Mahmoud, Garcia Hansen, Veronica, Drogemuller, Robin, & Black, Alex
(2020)
New methodological approach for glare analysis on tunnel endpoints.
In Rodriguez Alvarez, Jorge & Soares Goncalves, Joana Carla (Eds.) *PLEA 2020 - Planning Post Carbon Cities: Proceedings of the 35th International Conference on Passive and Low Energy Architecture, Volume 2. Vol. 2.*
University of A Coruna, Coruna, Spain, pp. 1012-1017.

https://doi.org/10.17979/spudc.9788497497947

PLEA 2020 A CORUÑA

Planning Post Carbon Cities

New Methodological Approach for Glare Analysis on Tunnel Endpoints

AYMAN WAGDY [1,2] *, FATMA FATHY [3], MOHAMMED ELHENAWY [2], MAHMOUD MASOUD [2], VERONICA GARCIA-HANSEN [1], ROBIN DROGEMULLER [4], ALEXANDER BLACK [5]

[1] Queensland University of Technology (QUT), Creative Industries Faculty, School of Design, Brisbane, Australia
[2] Queensland University of Technology (QUT), Centre for Accident Research and Road Safety – Queensland (CARRS-Q), Brisbane, Australia
[3] Ain Shams University, Faculty of Engineering, Department of Architecture Engineering, Cairo, Egypt
[4] Queensland University of Technology (QUT), Science and Engineering Faculty, School of Built Environment, Brisbane, Australia
[5] Queensland University of Technology (QUT), Faculty of Health, School - Optometry and Vision Science, Brisbane, Australia

ABSTRACT: When entering and exiting tunnels, high luminance variations may cause severe crashes due to the occurrence of glare and the blackout effect. In this study, we propose a methodology that will effectively minimise the exaggerated light variations that arise over a short distance at the tunnel endpoints. An underpass which has the same characteristics of a tunnel in Brisbane, Australia was selected as a case study; a 3D model of the tunnel was created using Points Clouds, Digital Elevation Model and Open Street Maps. Grasshopper-for-Rhino was used to merge this information in order to create the tunnel's model. The Radiance lighting simulation engine was used to simulate the High Dynamic Range (HDR) images from the drivers' field of view (FOV) to accurately understand their visual experience. These images were post-processed by Evalglare to conduct advanced daylighting and glare analysis. Luminance maps highlighted the problem of high contrast and glare probability in the tunnel entrance. The beneficial outcome of the proposed methodology is not only evaluating glare problems, but also allowing for the optimisation of pre-tunnel lighting that utilizes daylight to maximize energy savings. Thus, the effectiveness of the solar techniques in reducing the contrast and creating a transitional zone that blends the highly illuminated outside with the dark interior can be evaluated.

KEYWORDS: Glare, Tunnels, Daylighting, Road Safety, High Dynamic Range Images

1. INTRODUCTION

Glare is a light phenomenon that causes vision impairment or subjective sensations of visual discomfort [1]. While driving, this visual problem can be experienced due to high contrast or exposure to direct sunlight, resulting in undesired reflections and a low sun angle facing drivers. This causes excessive blinking or squinting. Near tunnels' endpoints, the risk of glare amplifies when the sun is positioned just above the tunnel entrance, thus increasing the light differential; this overwhelming visual load on the drivers can increase the possibility of crashes. Furthermore, when approaching a tunnel's entrance, the eyes become affected. As the driver's vision has already adapted to high luminance levels under the clear sky, the tunnel's entrance can appear to be a black hole, and once inside, a blackout effect can be felt as illustrated in Figure 1. Du, Z., et al. [2] examined the changes in eyes' pupil while driving using eye-tracking technology, and they found that more visual load was experienced by drivers when entering the tunnel. A less critical problem also occurs when exiting the tunnel. In general, eyes cannot adapt to sudden changes in luminance levels which may be experienced when entering or exiting tunnels.

Figure 1: shows the black hole effect and the white hole effect found when approaching and exiting the tunnel in images taken with a fisheye lens.

Poor lighting conditions in tunnels presents a major crash risk factor [3]. The sharp transition in lighting levels at a tunnel's portal is largely responsible for accidents that occur mainly in the morning [4]. Thus, the quality of lighting conditions in tunnels should be maintained, along with the variations of sun and sky conditions. Strategies should target minimising the differences of luminance levels that exist over short distances. According to LOUIS and Tziotis [5], the highest crash rates take place just

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

before and after the tunnel by a distance of 10 m, as well as near the entrance area (10-150 m). This was also confirmed by Tziotis, et al. [3], who reported that high contrast and a significant light differential at endpoints and glare were potential causes of accidents investigated in four different tunnels.

2. DAYLIGHTING IN TUNNELS

Lighting design should provide high luminance levels at the endpoints in order to address the outside daylight intensity and to reduce the high contrast between the outside and inside. Increasing the luminance through artificial lights without the consideration of energy consumption is not an efficient solution, as tunnel lighting can consume a large amount of energy, especially at the entrance zone [6]. Designing pre-tunnel screens, louvres and redirecting structures that exploit daylight luminance is a promising approach to minimise visual problems that occur while driving in tunnels. Several factors are guiding the lighting design that differ according to each tunnel's characteristics, which are detailed in the following sections.

2.1 Tunnel classification and zones

Tunnels are classified into three divisions based on their length and exit visibility to determine the appropriate lighting requirements [7]. The first category of tunnels consists of short tunnels, which are less than 25 m and do not require any daytime lighting. The next category, long tunnels, are either geometrically or optically long. The former refers to tunnels that extend to more than 125 m, which always necessitate the standard threshold zone lighting in the daytime. Meanwhile, optically long tunnels are those in which drivers cannot see the exit from the safe stopping distance (SSD), so they should be illuminated in the same way as long tunnels. The final category consists of intermediate length tunnels, which range from 25 m to 75 m and 75 m to 125 m. Other factors interact with these two ranges to determine the lighting requirements, such as the visibility of the exit, daylight penetration (good or poor), the reflectance of walls (either high, > 0.4 or low, < 0.2), and traffic flow (heavy or light) according to the CIE [7]. In the case of intermediate tunnels, all of these factors should be identified to determine if no daytime light is needed, similarly to short tunnels, or if either 50% or 100% of the standard threshold zone lighting is required, like long tunnels [7].

Safety problems in tunnels are commonly associated with poor lighting design. Usually, tunnel length is divided into zones that are used to standardise the lighting needs, which must suitably allow the eye to adapt to changes in light levels for each zone [8]. According to the Commission Internationale l'Eclairage [7], tunnels have different light zones; this starts at the tunnel entrance with the threshold zone, and is followed by the transition, interior and exit zones, as shown in Fig. 2.

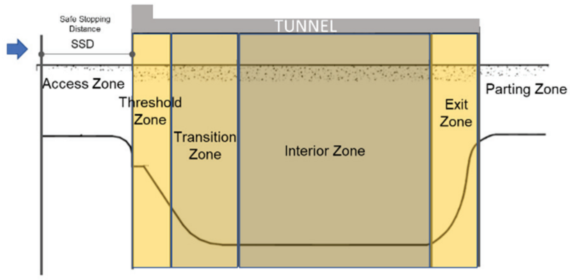

Figure 2: Lighting zones in tunnels adapted from [7]

The threshold zone starts at the tunnel portal, where the eyes start adapting to a lower luminance interior environment. Then, as the eyes get more adjusted, the transition zone starts, and the lighting level continues decreasing until reaching the lowest necessary level in the interior zone, at which point the eyes should have been completely adapted. At the exit zone, the light levels are elevated because of the high brightness of the outside environment, and the eye adaptation is reversed. This endpoint is considered less critical in comparison to the entrance from a safety point of view, as the eye adapts faster from darkness to brightness than vice versa. Also, any obstacle present near the end of the tunnel will appear clearly against the bright background of the exit [8].

The approaching distance before the tunnel portal is described as the access zone. The length of this zone is determined based on the safe stopping distance (SSD), which is measured from the point outside the tunnel where a driver can decelerate and completely stop at the entrance point. This distance depends on the traffic speed; the lower the speed, the shorter the distance [8]. This distance identifies the minimum length of the threshold zone, where the light required at the start of this zone is referred to as L_{th} [7].

2.2 Lighting requirements at endpoints

The light intensity at the tunnel portals is recommended to remain constant over half the length of the threshold zone; at this point, it can gradually decrease until it reaches 0.4 L_{th} at the end of this zone, marking the start of the transition zone [7]. The ratio of the sky that is visible in the field of view (FOV) of the driver when approaching the tunnel affects the luminance levels required for the threshold zone (L_{th}). The average luminance is calculated in a conical FOV of 20 degrees to identify the perceived surrounding luminance, which is referred to as L_{20}. It is measured at a point that represents the eyes of the driver when approaching the tunnel from the safe stopping distance (SSD) [8]. The recommended ratio of luminance at the threshold zone (L_{th}) to L_{20} ranges from 0.05 to 0.1 according to the lighting system and the allowed speed [7]. The L_{20} concept is used as a simplified method to identify the required luminance in the threshold zone, which has the highest lighting

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

demand [8]. In the exit zone, the lighting levels are usually kept the same as the interior zone [9, 10]. However, in some cases, these levels must be increased gradually to reach five times the interior lighting level over a distance equal to the SSD. The necessary lighting level for the interior zone is 10cd/m2 for high-speed roads with a heavy traffic flow, and is reduced to 3cd/m2 in low-speed roads with light traffic, as reported by van Bommel [9].

Adding more artificial lighting at tunnels' endpoints is not the optimal solution for glare-free tunnels. Artificial lights in tunnels are large consumers of energy, mainly because they operate 24 hours each day. Thus, strategies for energy reduction are oriented to:

1) Using efficient artificial lighting equipment.

2) Optimise tunnels' designs to make use of sunlight.

3) Apply lighting control systems that correspond with the outside ambient conditions, and

4) Improve the surface properties of walls and roads [11].

Controlling luminaire intensity in the threshold and transition zones can be automatically linked with the sun and sky conditions through real-time monitoring of light levels just outside the tunnel. A backup control system is recommended to manage light levels in case of photometric failure [12].

2.3 Pre-tunnel structures

Pre-tunnel lighting (PTL) is a common approach that makes use of ad hoc structures installed in the portal area in order to enhance lighting and reduce the blackhole effect [13]. These structures can reduce the scattered light falling on the eyes from the luminance of the surroundings [10] and can utilise sunlight to partially illuminate the portal, thus reducing the need of artificial lights for energy saving. A study by Gil-Martín, et al. [14] showed that a semi-transparent tension structure in the entrance of the tunnel can shift the threshold zone to start earlier, thus allowing sunlight to contribute in achieving the required illuminance for this zone. Different shapes and materials of the tension structure were compared using a simulation method to quantify savings in energy. The shape of the structure had a greater impact on illuminance than the type of material used [15].

The implementation of pergolas was suggested, as they are easier for maintenance than tension structures [16]. However, these structures caused non-uniform daylight distribution which may result in flickering effect and can obstruct clear road vision. Gil-Martín, et al. [17] approached this problem by suggesting the installation of diffusers in voids between the structural beams.

In other studies, more sophisticated systems that introduce daylight inside the tunnel were examined. In Peña-García, et al. [18], light pipes were integrated with heliostats to act as a coupled system to capture and inject sunlight into the tunnel road in the threshold zone. Through theoretical calculations and measurements taken from a mockup, energy savings ranged from 14% to 21% according to the tunnel orientation. Other factors, like landscape surroundings and reflectance of walls and road surfaces, can contribute to the reduction of energy consumption for artificial lighting [12].

The initial and life cycle costs of the applied systems or strategies should result in economic benefits when compared to using conventional artificial lights counterparts [13]. Thus, reliable calculation methods to quantify their benefits are needed.

2.4 Design evaluation methods

To evaluate the performance of the lighting condition in tunnels and the beneficial outcomes of daylighting strategies, analytical and mathematical methods were proposed. Jurado-Pina, et al. [19] suggested a method to identify the probability of sun glare using projections of the sun paths to examine the time intervals when glare problems may occur and identify when mitigation solutions and design countermeasures are needed. To determine the sun and sky's luminance contribution to road illumination, a general equation (SLT) was proposed in which the efficiency of PTL can be evaluated [20]. Analytical methods are proposed to define the geometric criteria for PTL, and they were applied on hexagonal-shaped meshes that act as a pre-tunnel structure [13].

4. METHODOLOGY

This study aims to introduce a new methodological approach for glare analysis in tunnels' endpoints using High Dynamic Range (HDR) images. Point clouds are also utilized for the detailed and accurate 3D modelling of tunnels. The proposed methodology was applied as a demonstration on a real case study of an underpass, which is similar to typical tunnels. The case was selected to examine an accessible tunnel in Brisbane throughout the expected critical times (during daylight hours) when the blackhole (entrance of tunnel) and white light phenomenon at the end of the tunnel is more problematic. This case study is located near Sun Corp Stadium on the M3 road, where multiple underpasses form a tunnel-like shape are highlighted in a red colour over the ELVIS- Elevation and Depth – Foundation Spatial Data map as shown in Fig.3

To model an accurate 3D representation of the tunnel, 3D point cloud extracts are used. The point cloud was published by Geoscience Australia in 2015 and was captured by an airborne LiDAR on five-metre grid. It was also combined with the Digital Elevation

DOI: https://doi.org/10.17979/spudc.9788497497947

Models (DME) of the area to model the ground terrains, as illustrated in Fig. 4 and Fig. 5. By fusing all this information and combining it with the data gathered from Open Street Map, the final 3D model was generated, as shown in Fig. 6.

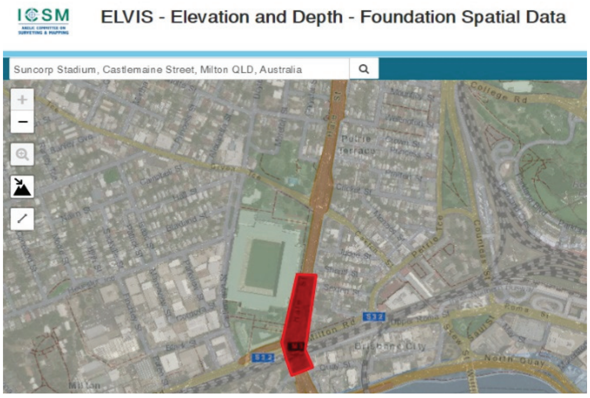

Figure 3: Shows the selected area for the study.

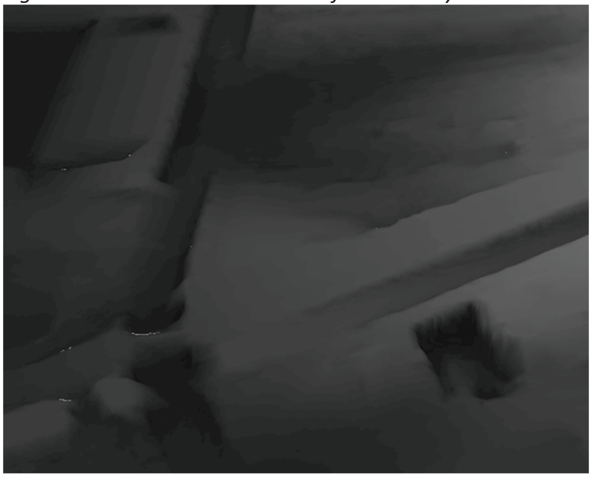

Figure 4: The DME data that was used to create the terrains.

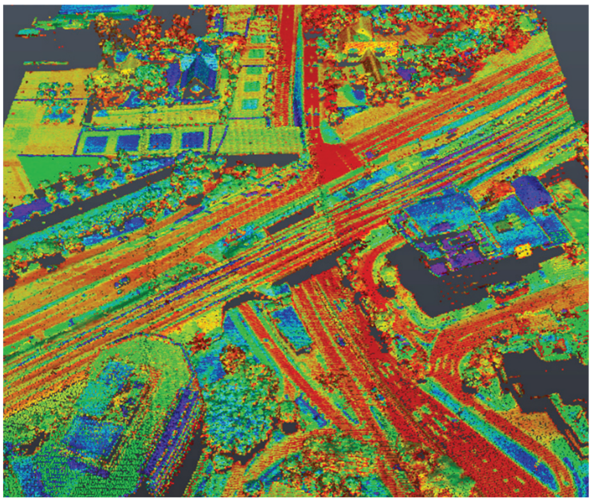

Figure 5: The 3D point-cloud used to create 3D environment.

Grasshopper, a parametric modelling tool for Rhino 3D modelling software, was used for modelling the tunnel. Diva for Rhino was the interface used for the Radiance and Evalglare lighting simulation engines to conduct the advanced daylighting and glare analysis [21-23]. Next, High Dynamic Range (HDR) images were simulated from the drivers' field of view (FOV) in order to perceive their experience at multiple, consistently-spaced points throughout the tunnel. Parametric simulation algorithms were used to estimate the daylighting levels, as well as the luminous contrast and glare severity based on luminance maps generated. Theses techniques were conducted based on the best practises in glare [24-28] and daylighting simulations inside the parametric environment [29], as covered in the literature review. The luminance maps were generated for the 180-degree fisheye HDR images for each hour of daytime throughout the year to predict where and when the glare problems could occur. Thus, using the proposed method for modelling and processing the data can yield reliable data for glare and daylighting analysis.

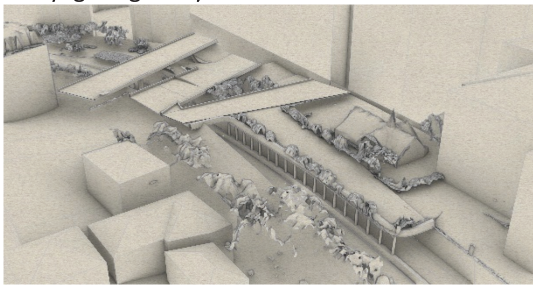

Figure 6: The 3d model of the underpass area.

4. DISCUSSION

Glare problems exist at the tunnel endpoints due to the high contrast between dark and light areas with a contrast ratio reaching more than 1:140, as shown in Fig. 7. The point cloud model is characterised by including all urban design elements and details that affect the luminance of the surroundings. Thus, the captured HDR images can efficiently represent the perceived luminance from the perspectives of drivers in their dynamic state.

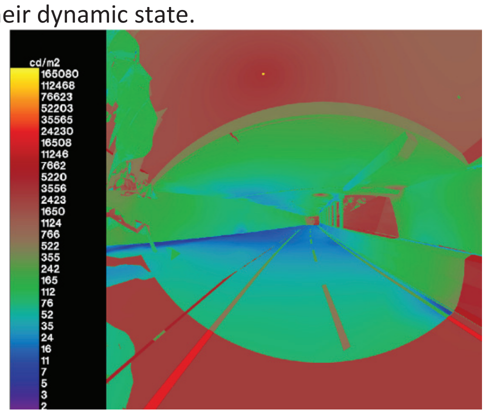

Figure 7: the luminance heatmap extracted from the simulated HDR image at the tunnel entrance.

Unlike mathematical equations or mock-ups, the applied method has a higher potential to explore multiple design solutions and to optimize their parameters for safer roads. Through the proposed method, a transitional zone can be assessed and optimized to ensure a gradual blend between the high illuminated outside and the dark interior of the tunnel. The next step will go towards enhancing the lighting

35th PLEA Conference. Planning Post Carbon Cities.
DOI: https://doi.org/10.17979/spudc.9788497497947

conditions of this transitional zone in order to match the adaptation rate of the human eye to a greater extent.

Being in a motion state with a certain speed makes it more challenging to evaluate the lighting design. The critical part in addressing glare problems in tunnels is increasing the lighting levels at the entrances using daylight techniques. Although these techniques are widely studied in buildings, it can be beneficial to transfer these techniques and apply them to mitigate the tunnel glare problem. For example, dynamic reflectors and shading devices are usually found to perform well in terms of daylighting performance and the control of direct sunlight [30, 31]. These systems can be adapted to the tunnel's endpoint and evaluated parametrically to increase the lighting levels at the portals areas. These reflectors can have simple shapes, like slats or external sun breakers that are usually used in buildings, which can be scaled up to cover the tunnel entrance [32, 33]. Another static design option that is worth investigating is the solar screens [34-37], as they have geometrical characteristics that are effective in redirecting the sunlight and minimising sun exposure, which may help in shifting the transition zone. Moreover, these screens can be designed based on specific mathematical rules, such as cellular automata, to have a pleasing apperance while maintaining excellent performance [38].

Nevertheless, most conventional tunnel entrances have a simple shade or arch-like geometry, which are easy to build and maintain. However, we believe that if these simple shapes were optimised based on the actual sun path diagram [39], they would have a better performance. On the urban scale, the heights of the adjacent buildings in new or retrofit areas can be regulated [40] by the local counsels to ensure sufficient daylight levels near the tunnel entrance for maintaining the efficiency of the new sun reflectors.

4. CONCLUSIONS

The illumination required at endpoint areas should be carefully estimated in order to overcome the blackhole effect and glare problems in the daytime. Increasing luminaires or their intensity do not align with sustainable considerations from the energy perspective. Thus, making use of daylight and redirecting sunlight systems are gaining more recognition. Adding pre-tunnel structures or redirecting techniques allows for the eye's gradual adaptation to low luminance conditions. This can positively contribute to mitigating problems of glare that occur when there is a large difference between the outside luminance of sunlight and the inside shaded area of the tunnel. However, to maximise their potential against their initial costs and maintenance requirements, a reliable method is needed to accurately predict their contribution to an increase in illumination.

Daytime luminance conditions at the tunnel's portals are varied according to the geographical location, orientation and surroundings. As this is also sensitive to the surrounding urban context, the detailed point cloud model showed an advantage for accurate prediction of the perceived luminance. Moreover, the parametric simulations of HDR images account for the dynamic changes that occur over the day and year by taking multiple images at critical times, which represent the frequent and severe conditions. Further research should utilise the proposed method to evaluate and optimise pre-tunnel reflectors in order to contribute to drivers' visual comfort and energy saving.

ACKNOWLEDGEMENTS

This research is supported by 2019 IHBI Synergy Partnerships Scheme (2019-2020) and funded by the Queensland University of Technology (QUT), Institute of Health and Biomedical Innovation (IHBI), Creative Industries Faculty (CIF) and Science and Engineering Faculty (SEF).

REFERENCES

[1] S. Carlucci, F. Causone, F. De Rosa, and L. Pagliano, "A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design," *Renewable and Sustainable Energy Reviews,* vol. 47, pp. 1016-1033, 7// 2015.

[2] Z. Du, F. Huang, B. Ran, and X. Pan, "Safety evaluation of illuminance transition at highway tunnel portals on basis of visual load," *Transportation Research Record,* vol. 2458, no. 1, pp. 1-7, 2014.

[3] M. Tziotis, T. Makwasha, B. Turner, and M. Regan, "Measures to reduce crashes adjacent to and within tunnels," 1925671240, 2018.

[4] Y. Dai and Z. Guo, "Effect of spatial visual pattern on driving behaviour in expressway tunnel section," *Journal of Tongji University. Natural Science,* vol. 39, no. 9, pp. 1307-1312, 2011.

[5] L. LOUIS and M. Tziotis, "Guide to road tunnels part 1: introduction to road tunnels," 1925671682, 2018.

[6] R. Dzhusupova, "Zero energy Tunnel-concept," Eindhoven University of Technology, 2012.

[7] C. I. d. l. E. CIE, "Guide for the Lighting of Road Tunnels and Underpasses," CIE Pubblications, Vienna, Austria2004, vol. vol. 88.

[8] W. van Bommel, "Visual Performance and Sense of Confidence," in *Road Lighting*: Springer, 2015, pp. 273-299.

[9] W. van Bommel, "Standards and recommendations," in *Road Lighting*: Springer, 2015, pp. 97-109.

[10] P. R. Boyce, *Lighting for driving: roads, vehicles, signs, and signals*. CRC Press, 2008.

[11] L. LOUIS, "Guide to road tunnels part 4: retrofitting tunnels," 1925854353, 2019.

[12] G. Vorobieff and L. LOUIS, "Guide to road tunnels part 2: planning, design and commissioning," 1925854159, 2019.

[13] G. Cantisani, A. D'Andrea, and L. Moretti, "Natural lighting of road pre-tunnels: A methodology to assess the

DOI: https://doi.org/10.17979/spudc.9788497497947

luminance on the pavement–Part I," *Tunnelling and underground space technology,* vol. 73, pp. 37-47, 2018.
[14] L. Gil-Martín, A. Peña-García, E. Hernández-Montes, and A. Espín-Estrella, "Tension structures: A way towards sustainable lighting in road tunnels," *Tunnelling and underground space technology,* vol. 26, no. 1, pp. 223-227, 2011.
[15] A. Peña-García, R. Escribano, L. Gil-Martín, and A. Espín-Estrella, "Computational optimization of semi-transparent tension structures for the use of solar light in road tunnels," *Tunnelling and Underground Space Technology,* vol. 32, pp. 127-131, 2012.
[16] A. Peña-García and L. Gil-Martín, "Study of pergolas for energy savings in road tunnels. Comparison with tension structures," *Tunnelling and Underground Space Technology,* vol. 35, pp. 172-177, 2013.
[17] L. Gil-Martín, A. Gómez-Guzmán, and A. Peña-García, "Use of diffusers materials to improve the homogeneity of sunlight under pergolas installed in road tunnels portals for energy savings," *Tunnelling and Underground Space Technology,* vol. 48, pp. 123-128, 2015.
[18] A. Peña-García, L. Gil-Martín, and E. Hernández-Montes, "Use of sunlight in road tunnels: An approach to the improvement of light-pipes' efficacy through heliostats," *Tunnelling and Underground Space Technology,* vol. 60, pp. 135-140, 2016.
[19] R. Jurado-Pina, J. Pardillo-Mayora, and R. Jiménez, "Methodology to analyze sun glare related safety problems at highway tunnel exits," *Journal of Transportation Engineering,* vol. 136, no. 6, pp. 545-553, 2009.
[20] A. Peña-García, "The SLT equation: A tool to predict and evaluate energy savings in road tunnels with sunlight systems," *Tunnelling and Underground Space Technology,* vol. 64, pp. 43-50, 2017.
[21] L. Solemma. (2019, 5 September). *DIVA-for-Rhino software version 4.1*.
[22] H. Ibrahim, A. Wagdy, P. Beccarelli, R. Carpenter, and J. Chilton, "Applicability of Flexible Photovoltaic Modules onto Membrane Structures Using Grasshopper Integrative Model," *Procedia Engineering,* vol. 155, pp. 379-387, // 2016.
[23] D. Rutten. (2014, 5 September). *Grasshopper-Algorithmic modeling for Rhino software version 0.9077*.
[24] M. Inanici, "Evaluation of high dynamic range photography as a luminance data acquisition system," *Lighting Research and Technology,* vol. 38, no. 2, pp. 123-134, June 1, 2006 2006.
[25] M. Inanici, "Evalution of High Dynamic Range Image-Based Sky Models in Lighting Simulation," *LEUKOS,* vol. 7, no. 2, pp. 69-84, 2010/10/01 2010.
[26] J. A. Jakubiec, K. Van Den Wymelenberg, M. Inanici, and A. Mahić, "Improving the accuracy of measurements in daylit interior scenes using high dynamic range photography," in *Proceedings of Passive and Low Energy Architecture (PLEA) 2016 Conference, Los Angeles, CA, July 11–13*, 2016.
[27] J. A. Jakubiec, K. V. D. Wymelenberg, M. Inanici, and A. Mahic, "Accurate measurement of daylit interior scenes using high dynamic range photography," in *Proceedings of the CIE 2016 Lighting Quality and Energy Efficiency Conference*, 2016.
[28] A. Wagdy, V. Garcia-Hansen, G. Isoardi, and K. Pham, "A parametric method for remapping and calibrating fisheye images for glare analysis," *Buildings,* vol. 9, no. 10, p. 219, 2019.
[29] A. Eltaweel and Y. Su, "Parametric design and daylighting: A literature review," *Renewable and Sustainable Energy Reviews,* vol. 73, pp. 1086-1103, 2017/06/01/ 2017.
[30] Y. Elghazi, A. Wagdy, and S. Abdalwahab, "Simulation Driven Design for Kinetic System: Optimize Kaleidocycle Façade Configuration for Daylighting Adequacy in Hot Arid Climates " in *IBPSA 2015-14th International Conference of the International Building Performance Simulation Association*, Hyderabad, India, 2015, pp. 182-189.
[31] A. Wagdy, F. Fathy, and S. Altomonte, "Evaluating the Daylighting Performance of Dynamic Façades by Using New Annual Climate-Based Metrics," presented at the PLEA 2016 - 36th International Conference on Passive and Low Energy Architecture, Los Angeles, California, USA, 2016.
[32] A. Sherif, H. Sabry, A. Wagdy, I. Mashaly, and R. Arafa, "Shaping the slats of hospital patient room window blinds for daylighting and external view under desert clear skies," *Solar Energy,* vol. 133, pp. 1-13, 8// 2016.
[33] A. Wagdy, A. Sherif, H. Sabry, R. Arafa, and I. Mashaly, "Daylighting simulation for the configuration of external sun-breakers on south oriented windows of hospital patient rooms under a clear desert sky," *Solar Energy,* vol. 149, pp. 164-175, 2017/06/01/ 2017.
[34] H. Sabry, A. Sherif, M. Gadelhak, and M. Aly, "Balancing the daylighting and energy performance of solar screens in residential desert buildings: Examination of screen axial rotation and opening aspect ratio," *Solar Energy,* vol. 103, pp. 364-377, 2014.
[35] A. Wagdy and F. Fathy, "A parametric approach for achieving optimum daylighting performance through solar screens in desert climates," *Journal of Building Engineering,* vol. 3, pp. 155-170, September 2015.
[36] A. Wagdy and F. Fathy, "A Parametric Approach for Achieving Daylighting Adequacy and Energy Efficiency by Using Solar Screens," presented at the PLEA 2016 - 36th International Conference on Passive and Low Energy Architecture, Los Angeles, California, USA, 2016.
[37] A. Wagdy, S. Mokhtar, and A. Abdel-Rahman, "Parametric analysis of solar shading parameters in intermediate orientations located in desert climates," presented at the Third IBPSA - England Conference BSO2016, Newcastle, UK, 2016.
[38] F. Fathy, Y. Mansour, H. Sabry, S. Abdelmohsen, and A. Wagdy, "Cellular Automata for Efficient Daylighting Performance: Optimized Facade Treatment," in *IBPSA 2015-14th International Conference of the International Building Performance Simulation Association*, Hyderabad, India, 2015.
[39] M. Amer and A. Wagdy, "Multivariable Optimization for Zero Over-lit Shading Devices in Hot Climate," presented at the Third IBPSA - England Conference BSO2016, Newcastle, UK, 2016.
[40] A. Wagdy, A. Morsy, and A. Hegazy, "Daylighting optimization for informal settlements in Cairo, Egypt," presented at the BSA 2015 - Building Simulation Applications, Bozen, Italy, 2015.

DOI: https://doi.org/10.17979/spudc.9788497497947